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Augmenting Cultural Heritage Through 4.0 Technologies: A Research on the Archival Jewelry of the Gianfranco Ferré Research Center

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***Abstract*—**Looking at design artifacts as bearers and disseminators of material knowledge and intangible socio-cultural meanings, the significance of archival jewelry was investigated following digital cultural heritage research streams. The application of the reverse engineering concept guided the research path: starting with the study of Gianfranco Ferré's archival jewelry and analyzing its technical heritage and symbolic value, the digitalization, dematerialization, and rematerialization of the artifact were carried out. According to that, the proposed paper results from research conducted within the residency program between the Gianfranco Ferré Research Center (GFRC) and Massachusetts Institute of Technology (MIT), involving both the Design and Mechanical Engineering Departments of Politecnico di Milano. The paper will discuss the analysis of traditional design manufacturing techniques, re-imagined through 3D scanning, 3D modeling, and 3D printing technical knowledge while emphasizing the significance of the designer's role as an explorer of socio-cultural meanings and technological mediators in the analog-digital-analog transition.

***Keywords*—**Archival jewelry, cultural heritage, rematerialization, reverse engineering.

I. Introduction

BY their very nature, design practices result in the production of culture-intensive goods, in which the cultural capital is expressed through the design of the artifact's shape, thus becoming catalysts of collective and subjective identities [1]. Likewise, fashion, resulting from a stratified historical experience, expresses the material culture of a given territory and community, the significance of which is not limited to the historical narrative but extends to the social meanings conveyed through the artifact [2]. Indeed, the *'high cultural content'* [3, p.239] of fashion items is identified in three distinctive features: first, they are *'mature and historicized,'* which gives them the capacity to transfer historical meanings through their constructions, materials, and production processes; second, they are *'institutionalized in everyday life,'* which expresses their capacity to shape people's lifestyles through their widespread adoption; and third, they are *'tools of mediation'* between the personality of the individual and the social group, becoming de facto *'identity prostheses'* [3], [1, p.351]. Fashion artifacts are, thus, in their essence, a powerful detector of social and cultural change [4]; even considering the transformative impact of technological innovation on the fashion industry, fashion items still bear witness to the distinctive features of our digital era. Indeed, within the current context of technological change, it is worth reflecting on "how Design acts as a cultural mediator shaping future artifacts rooted in the reinterpretation of the past" [1, p.350]. According to this perspective, design language can perform as a '*conservator'* or '*activator'* [1, p. 352], depending on whether it emphasizes the connection between material culture and cultural heritage or it reinterprets craft processes, acting on narrating the artifact's meanings [1]. Concerning the *activation* capacity, this leads to re-evaluating the artifacts' abilities to convey narrative paths from their materiality, consequently reviewing "ways of preserving and enhancing memory, cultural heritage, archives, and intangibles." [5, p.337].

Technological innovation, besides modifying the fashion industry's production models, also affects how design objects are exhibited, thus enabling new ways of communicating artifact value through immersive virtual experiences, reaching a wider audience with new forms of interaction that avoid the need for physical presence. In this regard, the subject of archival fashion attempts to combine with new technologies, working on a hybrid form of knowledge in which the information implicitly held by the archival object is revealed through the reverse engineering approach in which the object is examined in its components and the relationships between them, resulting in the process of re-elaboration of the outcomes [6]. Indeed, "the ever-increasing integration and hybridization of digital tools has led museums and fashion houses to consciously exploit opportunities for cultural expansion, ensuring a greater rapidity in the information access and transfer." [5, p.337].

This paper utilizes this context of fashion artifacts undergoing technological transformations to explore the cultural significance of fashion archive objects subjected to a process of dematerialization. The presented results derive from experimentation conducted during the GFRC and MIT residency program, which led to the documentation of state-of-the-art 4.0 technologies aimed at reverse engineering and rematerializing archival jewelry. The study will give rise to

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reflections on the central role of the designers in the analog-virtual-analog transition, in which they compensate for technological shortcomings and interpret and transfer the meanings of immaterial authenticity of the artifact in its new rematerialized form.

