THE PHYGITAL EVOLUTION

DIGITIZATION OF HISTORICAL FABRICS FROM PRATO

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Abstract

This contribution examines the results of a research project on collaborations between the audiovisual industry and the textile and fashion sector in the city of Prato, experimenting with new relationships between the physical and digital dimensions.
The main purpose of the project was the production of content for the textile manufacturing industry using innovative media production technologies such as 3D, animation, etc., transmitted through 5G network infrastructure. Specifically, the project focused on significant archives of the Prato textile district through a process of digitizing fabrics using productive reverse engineering techniques. This allowed for obtaining a digital representation of existing fabrics, preserving and enhancing the traditional textile heritage in a digital format. The use of advanced techniques enabled the accurate capture of fabric characteristics and properties, facilitating the creation of 3D models and their manipulation through media production technologies.

Keywords: Phygital, Prato Textile District, Reverse Engineering, Textile Heritage, Digitization

Introduction

The research project Prato Phygital[1] explores the development of a fabric digitization procedure and its subsequent application in dynamic models, culminating in their representation in interactive digital environments. The project, with the synergistic collaboration of designer groups with diverse expertise, aims to digitize ten fabrics, five of which are sourced from the historical archive of the Prato Textile Museum and the other five from Marini Industrie Spa company's archive. Prato Phygital delves into a territory that is still in an experimental phase and seeks to identify new methodologies for the enhancement and redesign of heritage within one of the most significant textile districts – Prato. The proposed digital transformation also offers new horizons of application for fabrics in various contexts ranging from fashion to product design, art, and even gaming, including gamification approaches (Tufarelli et al., 2022).

From Physical to Digital Fabric

The first phase of the research focused on a thorough study of the processes involved in the production of fabrics made through Jacquard and dobby looms. This phase analyzed all the stages encompassing the weaving process, starting with essential knowledge of textile fibers and yarns, fabric analysis (composition and manufacturing), interlacing, color effects, twists, warp and weft notes, drawing-in and drafting, weaving, and interpretation of technical specifications. This initial part was crucial for the subsequent digital reconstruction of the selected samples, simplifying the subsequent operations. The selection of fabrics took into account both the historical and cultural significance as well as the technical feasibility, with the Prato Textile Museum [Fig. 1] focusing on the former and Marini Industrie SpA considering

1 The project was initiated in 2022 at the University of Florence, under the scientific supervision of Prof.ssa. Elisabetta Cianfanelli. It was funded by the Ministry of Economic Development (MISE) as part of the financing program for 5G and audiovisual. The project, in which the author participates as a research fellow, involves a partnership between Fondazione Sistema Toscana, University of Florence, Municipality of Prato, Museo del Tessuto di Prato, Marini Industrie, PIN-Polo Universitario Città di Prato, Immerxive s.r.l, Indiana Production, and Wind Tre.

Fig. 01

their heritage by digitizing some archival fabrics no longer in production, along with aesthetic patterns that represented their distinctive brand.
The second phase involved the digital transformation of the selected fabrics using NedGraphics, one of the leading CAD software for digital fabric design.
The third phase encompassed the development of multilevel maps using Materialize software. This program allowed for the overlaying of multiple images with different characteristics, resulting in a simulation of the digital fabric that closely resembled reality.
The final phase involved the representation of the fabrics in digital environments through the design of iconic products in the world of design, such as statues, chairs, and cars, as well as the creation of a fashion collection. In this concluding part of the project, a redesign process was initiated, revisiting the original patterns in terms of colors and dimensions.

