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Craftsmanship, design and new technologies: digital sculptural jewellery

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Abstract

Purpose: The aim of this research is to find a new digital process for creating jewels that eliminates the problems inherent in the traditional production process and that maintains all the characteristics and identity of this sector.

Methodology: Experiments were conducted combining the traditional jewel production process with digital technologies (3D scanning, modelling and printing). The results are presented through a case study of a company in the jewellery business.

Findings: The potential for the use of digital technologies in the jewellery industry can be observed in a number of ways: retaining the professional's features in the pieces; allowing for maximum economy of material; letting jewellery models be created with less expenditure of time and labour; allowing the creation of geometries, fittings and joints with fewer limitations; and ensuring the standardization of pieces in a series. However, investment in professional training is paramount in the sector.

Research limitations: The study involved one particular case, but the findings can definitely be applied to similar cases.

Practical implications: Digital technologies can potentially collaborate with the traditional process of producing jewellery, and this can bring commercial advantages.~

Value: To the present moment, there have not been many efforts in the jewellery sector to rethink production methods. The popularization and the improvement of digital technologies call for a new approach. The main point of this article is to demonstrate the impact of new digital technologies.

Keywords: Jewellery. Production processes. Digital technologies. Three-dimensional scanning. Digital sculpture. 3D printing. Case study.

Paper type: Case Study.

1. Introduction

The digital technology revolution – design and image treatment software, 3D scanning, and digital manufacturing – has come to the jewellery sector, an area conditioned to production processes that use craftsmanship to construct, differentiate, and give value to its products.

Jewellery held to and was held back by craftsmanship, and it resisted the homogenized form in which technological advances guided the development of products and the production of prototypes in various sectors of industry (FERREIRA, DOS SANTOS and DA SILVA, 2007). The sector focused on the development of goldsmith techniques and wax modelling for casting, in a context that was mainly defined by costly materials and personalized or semi-industrialized products.

The sector remained in the traditional context, in large part, owing to certain characteristics of the crafting process in jewellery production. These characteristics allow the artist, designer, or company to develop exclusive designs and unique pieces that are valued because of the professionals' direct and full dedication to their production, which carries their personal traits – similarly to what happens in sculpture.

In the case of wax modelling, which is a traditional jewellery sculpting technique, the work begins with the conception of the piece in a two-dimensional representation (an artistic or technical drawing), and then a wax model is hand-sculpted with precision tools. This work, in addition to taking time, can be slowed down if the wax model breaks during the process because of its fragility. After this model is completed, for the first time the final object can be visualized three-dimensionally. Consequently, any changes that were thought necessary in the design or structure would render useless all the professional's efforts up to this point, and there would have to be some rework or even a new start to the whole process.

After casting the wax model, it would be easier for the professional to work on the metal piece, - as it is a more resistant material - carving the part for achieving an economy of raw material and reduction of the product's weight. Unfortunately, this process is difficult because the manual work lacks precision. One of the consequences of this is the waste of raw material, since, in the effort to reduce the walls of the jewel to the maximum, the professional's tools have to face the structural and geometric limitations of the pieces; in this situation, there is no other option than to use more material to produce the jewels. The second consequence is the irregularities in the weight and the dimensions among the pieces that are to be produced in a series; this is a problem that, besides directly affecting the calculation of the cost of each piece, risks the relationship of the artist, designer, or company with his final consumer.

All these difficulties cannot be resolved by the traditional process of jewellery production, since they come from the process itself. In view of this, the challenge would be to find an alternative process that would solve these problems and still preserve the distinctiveness of the traditional process of sculptural modelling in wax.

But how can a process that deals with new technologies – design and image treatment software, 3D scanning and digital manufacturing – coexist with craftsmanship in jewellery?

Digital technologies are not exactly a novelty, and, for some time, they have been expanding the designer's work into several other sectors. The use of CAD systems, for example, revolutionized product engineering, including the acceleration of the time needed for putting products on the market.

For jewellery, the difference is in the creation of software and devices that facilitate the interaction between the professional and the three-dimensional drawing. In a combination with digital scanning systems, high precision wax milling machines, rapid prototyping systems or additive digital manufacturing that is suited to the precision required by the sector, it is now a possibility and a priority for professionals in the sector to acquire skills through technical training, for there to be a full transposition or integration of the traditional process with the digital processes.

In order to answer the question above more thoroughly, while aiming to assess the costs of experimentation in innovation in the sector, the objective of this research was to find a new digital process for creating jewellery that eliminates the problems of the traditional production process and maintains all the characteristics and the identity of the sector.

The methodology adopted was the case study (EISENHARDT, 1989). The problems that are brought up are as much technical as they are commercial, since they originate from a practical demand in the sector. Although the results do not fully demonstrate that the sector adapted and made the conversion, they clearly point to the sector's capacity to do so in the long term.

2. Craftsmanship and new technologies in jewellery design

This case study arose from the demand of a company in the jewellery sector that needed to solve complex production problems that could not be resolved completely or efficiently through the traditional process.

The company in focus in this study is in the precious metal jewellery business, and one of the main features that differentiates its products in relation to those of the competition is the expertise and the craftsmanship of its jewellers. In other words, the uniqueness of their products comes as a result of the handcrafting process for creating its products.

The company concluded that, by using new digital technologies (scanning and direct modelling), it would be able to resolve its design, production, and cost problems. The company thus applied for and received funds from the state government through a public notice from FAPERJ[1]. However, despite having acquired technologies such as a 3D scanner and a digitalization treatment software, the company had no technical knowledge on how to use them or access to service providers, most of whom would not comply with the company's technical and business objectives.

Figure 1 – Some of the company's products in the case study: (i) "Beatriz and the Balloons" pendant; "Pinocchio" pendant; (iii) "Alice's Rabbit" pendant; (iv) "Sofia" pendant and (v) "Alice in a Tea Cup" ring.

In an industry where raw material such as gold has high costs, all the material that can be removed or not employed results in great savings when considering the entire production line, even if, from the point of view of a single piece, the apparent reduction is insignificant.

Still with respect to cost, another issue that must be addressed by this study is the maximum reduction of the size of the pieces and, consequently, of their weight, without sacrificing much of their level of detail. In this sense, there needs to be found a technology that allows this type of optimization with the differential of keeping the unique features that handcrafting production has guaranteed until now.

This being the case, an experimental approach was necessary for the application of digital technologies in the production process. Experimentation and investigation, which are characteristics of a research environment, proved decisive for the study of the production processes and the solution to the problem.

The specific objectives of the research were to: (i) reduce the final weight of the products (reduction of the amount of precious metal); (ii) standardize the amount of material used in each piece (since any small fluctuation would have a great impact on the calculation of the final price of each piece and its offer to the end consumer); (iii) reduce the size of the pieces, maintaining the level of detail and (iv) increase the aggregate value of the products (more accurate fittings, more sophisticated joints and greater variety of textures). Moreover, in this particular case, there is the requirement that, besides keeping the traditional, particular characteristics of the company, the jewels must be produced on a small scale.

2.1. Problems of crafting processes

The option to use precious metals as raw material for the products brought relevance to, mainly, two integrated factors: (i) the relation between the weight of the parts and the amount and uniformity of the material, since any small fluctuation would have a great impact on the calculation of the final price of each piece and its offer to the end consumer; and (ii) the possibility of reducing the dimensions of the parts, the maintenance and improvement of details and textures, and the inclusion of joints and fittings .

2.1.1. Reduction of weight and final material of products

For the traditional process of modelling and lost wax casting, the procedure of reducing the material of the pieces is laboursome and, indeed, in some cases cannot work.

The technique of wax modelling is commonly adopted by craftsmen in the production of jewellery by casting. Nowadays, there are two main wax modelling techniques, that is, (i) the one that uses soft wax, which is commercialized in sheets and malleable wires and (ii) the one that works with rigid wax in blocks and tubes of different formats, sizes and hardness. The present paper will focus on the second technique, in which the confection of the jewels begins with the jewellery wax being shaped to the desired three-dimensional formats.

With the help of dentistry and prosthetics tools, electric machines, saws and even needles, professionals remove material from a wax block or tube, gently sculpting shapes that show details such as texture, tool markings and inscriptions. Some minutiae can also be added by the application of molten wax in certain areas of the model's surface. (PIERCE, 1989). Models with large volumes normally need to have their interior carved out (TSUYUKI, 1999); this creates pieces with walls that have a minimum thickness, following the objective of conforming to the requirements for casting precious metals, which will be listed throughout this study. After achieving the desired shape, the models receive a surface finishing, with the aid of abrasive materials and substances, such as sandpaper, steel wool, and wax solvent.