II. Rematerializing Fashion Cultural Capital through Additive Manufacturing Techniques

The GFRC was established in December 2021 by Politecnico di Milano following the Ferré family's donation of the Gianfranco Ferré Foundation's archives and headquarters. It aims at incorporating digital innovation to explore fashion artifacts with high cultural significance related to the historical archive of Gianfranco Ferré, which obtained its formal recognition of heritage "of special cultural interest" in 2014 by the Ministry of Cultural Heritage and Activities, Archival Superintendence for Lombardy.

The heterogeneous repository, preserving the collections developed by Ferré during his design career, comprises 12,000 tangible artifacts, including garments and accessories from the Woman and Men collection of Gianfranco Ferré High Fashion and Ready to Wear Woman's and Men's Haute Couture collections and more than 22,000 sketches and technical drawings, organized chronologically, belonging to the different brand lines and collections. In addition, the archive houses an entirely digital section of 40,000 items composed of photos, films, videos, press reviews, magazines, lectures, and notes written by Ferré himself. The fashion archive, which holds immense historical value, contributes significantly to the Italian fashion design tradition. Moreover, the interdisciplinary perspective of the Research Center traces new trajectories of archival expansion. It fuses historical heritage with cutting-edge technologies through a design-oriented approach. The research presented in this paper, focuses on archival jewelry and digital documentation to enhance cultural heritage through educational and research activities. This research is part of the residency program *'Rematerialising Fashion Cultural Capital through Additive Manufacturing Techniques,'* conducted in collaboration with GFRC and MIT as part of MIT's International Science and Technology Initiatives, in collaboration with the Design and Mechanical Engineering Departments of Politecnico di Milano. It aims to contribute to the artifacts' reverse engineering investigation, using Ferré's archival jewelry as a vehicle to explore the technical heritage of the design tradition, seeking to transfer socio-cultural values through 4.0 artifact rematerialization.

The study involved 3D scanning, 3D design, and 3D printing methodologies, whose practical applications in jewelry design have been previously successfully demonstrated [7]. Fusing the analog with the digital environment and integrating scientific research with artistic expression in a multidisciplinary experimental framework, the study aimed to explore the theoretical concept of '*Post-digital design*' [8, p.72]. The outlined approach aims to navigate digital transformation through a reverse engineering model [9], providing a reinterpretation of technical heritage through a 4.0 reassessment of traditional techniques.

III. Methodology

The eight-week exchange program took place between June and July 2023, adopting a Research through-design approach (Frayling, 1993) in [10], in which mixed-method research [11] was conducted.

The project was structured into three main *phases: (i) archive literacy, (ii) reverse engineering,* and *(iii) rematerialization*. In *phases (i)* and *(ii),* a qualitative investigation of the jewelry was undertaken to analyze the selected items, relying on various design insights, their exterior appearance features, and archival information about the original manufacturing techniques employed in their realization. In *phase (iii),* experimentation with technologies 4.0 was carried out to rematerialize the investigated and selected jewel.

A. Phase (i) - Archive Literacy

The study first involved the consultation of the jewelry's physical archive and an initial literacy phase on the digital repository structure and contents. The archive's comprehensiveness and articulation enabled the identification of relevant information, tracing the history and significance of the artifact, both in its tangible and intangible nature. The provided data revealed insights into the construction materials, manufacturing technicalities, thematic inspiration, related fashion collection, associated exhibitions, and magazine publications relevant to the jewelry. The initial literacy phase of Ferré's archival jewelry led to the identification of the bracelet as the most representative piece for the study performed, as it emerged as the most recurring accessory in Ferré's collections and therefore allowed for a broader exploration and mapping of its material features and design varieties, eluding the temporal clustering of the archival bracelet based on the collection year and thematic inspiration.

A preliminary investigation of sociocultural value was conducted through Ferré's design principles: The *Body,* the *Matter,* the *Color,* the *Detail,* the *Volume,* and the *Movement* [12]. As stated by Gianfranco Ferré during a lecture given at Domus Academy in Milano (July 14th, 1997), "Jewelry was not limited to being an accessory but became an element part of the dress and integrated stylistic codes that determined its design" [13, p.84].