The CAD Process

The initial phase of fabric digitization involves carefully studying the technical specifications provided by project partners. For historical fabrics from museums, textile experts first sampled the selected fabrics and then created technical sheets containing all the necessary information for the designers to proceed with the digital transformation. The actual CAD software from the NedGraphics package, specifically Texcelle, was then used for the digitization process. Depending on the complexity of the selected sample, the reconstruction of the pattern unfolded in three main subsets, each considered separately.
The first subset includes complex patterns that required the use of other software, such as Adobe Illustrator, for the digital reproduction of the design. In this specific case, the procedure involved tracing the fabric pattern as closely as possible and then importing the resulting image into the CAD.
The second subset encompasses fabrics with a lower level of complexity compared to the first subset. These fabrics required refinement operations rather than tracing for digitization. A JPEG photo of the actual fabric sample, acquired directly from the

company, was imported into Texcelle, and the CAD's toolbar was used to digitize it. It is important to note this distinction because, leveraging certain CAD features like color reduction, the software automatically converts the image into a drawing, simplifying and speeding up the process.
The third subset includes fabrics with a low complexity gradient, such as stripes or tartan, which did not require importing or tracing the pattern for digital conversion. In such cases, the fabric's design was recreated by manually writing the warp and weft sequence, represented as an alphanumeric string (nAnB...nZ), in the CAD. This sequence automatically generated the key fabric pattern schema.
In all three cases, it was necessary to resize the images to match the actual loom size and assign attributes such as density and thread count. This process enabled the generation of the complete cardboard file necessary to reproduce the selected fabric on a physical loom.
Once a result that closely resembles reality, with a high level of detail, is achieved, an appropriate warp and weft sequence (n1n2...nn) or alphanumeric string[2] is created to define the number of warp and weft threads. This marks the completion of the digitization phase in Texcelle. The native file generated by the CAD is in the DES domain. This file is then read by the Product Creator software, initiating the next step. The DES file is transformed by the new CAD, translating the warp/weft sequence set in Texcelle into matrices of n by m. Each matrix corresponds to a color-divided area, and in each cell of the color chart, depending on the data specified by the technical specifications[3], a weave structure will be inserted, resulting in a particular warp and weft effect. In the YarnBook library, yarns (in terms of color and physical characteristics) can be selected and assigned to fill the design. Once all the matrices are filled and the yarns are set, a simulation of the fabric can be previewed; if deemed suitable, it is exported as the DSIM output file, which can be opened with the TrueColor program.

2 In Category 3, this, combined with image resizing, is the only step to be followed in order to complete all the operations on Texcelle.
3 Technical specifications could not be drafted for all fabrics. In such cases, reverse engineering operations were carried out starting from an image of the sample fabric.