From this positive model a negative silicone mould is extracted, and it will be used to replicate various copies when wax is injected into its cavity. These copies have their sprues fixed to a cylinder, which is also shaped in jeweller's wax. The set that is composed of a model, sprues, and a cylinder is named a wax tree. It is positioned in a container that will later be coated with a plaster and water mixture that hardens at room temperature. This solid set is taken to a kiln, where the wax will warm up with the heat, melt, and run off, generating a negative mould from the wax tree. The metal is poured inside the plaster mould by means of a casting technology (normally, centrifuge or vacuum) or manually. The cast mould is cooled in water, and it breaks because of thermal shock, which makes it possible to withdraw the metallic tree from inside (KLIAUGA and FERRANTE, 2009). The parts are extracted from the set and move on to the finalization, which includes assemblies, welding, polishing, stone settings, and enamelling, among other jewellery techniques (see lost wax casting in Figure 2):

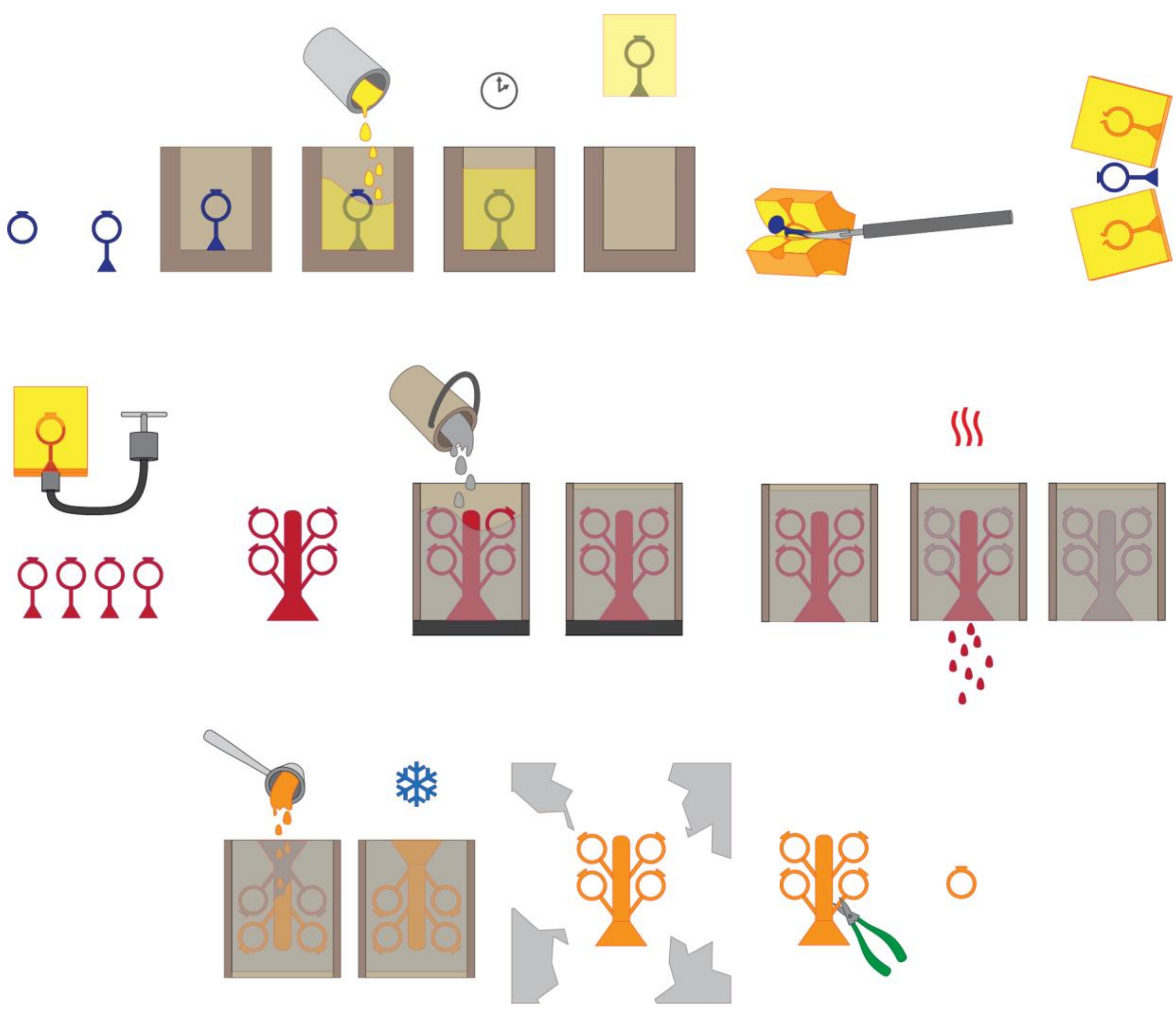

Figure 2 – Diagram of the lost wax casting process.
Source: Developed by the authors, adapted from KLIAUGA and FERRANTE, 2009, p. 188.

However, jewellers' wax is a delicate and brittle material, which can crack or break, making it difficult to mould very small and thin parts. When it breaks, a model rarely ruins a work definitively, but its repair demands extra work by the craftsman.

Furthermore, as illustrated below, with the tools used in the production of the wax model that has a minimum wall thickness, it would be difficult to produce a model with the maximum efficiency that is required for the commercial objectives of the company. The process of hollowing out and adding thickness to a piece is often prevented by the size and shape of the tools, besides the fact that they cannot reach certain areas of the model, and this results in a residue of wax that the mastermind of the jewel could not have planned or that is over the minimum called for by the casting techniques.

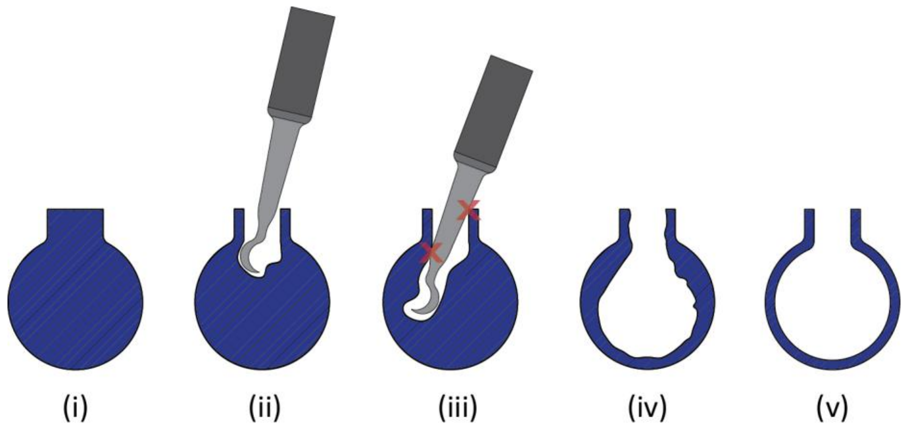

Figure 3 – Example of the tool's reach in which (i) a section of the wax model is still jointed; (ii) the sculptor is removing the material from the model; (iii) the dimensions and geometry of the tool prevent reaching into certain areas of the model; (iv) the maximum that can be dug with standard tools, in a non-homogeneous manner and (v) an ideal model with regular walls.

Manual labour is imprecise, and it is a challenge to maintain a constant thickness of the wax walls of the model. In addition, the irregularities of the wall's thickness are transferred to the silicone models. As can be seen in Figure 2, these negative three-dimensional models are used to generate positive replicas of the object by the injection of molten wax into the cavity. After the wax cools, a new solid copy is removed from the inside. Since the wax loses heat and solidifies quicker in the thin areas of the silicone model, it can form blocks that prevent the flow of the rest of the material from reaching all the cavities of the rubber mould.

Concerning jewellery design, it needs to be planned and executed in such a way that the wax model can be replicated by the silicone moulds, and also there needs to be consideration of and respect for the angle and extraction of the wax copy from the inside. In certain situations, the geometric complexity of the models allows them to be casted directly, but not copied by the silicone moulds, since the copy cannot be retrieved without breaking itself, something that works very well for the production of single products, but not for those in a series.

For these reasons, reducing the weight of the products in the jewellery sector is a complex task and one that can be better managed with the use of digital technologies, as will be seen later.