Secondly, a further analysis was carried out, considering the jewelry's outward characteristics, leading to the identification of three identified Aesthetic-Structural Principles (ASP): *Interweaving, Multiple Materials,* and *Surface and Texture,* which were then applied to a limited selection of 21 archival bracelets, based on the most prevalent ASP, observed during the literacy phase (Table I). Within each ASP, physical properties describing the jewel's appearance were identified to establish clear parameters for the coding process. Within each category of physical properties, subcategories were then determined to guide the description of jewelry's characteristics. These categories and subcategories were defined as an iterative process based on rules of design elements, aesthetic explorations, and creative motifs articulated in further scientific literature on the topic. In the following analysis, there is potential fluidity in defining which jewelry feature prevails over the others and in interpreting jewelry forms univocally due to the subjectivity of the researcher's point of view and the complexity of the artifacts' design.

Concerning the *Interweaving* ASP, the parameters within this group were informed by the study results by [14], in which jewelry's visual attributes were codified to determine the most relevant parameters of form-related qualities. Specifically, the following subcategories were recognized to define the clustering system applied to the research:

- *Pattern* describes a twisted, intersecting, and wrapped structure;
- *Space* defines the final piece as a whole, analyzing the visual result of the weave, either perceived as geometric, cluttered, eclectic, or linear;
- *Shape design* considers the geometric lens by determining whether the shape is elliptical-circular, parabolic, or freeform.

As for the *Multiple Materials* ASP and the related sub-coding process were informed by [15] due to the analogies between the provided definition of filigree jewelry (twisting, bending, wrapping, braiding metals to create a lace-like effect) and the explicit manifestation of filigree inspiration in Gianfranco Ferré's pieces. The *Multiple Materials* ASP was also fragmented into three additional sub-criteria:

- *Composition* defines the relationship between the materials composing the artifact, either having solid beads, jewels, and stones or embeddings or combinations;
- *Distribution* describes the impact of the physical quantity of each material and how this affects the visual, with balance, symmetry, or physical equality,
- *Decoration* addresses external decorative properties of the piece consisting of additional items or decorative borders of thicker, intertwined threads or intersecting pairs.

The *Surface and Texture* ASP underwent a similar analysis and labeling process, which led to the identification of the following subcategories:

- *Surface* reflects the intention of the material manipulation, classifiable as an imitative, geometric, or organic pattern;
- *Luminosity* defines how the piece responds to light, referred to as shiny, dull, or metallic;
- *Texture* depicts how the object feels in response to touch, with sharpness, extrusion, intrusion, or material effects.

The inherent fluidity of the *Surface and Texture* ASP, which represents the proper fusion of the physical-visual relationship, was informed by the previously reviewed studies by [14] and [15].

TABLE I
EXAMPLE OF A CLUSTERING OF AESTHETIC-STRUCTURAL PRINCIPLES

Bracelet	Bracelet S/S 2003 Bronze galvanized brass Archival ID: 50720 	Bracelet F/W 1992-93 Synthetic resin, polished gold galvanized brass Archival ID: 50703 	Bracelet S/S 1993 Blasa Wood, gold leaf Archival ID: 50608 
Bracelet category	*Interweaving*	*Multiple Materials*	*Surface and Texture*
Subcategory I	*Pattern:* The final decoration recalls the processing and weaving of bamboo from Asian/Chinese inspiration	*Composition:* The stamped resin creates an "engraved" the appearance of an intricate portrait	*Surface pattern:* The carved pattern is characterized by organic shapes and is inspired by tree bark
Subcategory II	*Space:* Described as semi-rigid, the matter gains form and strength only when combined with the other elements of the piece. The form is achieved by manipulating smaller tubular elements to form a valuable bigger piece	*Distribution:* Equal parts resin and brass, but the asymmetric "artwork" of the resin dominates the attention	*Luminosity:* The jewel shows metallic reflexes due to the gold plate applied to its surface
Subcategory III	*Shape Design:* The relationship of this piece with the skin is interesting because the negative space allows for the body to play a part in the total visual composition	*Decoration:* The brass of the body serves as a border to the red resin	*Texture:* The surface pattern consists of long, irregular grooves