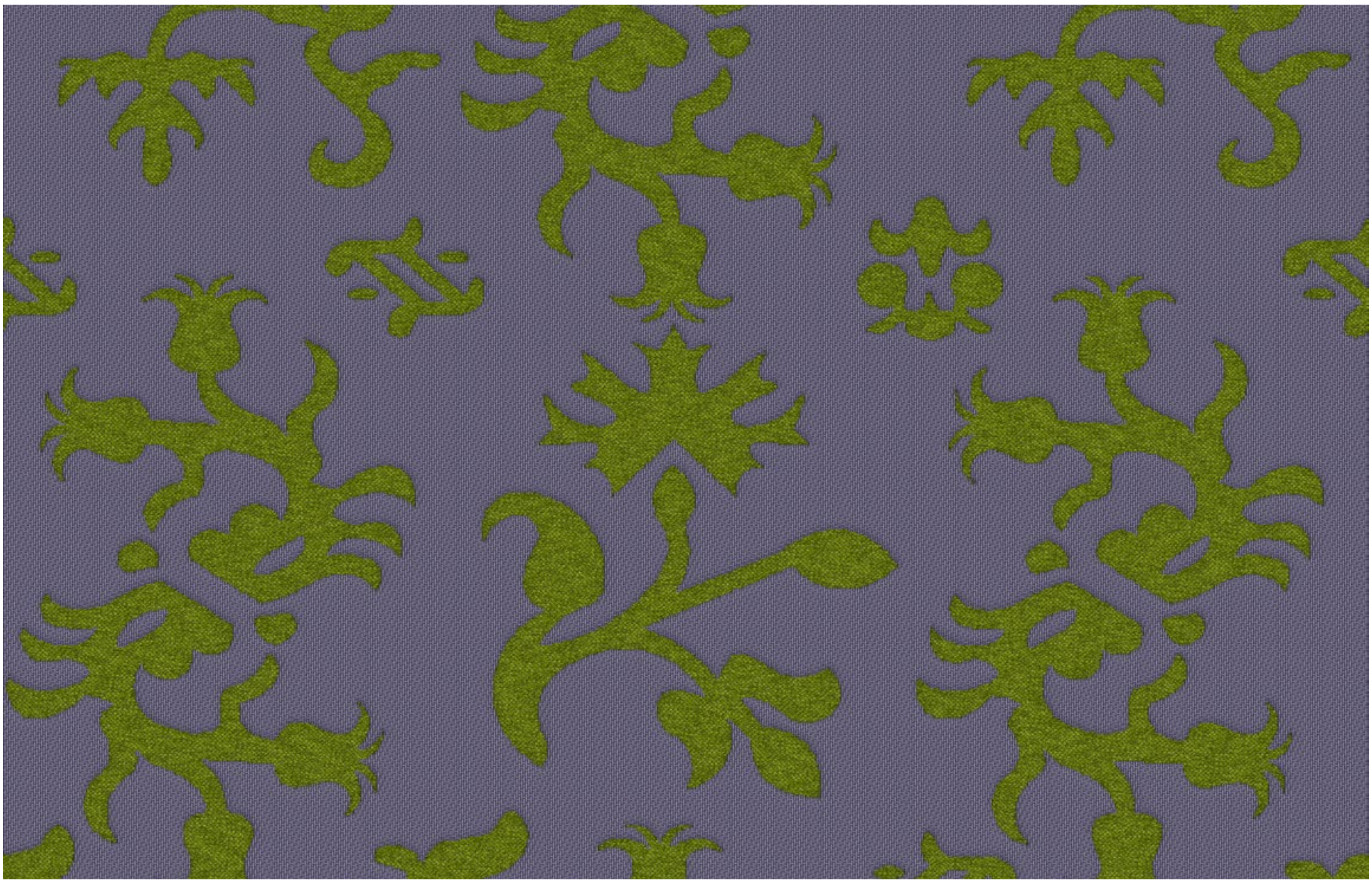

Fig. 02

With TrueColor, we can visualize the simulation in its highest quality; the 2D texture is enhanced with shadows, giving the image a three-dimensional effect. Using this program, a quality check was also performed to verify if the chosen shade corresponds to the real one. Once the texture base is validated by the partners, the CAD process concludes with the final export of a JPEG image at 4000 DPI.
A separate case, as it involves variations in the transformation methodologies, is the digitalization process of fabrics woven on a dobby loom. In this case, since the pattern is created solely by inserting the weave structure and correctly setting up the dobby shafts, the design phase is skipped. The workflow is almost the same, with the only difference being the aforementioned phase and the number of software used. In the specific program Dobby [Fig.3], everything is contained within a single window, eliminating the need for three different supports as analyzed in the previous paragraph.

Yarns between Physical and Digital

For the research, the study of yarn and its basic characteristics was central to the digitalization process. The program offers designers the ability to import new yarns of high quality into the default library. These yarns allow for greater definition of the base textures created by the previously analyzed CAD tools. Before proceeding with the importation methodologies, it is important to note that all yarns in the library can be modified in terms of yarn count and exposure size, twist direction (S and Z), and twists per meter. This allows for achieving an even more realistic level of definition during the simulation phase. Regarding the importation methodology, the program first proposes yarn insertion from a photograph or scan. In this phase, it is crucial to strategically choose the color of the yarn (beige, light gray, off-white) because using a colored or very dark yarn may result in the loss of its details. To expand the yarn archive, the first step is to load the file into Texcelle, ensuring it is in its maximum resolution of 1200 DPI. In the CAD