2.1.2. Reduction of dimensions, maintaining details

In jewellery made from wax modelling, one of the biggest differentials of the products of a designer, company or artist is the formal expression that comes from manual skills. However, the same human hand that ensures the uniqueness of the product and adds immaterial value to the jewellery imposes limitations regarding the modelling. Furthermore, modelling skills vary from one professional to another, as do the smallest dimensions that a given individual can sculpt and detail with traditional tools and techniques. For this reason, it is not uncommon for a professional to have to work on a much larger scale than the one

desired or planned, resulting in models that have a large volume and demand much material for melting and, therefore, are expensive to manufacture in precious materials.
Another feature of manual wax modelling is the shape of fittings and joints. With the imprecise nature of the manual work and the brittleness of the wax, the difficulties of sculpting are aggravated by the small dimensions of the parts, which normally only allow for models that have much simpler geometries of joints and fittings.

The challenge, then, is to achieve optimal results through technology and technique in the balance between, on the one hand, reducing the size of the final products for maximum savings in the use of materials and, on the other, maintaining the artistic details that are, as pointed out, a differential of the company and its employees, as well as maintaining the functions of the fittings and joints originally included by the professional in the piece of jewellery.

2.2. The differential of digital technologies for the jewellery industry

Considering the experimental character of the research conducted in NEXT[2], this study turned to digital technologies to solve the above mentioned problems and, when possible, make improvements in the models, always maintaining their important craftsmanship characteristics, such as texture, small details, and fluid modelling movement, among others.

Below, there are listed the kinds of functioning and technical bases of these technologies, which are necessary for understanding the solutions that were found in this research.

2.2.1. Three-dimensional scanning

The three-dimensional scanning systems permit the transfer of volumes and textures from the physical to the digital world. Nowadays, there is an ample variety of technologies for digitalization in three dimensions, which differ in applications and attainable results.

The company in question acquired a small desktop scanner with Multi-Laser technology and its software for digitalization treatment. Initially, the NEXT researchers took on the responsibility of discovering the way in which both this scanner and its software operate, in order to pass this information on to the company.

For the purpose of understanding the potential of this technology, some scanning tests were performed with the “Alice” wax model, one of the three components that constitute the “Alice in a Teacup” product, shown in Figure 5:

Figure 4 - Wax model of Alice

Using the four highest resolution configurations available from the scanner's software, we obtained four samples of digitalization. Unfortunately, the results were not satisfactory for two reasons: (i) all the digitalizations presented a high incidence of noise and distortions, as can be seen in Figure 5; (ii) the scanner software was not successful in the post scanning process, that is, in joining the multiple surfaces that compose a digitalization and in filling occasional discontinuities in the surface of the model.

Based on this test, comparative tests were done with Structured-Light scanner technology from the NEXT laboratory. This technology proved to be better, concerning the absence of noise and the precision of the object's geometry, after the digitalization treatment process with the scanner's own software.

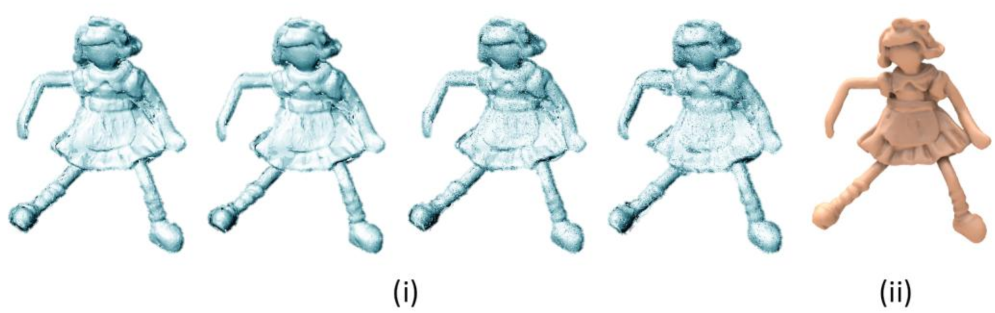

Figure 5 – Comparison between digitalizations already treated with (i) the company's scanner, from left to right in increasing order of resolution and (ii) scanner from the NEXT laboratory.

In this article, we will concentrate on the detailing and particularities of Structured-Light technology, considering that this was the technology that our specialists used with success in performing the experiments.

In Structured-Light, the model to be digitalized is positioned at the center of an automatic turntable. An array of light planes are projected and they scan the surface of the object as they move. The scanner's cameras register the positions of these projected planes as points on the surface of the object (PARK, DESOUZA and KAK, 2001). After the readings, the turntable rotates slightly, and the sweeping happens again for each new position of the object, within a 360 degree scope. This way, a series of scans are performed, and, afterwards, they are automatically aligned according to the coordinates of the points and fused into one polygonal surface (Mesh) by the device's software, as shown in Figure 6.

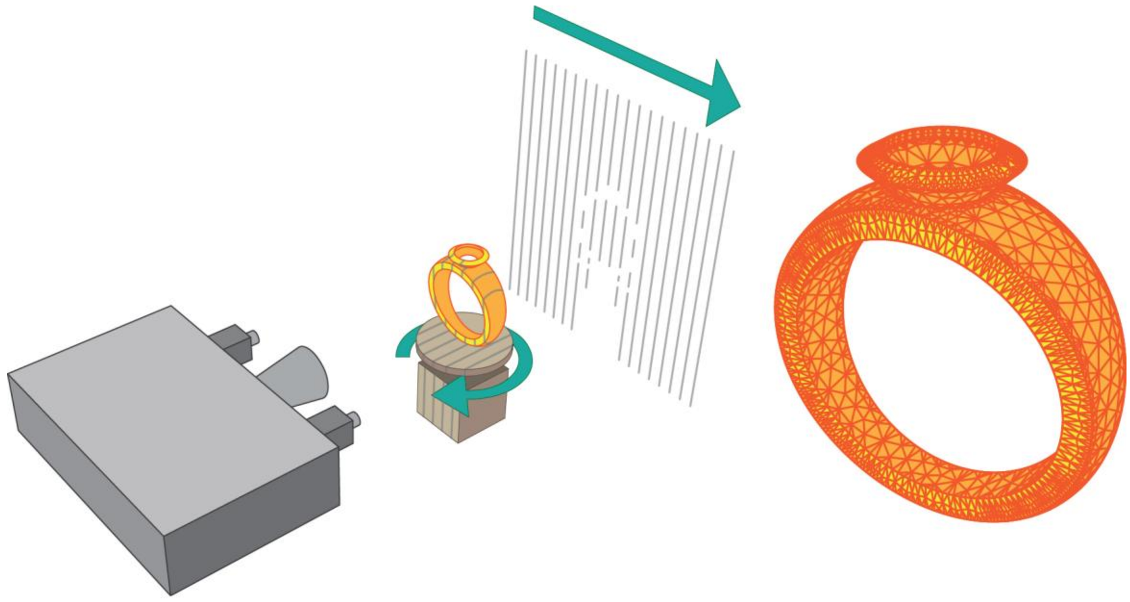

Figure 6 – Phases of digitalization done with Structured-Light technology.

This Mesh may have some irregularities that need later repairs by a professional, such as filling of discontinuities, separation of overlapping triangles, and reduction of possible noise, as shown in Figure 7.

Figure 7 – Company's wax model digitalized by Structured-Light and sequence of digitalization treatment.

2.2.2. X-ray microtomography

Widely used in studies of geology, odontology and materials sciences, microtomographs are devices that permit very detailed images of non-metallic structures to be obtained in a non-invasive way. With respect to the present study, computed microtomography, in contrast to other methods for scanning surfaces, allows the visualization of structures that are not noticeable and that, without the use of this resource, could only be observed by cutting the object, for example, the wall thickness of the wax models.

The X-rays emitted by the machine are transmitted through the sample, whose density attenuates the energy that is initially sent out, and the difference is measured and recorded by a sensor. Positioned on the turntable, the sample moves at a small and constant angle scheduled by the device, with a new measurement performed at each new position until it completes 360 degrees (ALVES, 2012), as diagrammed in Figure 8.