B. Phase (ii) - Reverse Engineering

Through the analysis of archival jewelry, meanings related to the technical heritage expressed in tangible form and the socio-cultural significance conveyed by intangible design knowledge was framed. Subsequently, a further bracelet screening was conducted to determine the ideal archival jewel for the final dematerialization and rematerialization. The analysis of the technical-engineering characteristics focused on three S/S 2003 bracelets: *Bronze galvanized brass (archival ID: 50720); Palladium galvanized brass, Swarovski crystals (archival ID: 50722); Silver plated galvanized metal (archival ID: 50721)*, clustered into the *Interweaving* ASP group. The three identified archival artifacts featured optimal design, structure, and shape attributes for the ultimate experimentation with additive manufacturing techniques. In this case, the investigation aimed to directly compare the bracelets' original manufacturing techniques with prospective rematerialization techniques, considering the design characteristics and cultural meanings previously analyzed. The main themes on which the examination was channeled concerned three different points of interest, expressed in material aesthetics, investigating the distinctive features of the design object and their potential performance through 4.0 manufacturing processes; the shape of the bracelet, studying the original form and its digital capture through 3D scanning and 3D modeling up to its rematerialization through 3D printing techniques; and finally post-processing, considering the possible finishing stages of the artifact 4.0. The resulting comparative clustering (Table II) led to a discussion of design criticalities and opportunities relative to one of Ferré's archival artifacts, evaluated as the optimal item for the analog-digital-analog transition.

TABLE II
EXAMPLE OF A COMPARATIVE CLUSTERING: ORIGINAL MANUFACTURING AND MANUFACTURING 4.0

Bracelet	Bracelet S/S 2003 Bronze galvanized brass Archival ID: 50720 	
Manufacturing	*Original Manufacturing*	*Manufacturing 4.0*
Material Aesthetics	Galvanized metal wire subjected to antiqued gilding: - Lacquer coating for luminosity - Galvanization to preserve visual appearance (prevent rusting) - Smooth texture as a characteristic of wire - Brass color	Fusion Deposition Modeling: - FDM Desktop Metal Studio System+ Bound Metal Deposition (BMD) system allows for integrity of the material - The result is likely to be less visually sophisticated, with simplified "dents," "weavings," and "overlaps"
Shape	Linearly-based and symmetrical: - Shaping process likely including annealing, intertwined/ patterned with a wire jig, and shaped with a mandrel - Potential use of adhesive welds	Scan, 3D Modeling, Fusion Deposition Modeling: - The precision of the shape will depend on the digital processing of the 3D scan - Utilize horizontal symmetry - FDM Desktop Metal Studio System+ Bound Metal Deposition (BMD) system to create the physical form
Post-Processing	Attention to the relationship with light, time, and handling: - Lacquer prevents rusting and adds shine - Sanding/ polishing to remove dents/ imperfects (potentially from pliers, relevant solutions, or adhesives) - Work hardening (potentially through a tumbler) to maintain shape	Inherent imperfections of FDM - Removal of support material (ceramic with Desktop Metal Studio System) - Sanding/ polishing to smooth out the resulting layers and remains of a support structure - Lacquer or potential galvanization for rust protection/ shine

C. Phase (iii) – Rematerialization

The *S/S 2003 - Bronze galvanized brass bracelet (archival ID: 50720)* (Fig. 1) resulted from the carried-out analysis as the archive jewel suitable for the rematerialization study. According to the reverse engineering method based on the path *'object-model-concept'* [9, p.518], three main technological exploration steps were identified for the research: scanning, modeling, and 3D printing.

Fig. 1 Bracelet S/S 2003 - Bronze galvanized brass - Archival ID: 50720

The strategy mentioned above was initiated by exploring hardware and software scanning systems to select the most suitable tool capable of capturing the physical artifact properties, respecting the integrity of the original dimensions, and overcoming the obstacle of the reflective property of the bracelet. The first acquisition test was carried out by photogrammetry with *RealityScan,* a mobile application converting user-taken images into volumetric renderings through neural network processing [16]. Despite the tool's user-friendliness, the obtained result highlights the inability of the app to process a 3D printing suitable file. The incompatibility of the medium with the design objectives is evidenced both by the FBX file format, which needs to be converted into an STL file to be printed, and by the inaccuracy of the resulting digital bracelet in which the item is fused with the support base, and the details are very rough and approximate. The *Structure Sensor* and the *Leo Artec 3D* scanners were employed in further experimentation with the ultimate goal of capturing the material texture of the archival bracelet. The *Structure Sensor,* characterized by its simple usage through an iPad app and an integrative device, applied infrared light to acquire and digitalize items [17]. However, concerning its application to the jewelry, it failed to grasp the complexity of the bracelet's design. Likewise, the *Leo Artec*, based on a structured blue light projected perpendicularly to the object [18], proved ineffective in virtualizing the jewel under investigation. In both cases, the generated models had a fragmented structure and lacked detailed transmission of material attributes. The last experimentation was performed via the *EvixScan 3D* tool, a system largely adopted in reverse engineering processes due to its capability to capture the form peculiarities of tiny objects thanks to the scanner accuracy of 0.02 mm [19]. Based on the analysis of the deviation of the white striped pattern emitted by the instrument, the scanning process was marked by 30 different acquisitions of the archival bracelet, scanned first from the upper and then from the lower side. The resulting scans were merged into a single digital model formed by a point cloud exportable to an OBJ file (Fig. 2).