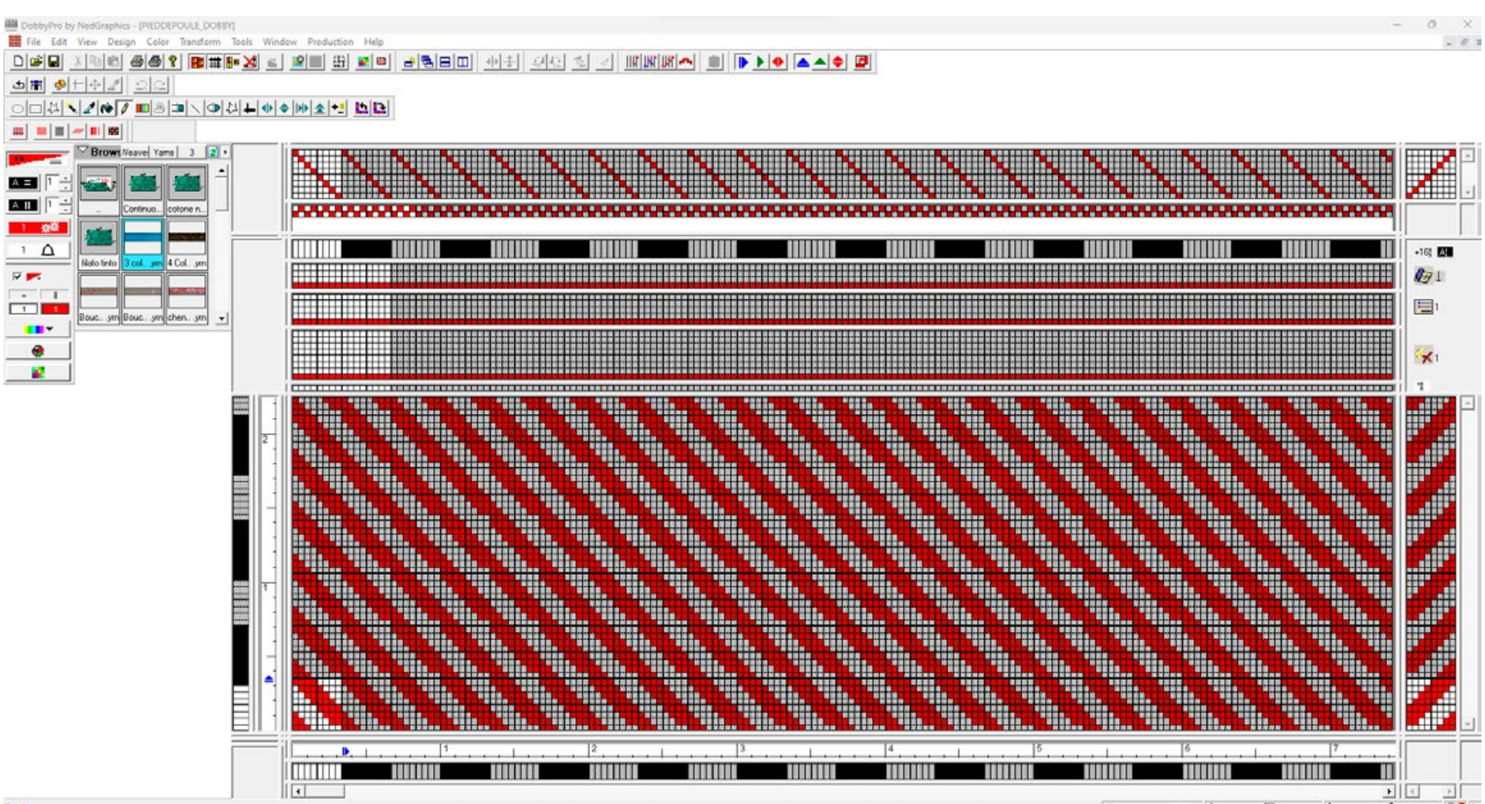

Fig. 03

program, refinement and, if necessary, correction[4] operations are performed, starting with color reduction in its maximum range, which is 240 shades. This allows us to preserve the shading effect and other yarn characteristics when transforming the photo into a drawing, while maintaining an excellent level of texture detail. The second step is to create a contrasting background with the yarn. The background color must be assigned to position 0 in the palette so that the CAD program can recognize and automatically remove it. The first part of the work concludes by saving this initial file as a TIFF and renaming it with "_texture". The essential second part to successfully complete the importation methodology is to create a mask called alpha. This is an image of the yarn with a generally black background and a contrasting color on the yarn, which enables the mapping and preservation of the aesthetic characteristics of the sample to be inserted. The final step is to insert the texture and alpha files into YarnBook, thereby completing the importation. Contrary to what one might think from the analysis presented so far, although the yarn is loaded into CAD Texcelle, it is not limited to use only on Jacquard looms. It can also be implemented for use on dobby looms and opened in the library present in CAD Dobby.
In light of this analysis, considering that yarn can be added to the library from an image, the research also experimented with the importation of digitally modeled yarns using procedural systems. The tests started with the development of a parameterized algorithm based on 3D modeling using Geometry Nodes. Through nodal geometry and combining multiple nodes together, it is possible to create complex effects and have detailed control over the object's geometry. This allowed us to systematically generate digital yarns by adjusting parameters such as twist, number and diameter of strands and individual fibers, resulting shape, and more. The outcome of this activity made a significant contribution to the research, both due to its highly innovative nature and the optimization of simulation rendering. Regarding its innovative nature, by further exploring this phase of the research, it may be possible to digitize the