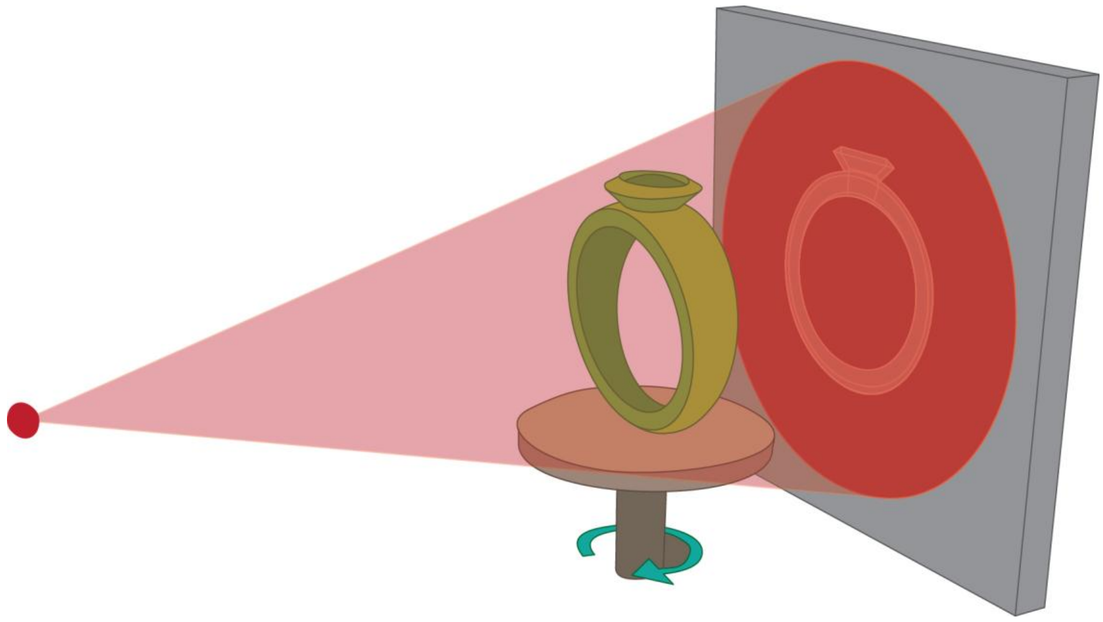

Figure 8 – Diagram of how the computed microtomography functions.

These measurements produce the horizontal projections (Figure 9, [i]), on whose base the two-dimensional images are reconstructed, that is, a graphic representation in pixels of each horizontal slice of the object (Figure 9, [ii]). With the images in hand, one proceeds to the construction of a three-dimensional object using the segmentation process, in which appropriate software establishes the boundaries of the sample in the two-dimensional image (Figure 9, [iii]). With this information, together with the numerical value that represents the interval between one image and another, that is, the height between each one of the slices of the sample, the software can create a polygonal surface that configures the virtual three-dimensional model of the object captured in a microtomograph (Figure 9, [iv]).

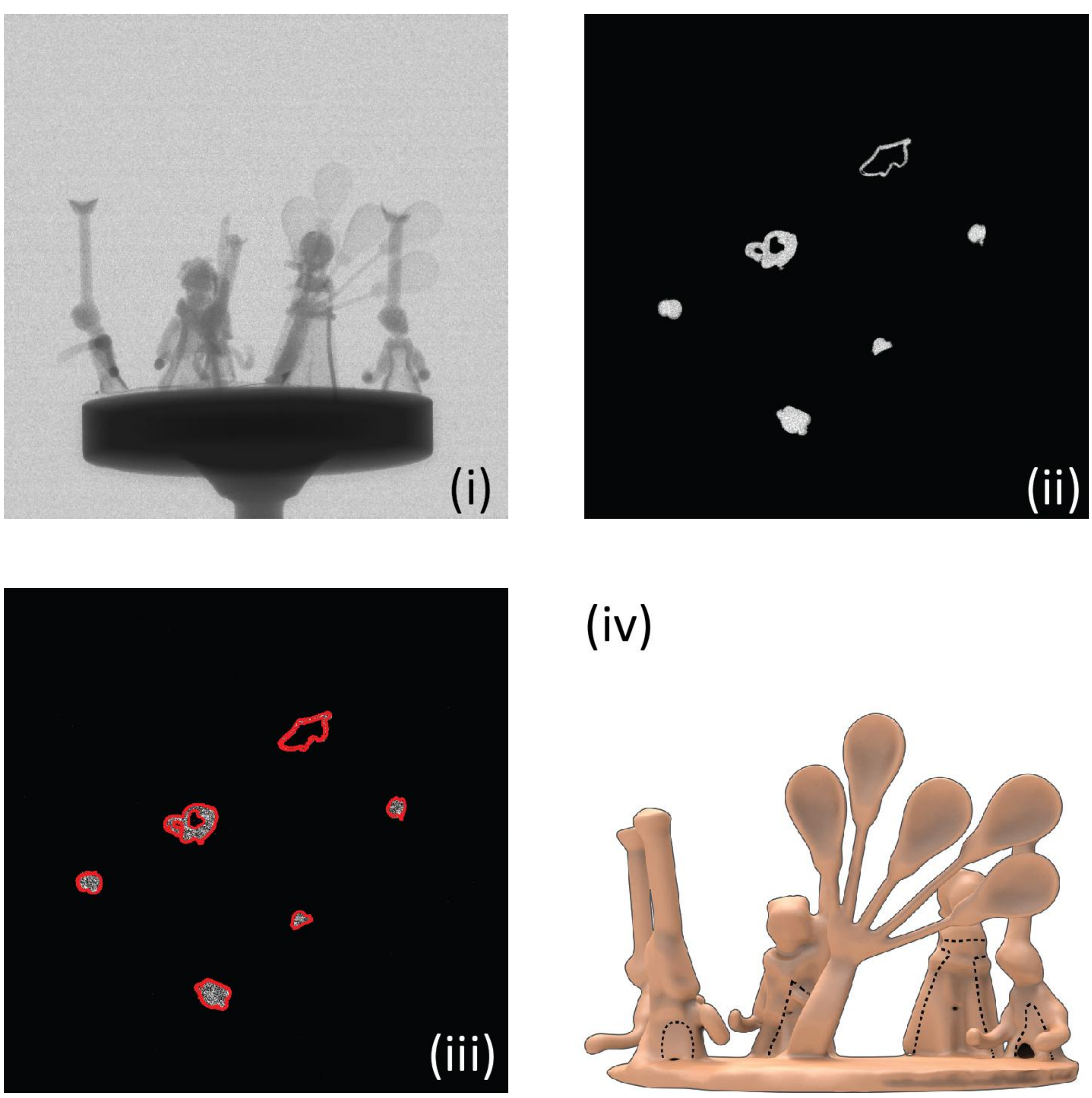

Figure 9 - Steps for building a three-dimensional model from the CT Micro.

2.2.3. Direct and Parametric modelling

Direct and parametric modelling makes it viable to represent objects virtually and in three dimensions with the dimensional accuracy required by the jewellery industry. These are the platforms commonly used by jewellers who have already adapted digital technologies in their production process.

In direct modelling, as can be seen in Figure 10, starting with straight or curved lines, arches and geometric figures that have dimensions defined by the user, and that, for example, can be turned on an axis and displaced from a reference or extruded, generate surfaces to form a model. There is also the alternative of starting the modelling from geometric solids, for example, prisms, pyramids, cones and spheres whose parameters - such as diameter, height and side of the base - are numerically defined by the user. The resulting structures are likely to experience scaling, bending, twisting and trims, and thus form other structures that can be joined, subtracted or intersected by Boolean operations, resulting in different forms coming from the first ones.

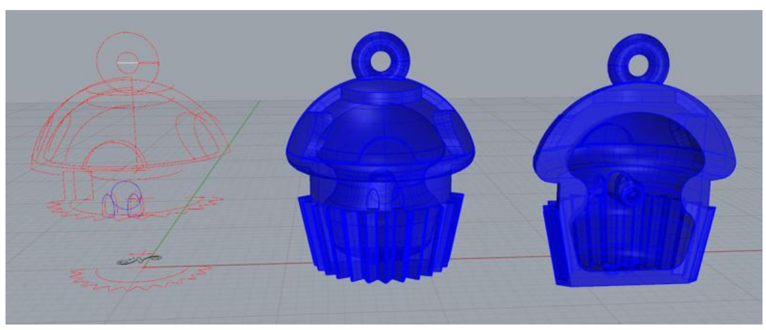

Figure 10 - Steps for building a three-dimensional model with direct modelling

With parametric modelling, unlike direct modelling, dependencies and relationships are created between the geometric entities that produce and compose an object. Therefore, parametric modelling requires professional planning in structuring a definition that will be followed in order to achieve a particular outcome from the input data.

In other words, as a question of making definitions in algorithm-parametric platforms, an object can be built that maintains its thickness in a certain range, regardless of which value is attributed to it, or which prongs and pre-patterned ring bezels go along with the dimensions and shapes of different lapidations and sizes of stones - as illustrated in Figure 11 - among other endless possibilities.