However, the incompleteness of the shape and texture and the noise captured within the mesh made it unsuitable for direct printing. Based on these assumptions, the OBJ file was imported to the 3D modeling software *Rhinoceros 3D*, on which the bracelet was then manually reshaped. The bracelet acquisition was employed to reproduce the precise dimensions, proportions, thicknesses, and construction details, using selected points from the rough model as a guideline. Several iterative steps marked the virtual modeling process, which led to the realization of the final 3D model (Fig. 3).

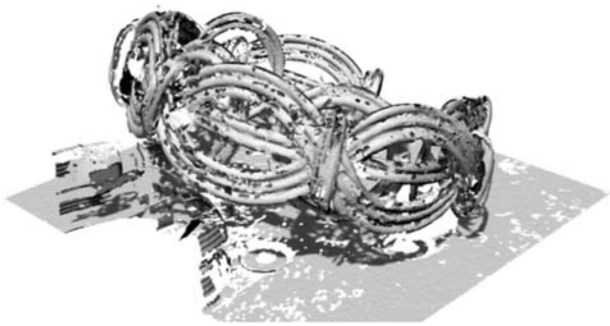

Fig. 2 EvixScan results of the Bracelet S/S 2003 - Bronze galvanized brass - Archival ID 50720 scanning process

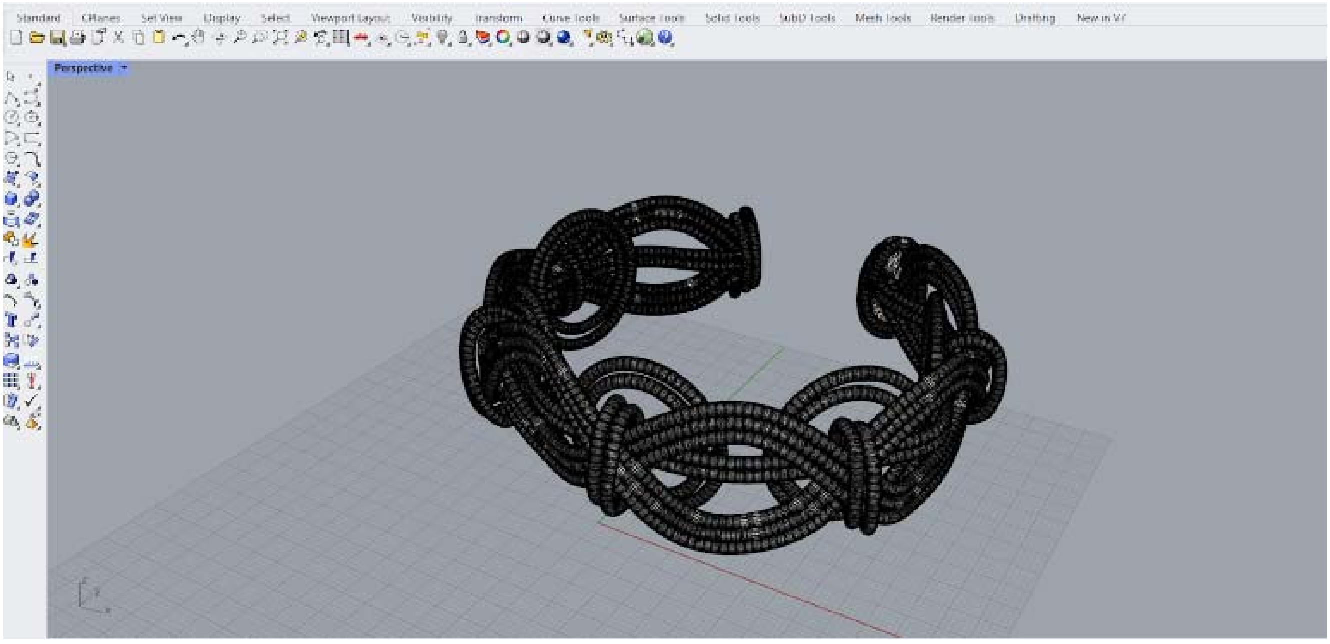

Fig. 3 3D model made with Rhinoceros 3D of the Bracelet S/S 2003 - Bronze galvanized brass - Archival ID 50720

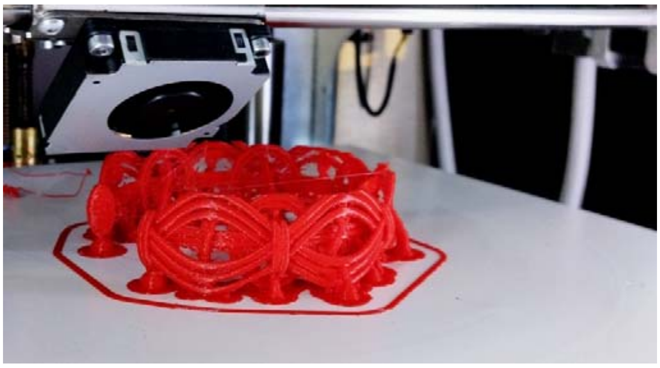

Fig. 4 3D printing of the S/S 2003 bracelet - Galvanised Bronze Brass - File ID 50720 with the FDM Sahrebot 42 PLA printer

Following this phase, experimentation with different 3D printers began. An initial rematerialization testing of the digital model was conducted through *Sharebot 43* and *Sharebot 42*, two 3D printers based on Fused Deposition Modeling (FDM) with a PLA (Polylactic acid) filament. Print settings in the case of the first machine were made with *Simplify 3D* software. Conversely, the second machine worked with *Prusa Slicer* software, which allowed for the setting of tree-shaped support, resulting in faster printing and a cleaner setup compared to the previous printing results. In both experimentations, the resulting outcomes were extremely rough, and the thickness of the extruded filament was deemed unsuitable for rendering the jewel's details (Fig. 4).