yarn importation process almost entirely, eliminating the need for photographs or scans. Additionally, it would be plausible to stimulate the creativity of designers by allowing them to invent and design entirely new yarns, which would be the result of their creative inspiration, with subsequent feasibility verification using the tools in the NedGraphics package. Regarding the improvement of simulation rendering, it was observed that, at the same resolution, a fabric with yarn generated using the algorithm developed in the research phase has significantly higher quality compared to a scanned or photographed yarn.

Mapping

Before proceeding with the dressing phase, where the digitalized fabric textures were applied to 3D models, it was considered essential during the process, once the 2D fabric texture was acquired, to use a mapping procedure. This was done to further enhance the features and give the texture, and therefore the 3D model, an even more pronounced three-dimensional effect. When referring to mapping, it is the practice of selecting, manipulating, and visually and spatially representing relationships in a "new" form, in order to illustrate or reproduce a particular salience (Manchia, 2015). In other words, with multilevel maps, we are able to give our three-dimensional model, to which we will apply the final texture (diffuse map) extracted from the entire CAD process, various aesthetic components such as roughness, transparency, opacity, etc. All the images derived from the diffuse map define a particular area of the texture and can be overlapped in such a way that, layer by layer, they together provide all the three-dimensional details that would be lost with only the base texture. The software used for generating the images is Materialize, a specific parametric texture generator. In the design phase, for highly complex fabrics or those with particular aesthetic characteristics, the manual filling of specific textures has been indispensable. This allowed us to generate specific maps [Fig.4] useful for simulating the fabric's fuzziness or opacity. This technique has been very important to fill in the gaps inherent in CAD, such as the reconstruction of fabric fuzziness, which is an important characteristic of our samples and was lost in the CAD simulation.