Image 11 – 3D rendered stone bezels parameterized according to the gemstones' diameters.
Source: NEXT, project developed by Thiele A.C.S and Magalhães C.F.

In light of the above, the models designed for algorithm-parametric and direct modelling platforms have a more geometric than sculptural character, and, in the case of this study, they are ideal for configuring precision structures such as joints and fittings and other objects that may be represented geometrically.

2.2.4. Digital sculpting

Digital sculpting, generally speaking, is very similar to sculpting in materials that are soft or can lose their shape, such as argil or clay. The logic of the construction of objects is the same as that of real sculpture which, similarly, starts with a basic initial shape or an arrangement of several shapes that are grouped and altered, to reach the desired configuration. This first sketch is restricted to a surface composed of polygons, in other words, a Mesh.

In digital sculpting, the surface of the Mesh modifies its shape because tools are employed that allow the user to perform various actions, among them, to pull, smooth, level, inflate, or put pressure on an area of the surface (Figure 12). Both the intensity and the dimension of the area of action of these resources can be determined, which greatly facilitates the configuration and detailing of a digitally sculpted object. When the modelling is completed, a uniform and constant internal thickness may be attributed to the model, as illustrated in Figure 12.

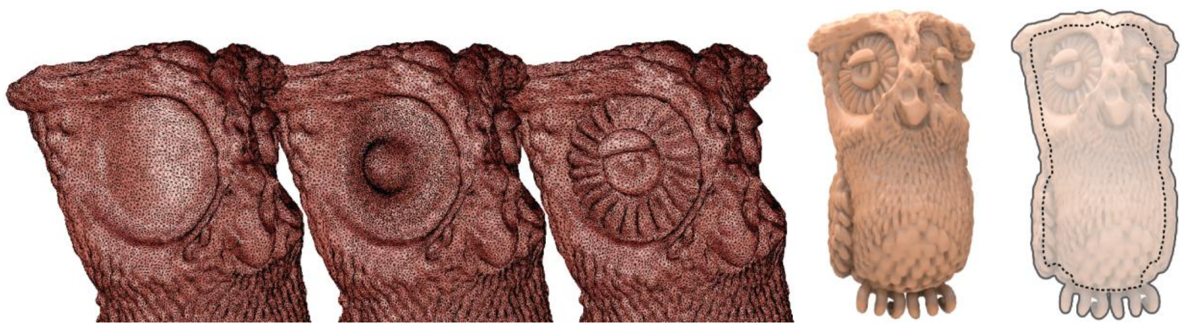

Figure 12 – Example of a digitally sculpted owl, demonstrating the way in which one of the eyes was modelled and the model's characteristic of continuous internal thickness.

As a result, digital sculpture software make it possible either to sculpt an object entirely by this technique or to include or modify details and add thickness to Meshes coming from other sources, such as digital scanning and direct and parametric modelling, as can be seen in Figure 13.

Figure 13 – Modifications done by digital sculpture in a three-dimensional model digitalized by Structured-Light: (i) digitalized model; (ii) modified model.

2.2.5. 3D printing

For at least a decade, the jewellery industry has been benefiting from 3D printing for manufacturing models that are conceived digitally on Computer Aided Design platforms. However, the evolution of printing systems and the increasingly lower cost of these technologies have provided the jewellery industry with a myriad of new possibilities. The process gained properties that ensured the expansion of the initial manufacturing of models and prototypes applied to lost wax casting for direct manufacturing of final products made in plastics and metals.

At present, there are a number of 3D printing systems; the main differences between these processes come from the needs of raw materials that have very different natures and that are special to each technology.

To print a single item, it became viable to use either a thermoplastic in its solid state, a liquid resin that is photo curable or even metallic powder.

Taking into account the requirements of the company in this case study, experiments were carried out with two technologies.

- Direct-Light Processing (DLP), for making models to be used in conventional lost wax manufacturing;
- Direct-Metal Laser Sintering (DMLS), for manufacturing pieces directly in metal, without using traditional processes.

Essentially, both of the technologies chosen above begin constructing the object with the same logic. The file of the three-dimensional model is segmented virtually by the software into flat layers of minimum thickness, and, from there, 2D level curves will be extracted that indicate the locations to be filled by the material, or not. Based on this information, the slices are produced in an overlapping manner and in succession, constructing the object as a whole. In the particular case of these technologies, while the file is being prepared for printing, the software automatically generates structures to help construct the model, and these structures are called support. The processing of the digital file for three-dimensional printing can be visualized in Figure 14.

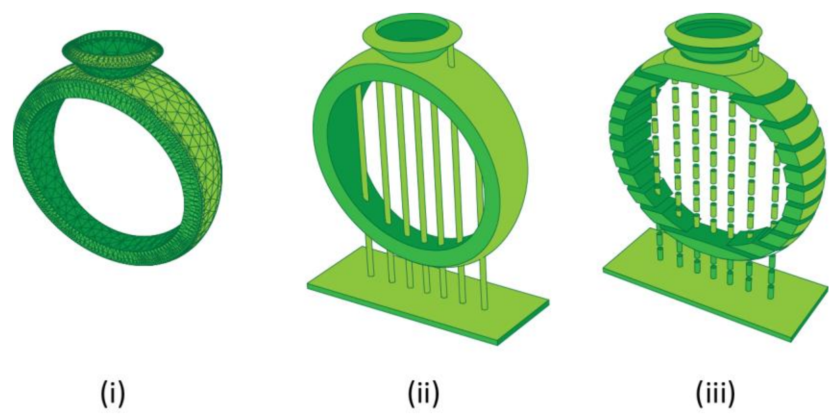

Figure 14 – Sequence of processing of a 3D file: (i) digital file in Mesh format; (ii) support generated to aid construction of piece; (iii) slicing process.

This logic of constructing objects layer by layer creates geometries that cannot be obtained through the conventional modelling process, with respect to the range of the tool, even when there is maximum efficiency in the use of materials and the wall thickness is minimum. Three-dimensional printing also outdoes the geometric potential of other classic industrial processes such as plastic injection, which demands considering removal of the piece from the mould at the moment when the shape is designed (HOPKINSON, DICKENS and HAGUE, 2006).

2.2.5.1 Direct-Light Processing (DLP)

Since DLP systems are liquid based, the construction material is first in a liquefied state, and an object is materialized by transforming the matter into a solid state. According to geometric data generated by slicing the file, a UV-light is projected by a set of mirrors and lenses into a container that has a photo-curable resin, and a whole layer of the object is solidified. The support structures are constructed in a platform that holds the object in place, and, as the platform moves upward, another resin layer is cured. This process is repeated until the whole model is printed (HOPKINSON, DICKENS and HAGUE, 2006).

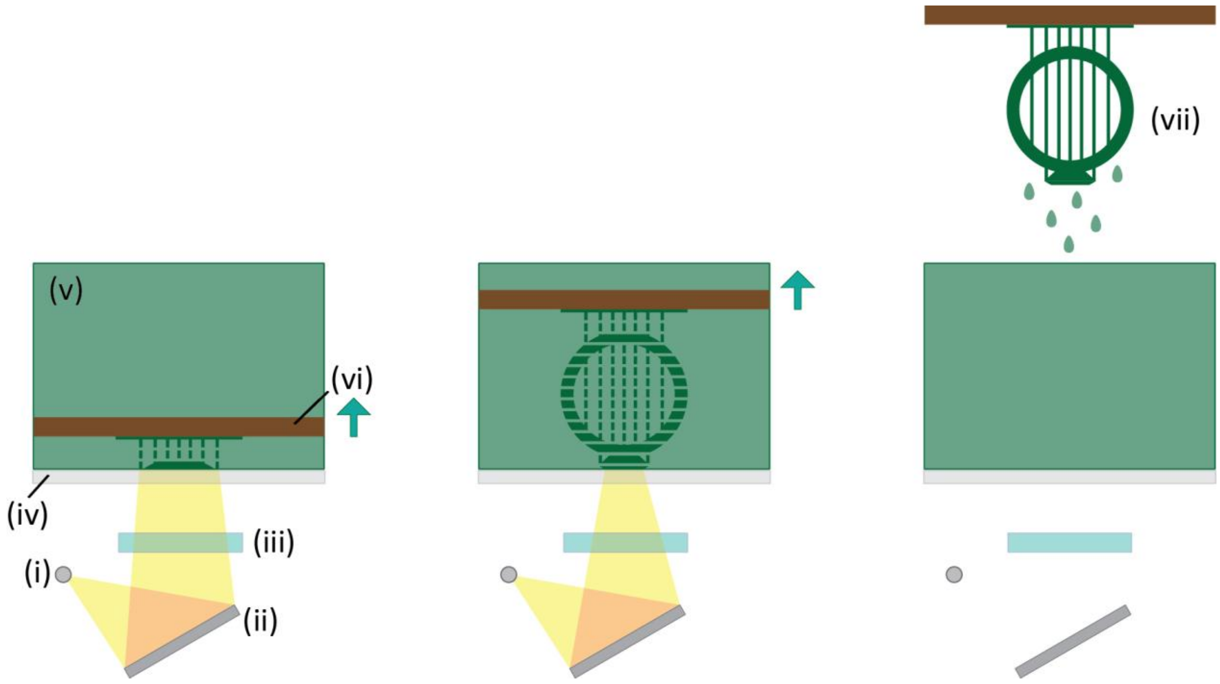

Figure 15 – Diagram of Direct-Light Processing printing: (i) light emitting source; (ii) set of mirrors; (iii) lenses; (iv) transparent tray; (v) container with liquid resin; (vi) platform, and (vii) printed model.