A second evaluation took place through the *Creality 3D - Resin* printer, based on Stereolithography (SLA) processing through which a layer of photosensitive liquid resin is exposed to a UV laser beam that solidifies the material into the desired pattern, layer by layer. The bracelet was printed vertically, necessitating a dense support structure. Next, the model was subjected to post-processing to remove the supporting structure, whose imperfections left behind were smoothed out with sandpaper. The operation was performed underwater immersion to maintain the quality of the resin. In this case, the type of technology and material allowed excellent rapid reproduction of a highly accurate prototype with a minimum of manual labor (Fig. 5).

Fig. 5 3D printing of the S/S 2003 bracelet - Galvanised Bronze Brass - File ID 50720 with the SLA - Creality 3D Resin 3D printer

Fig. 6 3D printing in copper of the S/S 2003 bracelet - Galvanised Bronze Brass - File ID 50720 with the FDM and BMD Desktop Metal 3D technology

Finally, a last experiment was conducted to rematerialize the bracelet through a *Desktop Metal Studio* 3D printer, which adopts a combined technology of FDM with Bound Metal Deposition (BMD). The *S/S 2003 - Bronze galvanized brass bracelet (archival ID: 50720)* was set up through the *Prusa Slicer* software, and the metal selected for printing was copper. The machine is based on a very complex process consisting of the extrusion of metal bars held together by a polymer binder, which is squeezed onto the build plate, on which the model begins to be built layer by layer. Once printed, the binder is removed through the de-binding procedure and sintered, causing the metal particles to densify. This additive manufacturing technique requires using two extruders, one that reproduces the path described above and a second to generate thin layers of ceramics that will separate the model from the support substrate. This technological process led to a copper rematerialization of the archival bracelet (Fig. 6). Despite the materiality of the metal that the original jewel shares with the 4.0 bracelet, the final version encompasses the technical knowledge of a novel form of craftsmanship.