4 Operations of thread realignment due to errors in modular repetition.

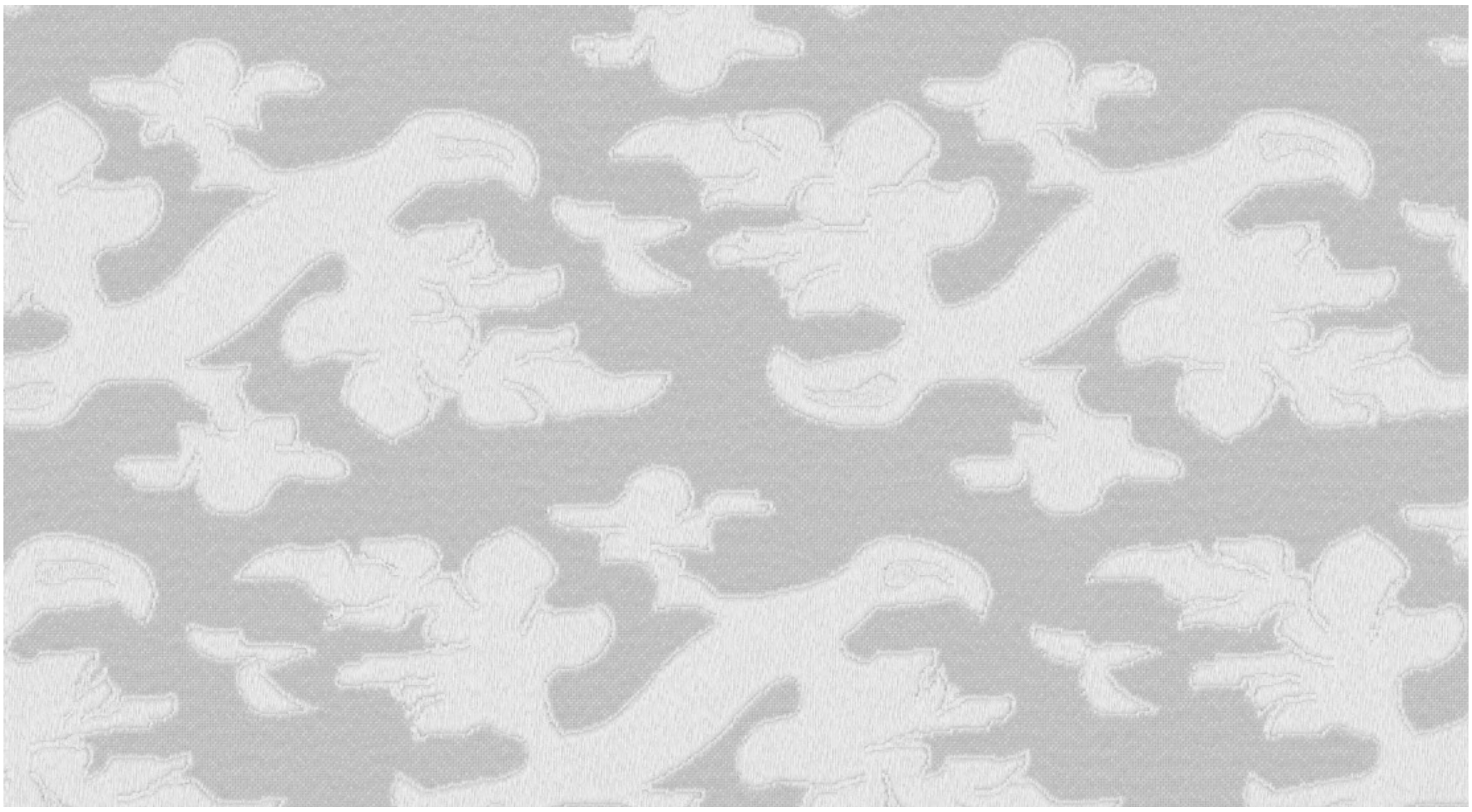

Fig. 04

Redesign

The last part of the research work focused on a complex redesign process in order to initiate a dissemination cycle that would showcase the obtained results and generate increased interest from stakeholders in the work done. The purpose in this case was conveyed through the creation of film content strategically divided by themes. Specifically, there was an introductory section related to the research work and the chosen fabrics, emphasizing their aesthetics and heritage, followed by three main sections divided into fashion, product, and textile macro areas. The goal in this case was to showcase the potential of the fabrics through the modeling and subsequent rendering of a capsule collection of ten garments and iconic products in the world of design and art. All these models then existed in the digital space of the metaverse, where users can interact in the virtual environment, observing the products and enjoying the audiovisual content created in the first phase of the redesign cycle. The digital reworking involved not only the simple application of fabric textures on contemporary design objects and fashion items but also the exploration of variations in fabric colors through the study of color variants and the investigation of formal alterations in terms of pattern size.