Since in DLP the layers are very discrete and nearly imperceptible, the need for surface finishing afterwards is practically eliminated. The exception would be to trim the sharp edges of the support for the model with scissors and pliers. Later on, finishing is gently done with fine sandpaper and solvent. In addition to the surface quality of the models, this technology allows printing that is highly detailed and in minute and highly precise dimensions, all important requirements for jewellery production requirements. As an alternative to the traditional process, DLP allows printing multiple copies of a 3D model directly in a casting resin, which makes the wax injection into the silicon mould an optional procedure to replicate the parts.

2.2.5.2 Direct Metal Laser Sintering (DMLS)

In this process, sintering occurs in an isolated compartment where the inner temperature and atmosphere are controlled. The metallic powder[3] that will give the piece its shape is spread in a fine layer on the work surface, and, on top of the powder, a laser beam describes the geometric information contained in the virtual slice. As a result, the laser action makes the metal particles aggregate to each other and form a layer of the item. When this is done, the system moves the printing compartment downward and sets one more layer of powder above the one that came before. The process is repeated until the last layer of the object is constructed. When the printing is completed, what is obtained is a solid piece with a support set that is immersed in non-sinterized metallic powder (HOPKINSON, DICKENS and HAGUE, 2006).

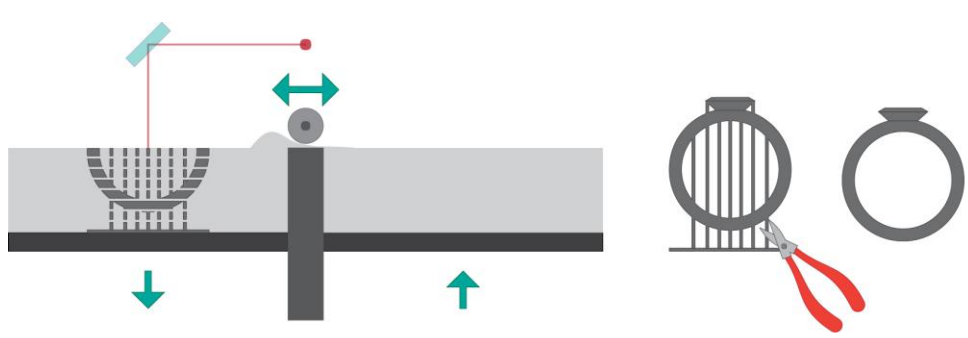

Figure 16 – Diagram of Direct Metal Laser Sintering printing.

This technology requires considerable manual work for the finishing – considering that the removal of the support and the surface quality with this type of printing demand vigorous polishing. Nevertheless, the technology shows relevance for jewellery, in that it allows the manufacturing of integrated and functional parts, and this makes it viable to print articulated models directly, without the need for soldering.

3. Results

In view of the peculiarities of each technology, the best results obtained from the application of digital technologies in the jewellery sector involved a mixture of the processes described above.

For the experiment, five crafted products were selected in order to verify the benefits of digital technologies for the problems arising from traditional production. All the pieces and their wax components – in this case, the replicas of the models that were made by injecting wax into the silicon moulds – were digitalized by Structured-Light technology.

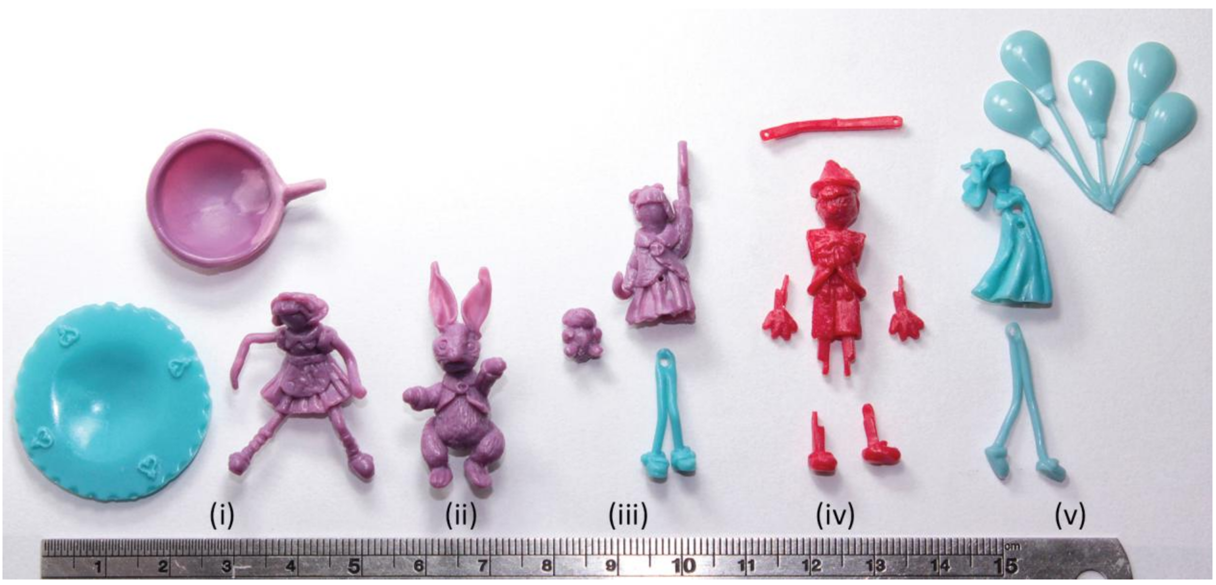

Fig 17 – Digitalized wax models for the study: (i) "Alice in a Teacup" ring; (ii) "Alice's Rabbit" pendant; (iii) "Sofia" pendant; (iv) "Pinocchio" pendant and (v) "Beatriz and the Balloons" pendant.

These digital files went through processes that followed specially formulated guidelines in light of the peculiarities of each component, always mindful of which characteristics of each technology or technique would make it more adequate for the solution to the problem, as is shown in Table 1 below:

Product name	Problem of traditional production process	Possible solutions with digital technologies
Alice in a Teacup Ring	(i) heavy piece for casting in gold and silver; (ii) faded details and textures.	(i) hollow out the scanned piece of the doll digitally in a continuous thickness of 0.6mm, removing all the back part of the dress that is hidden by the cup; parametrically remodel the cup and saucer; make a smaller scale of the set especially for casting in gold; (ii) detail and improve the digitalization by digital sculpting
Alice's Rabbit Pendant	(i) heavy piece for casting in gold and silver; (ii) faded details and textures.	(i) digitally segment the body of the scanned pendant in two hollow parts with fittings and 0.6mm continuous thickness; make a smaller scale of the piece specially for casting in gold; (ii) detail and improve digitalization by digital sculpting
Sofia Pendant	(i) heavy piece for casting in gold and silver; (ii) faded details and textures; (iii) rough joints; (iv) little bear has asymmetric halves.	(i) digitally segment the body of the pendant into two hollow parts with fittings and 0.6mm continuous thickness; make the piece in a smaller scale specially for casting in gold; (ii) detail and improve digitalization by digital sculpting; (iii) directly remodel the joints; (iv) add lateral symmetry by digital sculpting
Beatriz and the Balloons Pendant	(i) rough joints; (ii) faded details and textures; (iii) balloons with unsatisfactory shape.	(i) reproject the piece for printing in metal, with its joints assembled; (ii) detail and improve digitalization by digital sculpting; (iii) remodel balloons directly.
Pinocchio Pendant	(i) rough joints; (ii) faded details and textures.	(i) reproject the piece for printing in metal, with its joints assembled; (ii) detail and improve digitalization by digital sculpting.