IV. Results and Discussions

The following analysis discusses in parallel the rematerialization results obtained through 4.0 technologies and their consistency with the peculiarities of the original jewel read through the lenses of ASP and Ferré's Design principles. The manufacturing methods discussed are based on archival description, observation assumptions, and prior knowledge of fine metalworking. At the same time, the considerations on technological methodologies resulted from a literature review and information provided by researchers of the Department of Mechanical Engineering of Politecnico di Milano. In particular, the interpretation of the outcomes will focus on the *Creality 3D - Resin* and *Desktop Metal Studio* rematerialized models, the output of which was more satisfactory compared to the experiments conducted with *Sharebot 42* and *Sharebot 43*, in which results were not sufficient in terms of consistency with the original piece and final aesthetic rendering.

The *S/S 2003 - Bronze galvanized brass bracelet (archival ID: 50720)* is composed of a galvanized metal wire subjected to antiqued gilding; this process, which allowed the metal to shine and prevent rust, is an example of Ferré's *Matter* principle [12], in which value is generated through unconventional material treatments. In terms of aesthetic appearance, wire allows for smooth texture, defined lines, brightness, and malleability. In response to these characteristics, the *Desktop Metal Studio* system permitted for perseverance in the experimental use of the matter, as a metal powder supported by wax and polymers is transformed into a valuable object. Furthermore, using FDM allows the brightness characteristic of metal to be maintained, which efficiency was also revealed by the case study by [20]. However, the similarities with the original object could be further explored through the post-processing phase, which would also offer the possibility of including the design principle of *Color* [12] in the rematerialization investigation. The use of color in Ferré's jewelry production emerged as an intrinsic property of the material's features; instead, the chromatic properties of the original piece, lost during the dematerialization and rematerialization process, could be reintegrated within the design path by adding finishing or lacquering stages after 3D printing phase.

The original piece's shape, uniform structure, and absence of dents involved a wire template, a mandrel, an annealing process, and an abrasive polisher. Through these instruments, Ferré guided his principles of *Volume* and *Movement* [12]; however, the new materialization relies on a different set of tools. The scanning process allowed for exact references to maintain the integrity of the *Volume* resulting from the intricate weaves of the original piece for both 3D printing tests. Analyzing, more specifically, *Desktop Metal Studio*'s direct printing of the bracelet, it passes many of the initial processing steps; however, due to the layered nature of FDM printing and residual ceramic support structures, post-processing is an essential area of focus. Polishing, sanding, coating, and heating remain relevant while encapsulating a different purpose or process [21]. Whereas polishing in the original part served to overcome dents and imperfections, polishing 4.0 must be abrasive to overcome the orientation of layered construction. Given that heat was used for annealing and bonding in the original piece, in 4.0 pieces, heat becomes a post-processing step, as it must be used to fuse the ceramic support structure. The purpose of the coating, however, remains constant: to improve brightness and preserve quality. Borrowing these steps in a new light makes it possible to maintain the aesthetic properties that defined the original jewel while simultaneously adopting a new meaning of materiality and valuable craftsmanship through 3D printing. *Movement* [12] can instead be reflected in the characteristics of the material selected for the 3D printing of the bracelet, which consequently defines the material's strength, rigidity, flexibility, or malleability when subjected to external pressure or movement.

Furthermore, the *Body* principle [12] is reinvested with new meanings. Suppose its original definition was associated with the jewelry's ability to transcend the classical conception of the bracelet as an ornament in favor of stylistic codes; in its 4.0 form, this peculiar feature undergoes a process of reinterpretation. So far, the rematerialized jewel neglects its nature while maintaining its form and becomes a disseminator of messages about the technical heritage and cultural value of the artifact in its original and rematerialized manifestations. Also, the *Detail* design principle [12] was investigated during the rematerialization phase by examining the relationship of jewelry to the body wearing it and its proportions and shapes, transforming it from a piece of jewelry to an essential element that completes the look. The search for detail, incorporated into the main points of attention during the various design phases, ensured that the jewelry maintained its nature as a prosthesis of the garment that enhances the body's shape.