New Perspectives and Life Scenarios

Based on the analyzed processes in the previous paragraphs, some significant unresolved issues have been observed, further complicating the digitization process. The first aspect to emphasize, perhaps the most important one, concerns the surface finishing of the fabrics or the simulation of their pile. In this case, the studied CAD was unable to provide an optimal surface representation of the selected samples, resorting to workarounds that made the digitization process longer and more complex. The strategies employed, as seen in the mapping paragraph, involved creating specific fur mappings or converting the particle system into a mesh. This advanced level of modeling significantly extended the rendering time and did not entirely solve the issues related to the external representation of the fabric. One more challenge to consider was the aesthetic rendering of certain selected samples belonging to the Museo del Tessuto di Prato group. In this case, most of the designated designs were velvet artifacts, obtained

mostly through post-weaving processes that gave them a particular character. Although the CAD offers specific tools for simulating velvet, the final result of the representation did not meet the intended objective, partly due to the absence of a yarn in the YarnBook library that fully represented the physical and aesthetic characteristics of velvet. In this specific case, the problem was initially addressed by utilizing the software Clo3D, which includes a specific preset for velvet, and subsequently through lighting techniques that enhanced its aesthetics. For the yarn, a selection was made to find one that closely approximated the intended result for the mentioned fabrics. Another complexity arose from technicalities related to the production of fabrics using different shafts in dobby looms. The specific CAD software, Dobby, did not have a methodology capable of meeting the technical specifications. During the research period, the software was updated and implemented by the manufacturer with the addition of a technique that allowed the use of multiple shafts simultaneously. However, the upgrade failed to generate the pattern of the chosen fabric, resulting in the digitalization of multi-shaft fabrics using other programs.
The analysis presented so far highlights interesting points for reflection that could lead to an innovation scenario in the field of textiles, design, and fashion design. Firstly, by combining multiple software, immersive experiences could be created that leverage the strengths of both the physical and digital worlds in a phygital approach. It is worth noting that from a strictly digital perspective, what has been studied and presented previously is still an experimental area, as digitizing complex fabrics[5] (as explained in the analysis) presents unresolved challenges. Another aspect to consider is that several museums do not have enough space or materials to exhibit all their artifacts. Many of these artifacts, such as the samples from the Museo del Tessuto di Prato, are fragile and cannot be displayed. One solution to this problem could be the creation of a digital archive that showcases historical pieces that cannot be exhibited, generating interest among visitors. Typically, the interaction of spectators with physical museum objects is limited, as they cannot be shown from all angles, preventing visitors from examining them in a 360-degree view. The digital archive would offer innovative solutions for these institutions, leveraging the digitization methodologies discussed in the contribution (Arayapan et al., 2022). Another horizon of innovation lies in the prototyping process, as reverse engineering techniques reduce the time to market, thanks to the CAD's ability to quickly perform style checks and study variations (both in form and color). Furthermore, new perspectives and life scenarios open up for archival fabrics from both companies, as they can be contemporized through redesign approaches. In the fashion and textile industry, software such as Clo3D can provide valuable assistance by enabling immediate stylistic comparisons. On one hand, companies like Marini Industrie Spa can showcase their fabrics applied to 3D models, increasing stakeholders' interest, and on the other hand, museum institutions can digitally revive their textile imagination.

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Figure Captions:

Fig. 01: Real fabric sample from the 1500s.
Fig 02: Digital fabric with "basket weave" pattern from 1580-1620.
Fig 03: Digitization of Pied De Poule through Cad Dobby.
Fig 04: Example of multi-level map: Ambient Occlusion (AO) of the 1500s fabric.

5 Specifically, this refers to fabrics with significant surface details such as fur, wrinkles, ruffles, etc.