Table 1 – List of problems and solutions studied by individual piece

With the exception of the "Beatriz and the Balloons" and "Pinocchio" pendants, which were printed directly in steel by Direct Metal Laser Sintering (DMLS), the models of all the components of the other jewels were printed by Digital-Light Processing (DLP). The products went through the conventional phases of the process of lost wax casting and, after that, the casts were assembled by traditional techniques of goldsmithing and laser soldering.

Figure 18 – Models printed in Direct Metal Laser Sintering and Digital-Light Processing

3.1 Reduction of final weight of products

The results of reducing the weight of the pieces were significant, owing to the advantages of the geometric shapes that 3D printing allowed. As can be seen below, for purposes of comparison, there is a digitalization of the body of the original Sofia pendant in wax, done by means of computerized microtomography. The dotted lines identify the volume that could be kept hollow with traditional tools and, later, with new digital technologies.

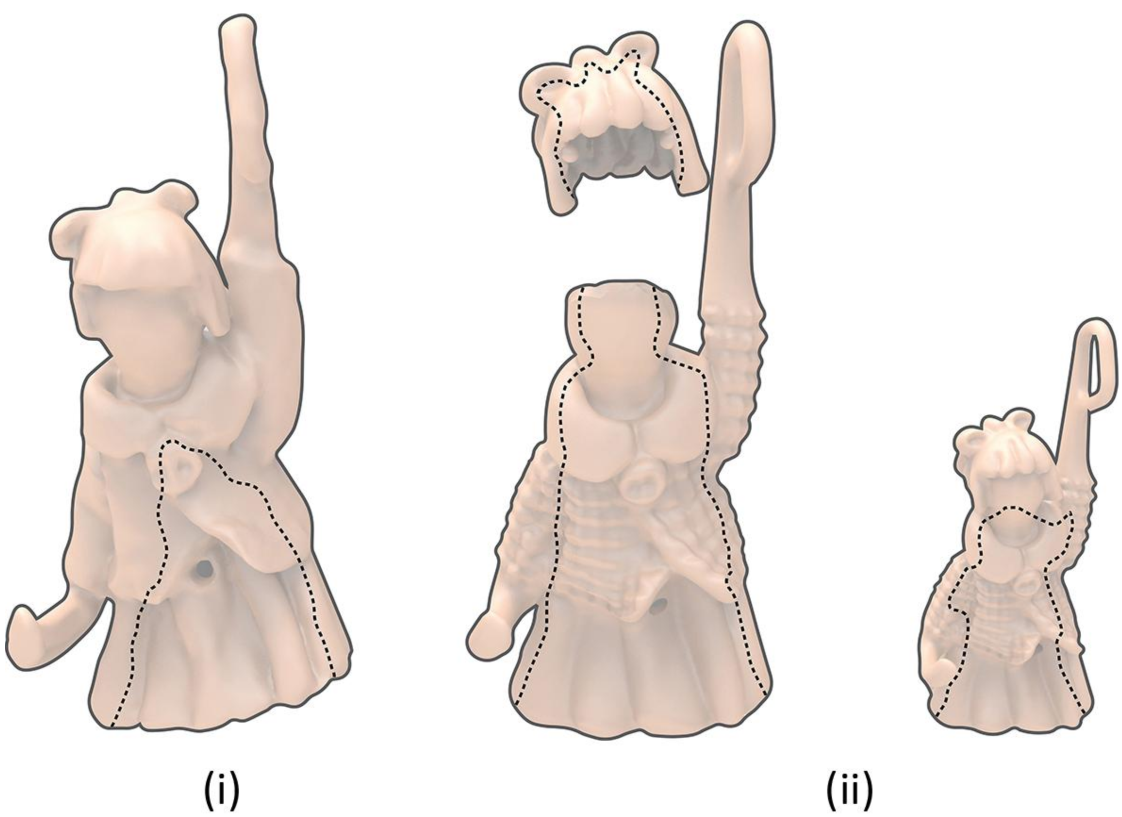

Figure 19 – Qualitative difference of hollow areas: (i) traditional tools and (ii) digital technologies.

For a quantitative visualization of the data on the economy of material afforded by the new process, see the tables below:

	Alice in a Teacup Ring in 18K Gold[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced Scale (digital technologies)**
Weight (in grams)	28,928	18,183	12,172
Approximate percentage of mass	100%	62%	42%
Economy per piece[5] (USD)	0	324,81	506,52
Economy of 50 pieces[5] (USD)	0	16.240,60	25.325,97

Table 2 – Quantitative results of the reduction of material and weight in the "Alice in a Teacup" ring in 750 gold.

	"Alice in a Teacup" ring in 950 Silver[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced scale (digital technologies)**
Weight (in grams)	18,993	11,939	7,992
Approximate percentage of mass	100%	62%	42%
Economy per piece[5] (USD)	0	3,98	6,21
Economy of 50 pieces[5] (USD)	0	199,11	310,52

Table 3 – Quantitative results of the reduction of material and weight of the "Alice in a Teacup" ring in 950 silver.

	"Alice's Rabbit" Pendant in 18k Gold (750)[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced scale (digital technologies)**
Weight (in grams)	14,383	9,153	1,128
Approximate percentage of mass	100%	63%	8%
Economy per piece[5] (USD)	0	158,10	400,69
Economy of 50	0	7.904,92	20.034,36

pieces[5] (USD)			

Table 4 – Quantitative results of the reduction of material and weight of the "Alice's Rabbit" pendant in 750 gold.

	"Alice's Rabbit" Pendant in 950 Silver[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced scale (digital technologies)**
Weight (in grams)	9,440	6,010	0,741
Approximate percentage of mass	100%	63%	8%
Economy per piece[5] (USD)	0	1,94	4,91
Economy of 50 pieces[5] (USD)	0	96,82	245,55

Table 5 – Quantitative results of the reduction of material and weight of the "Alice's Rabbit" pendant in 950 silver.

	Sofia Pendant in 18k Gold (750)[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced scale (digital technologies)**
Weight (in grams)	10,443	7,883	2,227
Approximate percentage of mass	100%	75%	21%
Economy per piece[5] (USD)	0	77,39	248,36
Economy of 50 pieces[5] (USD)	0	3.869,32	12.418,13

Table 6 – Quantitative results of the reduction of material and weight of the "Sofia" pendant in 750 gold.

	Sofia Pendant in 950 Silver[4]		
	Original (traditional production)	**Original scale (digital technologies)**	**Reduced scale (digital technologies)**
Weight (in grams)	6,857	5,176	1,462
Approximate percentage of mass	100%	75%	21%

Economy per piece[5] (USD)	0	0,95	3,04
Economy of 50 pieces[5] (USD)	0	47,45	152,28

Table 7 – Quantitative results of the reduction of material and weight of the “Sofia” pendant in 950 silver.

3.2 - Reduction of dimensions with maintenance of details

This phase deals with visual details and textures – which are extremely important for the appreciation of the piece as rendered by the professional. The phase is also concerned with the functionality of the joints and the symmetry of the pieces that were damaged by the traditional process, for all the reasons explained in section 2.1.2.

What follows is a display of the pieces as they were produced in the traditional process and in the new process, which uses digital technologies together with traditional techniques. As can be seen, in terms of the quality of the visual result and the textures, the pieces that use the new process are detailed, which represents a technical and commercial advantage, in line with the company’s requirements, as explained in section 2.1.2.

Figure 20 – “Alice in a Teacup” ring: (i) traditional production process, (ii) new production process with digital technology

Figure 21 – “Alice’s Rabbit” pendant: (i) traditional production process, (ii) new production process with digital technology

Figure 22 – “Sofia” pendant: (i) traditional production process, (ii) new production process with digital technology

Concerning the functionality of the joints and correction of symmetry, the case that merits attention is the “Sofia” pendant, whose solutions were studied and carried out during the process of reducing its dimensions.