V. Conclusion

The advent of the Fourth Industrial Revolution and the spread of disruptive technologies have caused a syncretism of the physical with the digital world [22]. Indeed, the introduction of 3 DVD technologies (3-Dimensional Virtual and Digital) within the fashion industry demonstrated its advantages in optimizing design, prototyping, production, marketing, and retail processes [23] while increasing the quality of products and systems [24]. These new production, communication, business, and creativity models articulated a need to overlay technology with creativity and the physical with the digital to achieve a post-digital aesthetic. The nature of the fashion artifact is thus highlighted as a powerful expression of an artistic act, narrated in its hybrid forms from the physical to the digital, and a powerful presentation of collective and individual history [8]. The digital innovation tools thus filter into the archival realm, enabling novel fashion's cultural heritage analysis trajectories, reexamining and rematerializing knowledge of fashion production through human-computer interaction experiences [25]. Within this framework, the rematerialization of Gianfranco Ferrè's archival *S/S 2003 - Bronze galvanized brass bracelet (archival ID: 50720)* added a new layer of cultural-historical meanings expressing the contemporary era, providing new values related to manufacturing evolution to cultural narratives, technical heritage, and design approach.

This investigation led us to two major results: first, it allowed the mapping of state-of-the-art 4.0 technologies applicable to the exploration of fashion heritage, highlighting strengths and weaknesses of digital innovation in the dematerialization and rematerialization phases; second, it led to reflection on the archival artifact authenticity concept.

Regarding the first consideration, 3D scanners, 3D CAD software, and 3D printers that have proven effective in creating and recreating jewelry [24] were applied to explore Ferré's selected bracelet. However, the steps that characterized the analog-virtual-analog reverse engineering process highlighted the technological gap of Industry 4.0 tools, which failed to fully capture and dematerialize the complexity of the design technical heritage. Within this vision, designers acted as mediators of signification, deploying their technical knowledge to overcome the shortcomings still present in the examined technological tools to enable a smooth transition between the scanning, modeling, and 3D printing phases of artifact 4.0. Indeed, reverse engineering application to the fashion archival domain enables new connections between actors and disciplines, ranging from technological and engineering fields to curatorial skills, which can be merged within the fashion designer Figure [1].

The second reflection emerging from the research must be contextualized in the broader debate about artifact authenticity [26]. Insofar as the reproduction of items through 4.0 technologies makes their authenticity falter; indeed, as expressed by W. Benjamin's concept of aura, "even the most perfect reproduction of a work of art lacks one element: its presence in time and space, its unique existence in the place where it is located" [27, p.3]. Still, authenticity is defined by a set of intangible values that contribute to forming the object's identity through solid ties with the social fabric and territory in which it is referenced [3]. According to this perspective, the artifact's material existence is separated from its intangible meanings, which continue to exist and be conveyed even by replicas of the original artifact [28]. Thus, from a cultural perspective, goods result from cultural and cognitive synthesis processes [29]; therefore, part of their meaning is unrelated to their purely material nature. In light of these interpretations, authenticity is closely linked to a process of cultural recognition, which can also be ensured by transferring intangible values to new manifestations of cultural meanings and authenticity [30].

By integrating this point of view within the rematerialization process, which meticulously explored the technical heritage of the original artifact through the involvement of advanced technological expertise, this research can be perceived as an *amplification of the authenticity* of the archival jewel. In light of this perspective, the outcomes demonstrated how archival artifacts can serve as catalysts for exploring unique intangible meanings of fashion cultural heritage while highlighting the importance of designers' role in translating the socio-cultural values embedded in the archival object into novel design interpretations. As the item underwent various analog-digital-analog stages, it achieved *amplified authenticity*. Indeed, its historical significance is validated and recognized during the process for its cultural and historical value, extending into the present context. This transformation creates a meaningful narrative of its significance, bridging the gap between the past and the present.

VI. Limitations

The experimentation described in the article does not assess all the possibilities of rematerializing archival jewelry. It is limited to evaluating the technological tools explored and made available by the Department of Design and Mechanical Engineering of Politecnico di Milano. Further research in this field may consider other trajectories for exploring the GFRC's jewelry physical and digital archive, as well as other 4.0 technological tools relevant to the dematerialization and rematerialization of fashion cultural heritage artifacts.

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