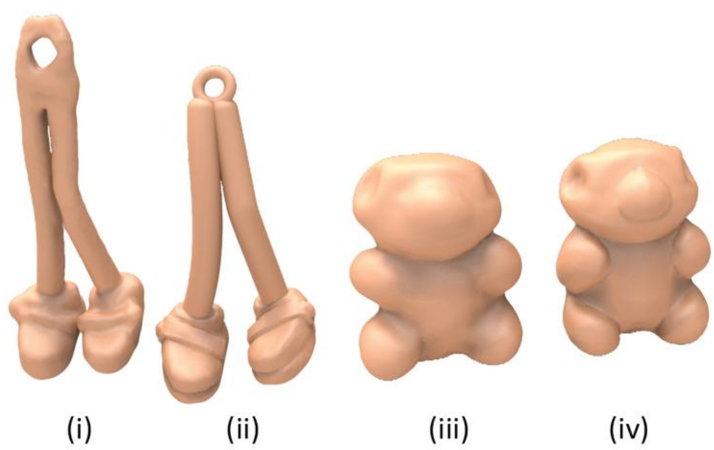

Figure 23 – Details of the “Sofia” Pendant: (i) joints in the traditional production process; (ii) joints in the new production process with digital technology; (iii) shape of the bear in the traditional production process and (iv) shape of the bear in the new production process with digital technology.

These advantages were also used for other pieces, although the company did not request them. In this case, the know-how was applied with the purpose of improving the joints and the shapes of the “Beatriz and the Balloons” and “Pinocchio” pieces, without any modification needed in their original dimensions.

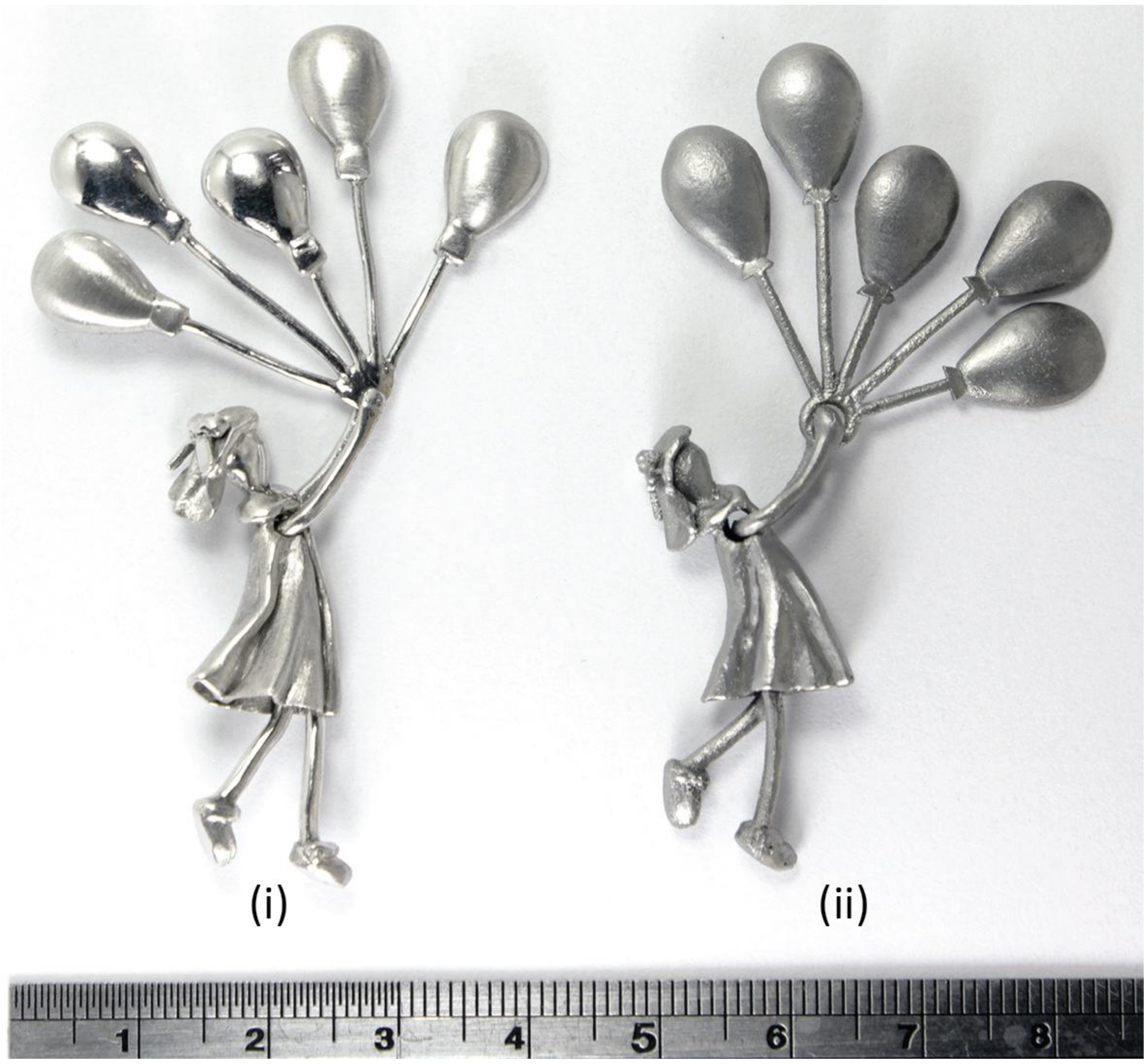

Figure 24 – “Beatriz and the Balloons” Pendant: (i) traditional production process, (ii) new production process with digital technology

Figure 25 – “Pinocchio” Pendant: (i) traditional production process, (ii) new production process with digital technology

4. Conclusions and implications

The aim of this research was to find a new digital process for jewellery creation that eliminates the problems of the traditional production process and that maintains all the characteristics and identity of this sector.

The results show that, when applied to wax modelling, digital technologies bring benefits in several ways: they conserve the traits of the professional in the piece; they allow for a maximum economy of material, the creation of wax models with less expenditure of time and work, and a more efficient visualization of the prototype; they make it possible for fittings, structures, geometries, and joints to be created with fewer limitations; they ensure the small-scale production of pieces in a series.

All this evidence confirms the hypothesis that reducing the weight and dimensions of the pieces using these new technologies is technically and commercially viable. This implies, moreover, that the new production process based on digital technologies can potentially coexist with the traditional production process of wax modelling, even if, for this to happen, there needs to be a period when the professionals in this branch can acquire skills or else specialist designers and technologists in the area are contracted. Contrary to the belief in the jewellery sector, the purchase of equipment and new technologies is not the salvation that was idealized. And this study points out the importance of the skills the professionals need in the jewellery sector, particularly the designers.

In the end, the economic advantages that are obtained with investments in this phase more than compensate, as can be seen in the tables shown in section 3.1.

5. Limitations and suggestions for future research

This study examines the case of only one company in the jewellery sector; the company possesses a trait that distinguishes its craftsmanship, which is geared toward production in series. Nevertheless, the results obtained with the techniques that were developed in the study can be equally replicated in other cases, with no alteration in the technical result, only in the commercial result.

Although digital technologies have put to use all their potential for resolving the questions brought up by the company, one negative point was identified while the work was in progress, and it should be discussed here. It is extremely difficult to remove the support for the piece that is directly printed in steel by DMLS, depending on the model geometry. Even so, this additional phase in the productive process is insufficient to affect the efficiency of the results obtained. However, in the future, when there are viable support structures that do not involve so many difficulties to be overcome, this scene may change radically. At the moment, additional research is needed to find a solution to this obstacle, in the case of printing done in steel or even in gold with the DMLS process.

Therefore, there is still space for research that aims to refine digital technologies constructed for jewellery, principally with respect to reducing or modifying the structure of 3D printing supports. This would certainly bring greater efficiency to this new production process.

Notes

1. CARLOS CHAGAS FOUNDATION FOR RESEARCH SUPPORT OF THE STATE OF RIO DE JANEIRO, state organization that provides incentives for scientific research and technological training.

2. THREE-DIMENSIONAL EXPERIMENTATION NUCLEUS at PUC-Rio, Brazil.

3. In DMLS technology, it is possible to print objects in many metals such as titanium, steel - and even gold. Due to the impossibility of testing this technique directly in gold, the most adequate metal for the jewellery industry, this article deals with steel printing, since the technical issues analysed do not depend on which metal that piece of jewellery is made of.

4. 18k gold (or 750) and 950 silver are alloys whose main metal content is 750 and 950 parts over 1000. For purposes of calculating the cost of the alloy, the metal considered for supplementing it was copper.

5. Values in USD, according to exchange rate in October 22nd 2014: 1g of silver (COMEX) = 0,559110054 USD; 1g of Gold (COMEX) (1000) = 40,0829502 USD and 1g of copper (COMEX) = 0,66767345 USD. Source: http://www.bloomberg.com/markets/commodities/futures

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