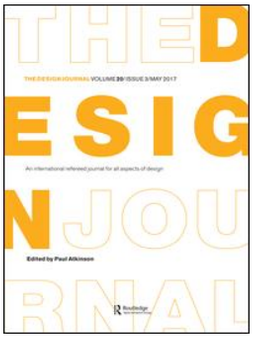

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Footwear Design. The paradox of "tailored shoe" in the contemporary digital manufacturing systems

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Abstract: This paper aims to describe the scenario of the contemporary footwear sector, giving a perspective to the product design methodological approaches in the context of the so called 4.0 Industry standards.
To do this the text proposes the description of practical experimentations carried out focusing on cad-cam design and cnc production methods.
The digital design and manufacturing processes (from the 3d scanning of the foot to the shoe last definition, from the style concept to the virtual parametric prototype of the shoes, from the definition of all the components to the final production) address from the one hand the advanced production methods supported by the enabling technology, from the other hand the renew of the traditional hand made production for the small and custom made series. Tradition and innovation aims to enable new cultural approaches to the made in Italy standards and new competitiveness keys for the footwear industry.

Keywords: Digital design and manufacturing, Digital craft, Manufacturing for custom made parts.

1. Introduction

The shoes, among the “useful objects”, have a history that precedes the contexts of civilization. We can say that primitive society developed the ancient models with a purely protective purposes, but in the most evolved society the footwear has started to be conceived with an increasingly complexity between aesthetic, functionality and innovation in technology and materials. Is not a case that as a most meaningful example for Italian women's footwear design history we have to refer to Salvatore Ferragamo, who, since ‘30s, brought the level of Italian creativity to the forefront, setting a leadership characterized by the originality of design, experimentation on models and materials as well as production methods and high innovation in the components; “by coupling style with the necessity of that time, he presented the autarchic shoes in 1937, with cork for an «hortopedic» hill and braided paper in face of leather” (Bianchino, 1987, p. 62).

Also during the grew up of the footwear industry, since ’70s, the made in Italy standards for the shoes systems continued to be supported by the combination between design innovation and production methods (from the hand made to the industrial processes), establishing the born of the main Regionals industrial districts and the supply chains organization. Basically the footwear industry is characterized by a supply chain specialized for each part of the shoes and for the different kind of works: shoe last, components (such as sole, hills, uppersoles, and so on), finishing works and decoration (such as cutting, assembling, embossy, microinjection, laser cut and engraving, and so on). An other aspect which defines the consistence of the supply chain is the type of shoes (for fashion, for sport, for workwear and so on) and the kind of material used (from leather to textile, from cork to plastic, and so on): as a consequence the more the number of the suppliers is wide, the more the number of the shoes (to be stored) is high, in order to be competitive on price.

The recent global economic crisis has had effect on footwear sector due to the enlarging of the market to that most competitive on low prise nation. As a consequence all the supply chain devoted to the assembly of the upper sole started to be dislocated toward that country much more affordable, in term of labour costs, for the Footwear company (Milone, 2015, p.113).

Today the required performances in the footwear industry are extremely complex, and must meet different requirements dictated by fashion or anti-fashion trends.[1]

Nowadays the footwear industry seems, also, to be one of the sectors mostly interested in the advanced manufacturing systems implementation, with reference to additive manufacturing, 3d print, robotics, internet of things, interaction machine to machine, 3d scan and the remote use. In the context of the Industry 4.0, for example, promoted by German government, Adidas, after several years of delocalized strategies for productivity, this year come back to produce in its country, thanks to the introduction of the Speedfactory supply chain re-design (Ivanov et al., 2017, p.21).

The question of the 4.0 standards for the footwear sector is here intended, not just as the merely possibility to apply smart technology, such sensors device to the shoes but, much more, as how technology can have effect on the manufacturing systems as well as on the product designed on the base of *user centred* parameters*,* in term of comfort, safety, customization and on the base of an interactive process. The design and production of the shoes, made to measure at distance, the customization, the production of small series, in fact, are not just a paradox but a concrete possibility for the innovations of a sector traditionally tied on the one hand on standardized production practice, and on the other hand on handmade on measure systems could be also for made in Italy standards a new possibility to approach.

In add to this the upgrading of the specific performance (related with sports, security, comfort and also fashion) is now a concrete possibility thanks to the exact anthropometric coding and to postural attributes by the bi-dimensional and three-dimensional scanning systems.

Protection, comfort, athletic enhancement, medical applications, in fact, are implemented in the current system of needs and requirements, and most of the research investments for the footwear industry is dedicated to the development of the virtual prototype and the engineering.

The technologies to support this requirement range from the reverse engineering to the additive and rapid manufacturing, from cad /cam/ cae design to the cnc and laser engraving machine.

1“People towards fashion have taken three different attitudes. Indeed, we can distinguish the faithful followers, the die-hard opponents and indifferent (more or less) absolute (or unrepentant traditionalists). There are so, to borrow a distinction dear to Davis and Brubach, fashion, anti-fashion and not fashion. Fall within anti-fashion all the various types of clothing of fashionable opposition.” (Baldini, 2005, p. 29)

“The three-dimensional modelling technologies allow to produce an elaborate exact project, detailed, increasingly similar, even if virtual, to the final product” (Trabucco, 2015, p. 81). The same 3d file is shared between much different professionalism, from the industrial designers to the engineers, from the marketing responsible to the communicative group an so on, reducing the gap between the design process and the production (Di Roma, 2016, p. 35).

The introduction also into the market of new structural forms of the shoe, on the organization of the sole and heel, need methods and design tools can match the aesthetic to the study of forces and stresses to which the shoe is subjected, predetermining the constituent characterizations.

So, the transfer of a traditional material system into a digital one could allow a reflection about the updating of the technic and technology both in design and in production methods and the presented study case will try to show the complexity and the potentiality of the matching between the traditional analogical systems and digital one, in order to generate new applications for “custom made” and “on demand” design for the shoes sector.

Finally, complementing this scenario in which research and experimentation are evolving, must be counted the growing interest on technical solutions inspired to eco-sustainability. Large investments in the materials industry have turned into innovative eco materials and biocompatible materials to replace those "dangerous". The development of materials, moreover, is oriented to combine the technological component sensors, to provide a more complex range of interactive performance and connectable.

2. The impact of the industrial production methods on the design methods

The Industrial Design project rises up during the second Industrial Revolution, interacting with science and technology outcomes.

> “The origin of design methods lay in ‘scientific’ methods, similar to decision theory and the methods of Operational Research. The originators of the ‘design methods movement’ also realized that had been a change form pre-industrial design to industrial design – and perhaps even to post industrial design? The reason advanced for developing new methods where often based on this assumption; modern, industrial design is too complex for intuitive methods [...].
>
> So we might agree that scientific design refers to modern, industrialised design – as distinct from pre-industrial, craft - oriented design – based on scientific knowledge but utilizing a mix of both intuitive and non – intuitive design methods.” (Cross, 2001, pp. 20-21).

Serial, standard, mass production is the first assumption expressed by the “after war” industrial design. Appropriateness of the standard to the user needs is the cultural role that has put the user at the centre of the Design processes.
Nowadays the technological aspects originated by the fourth industrial revolution completely sets down the “mass production” meaning, standard e user interaction with the product/service designed according to the 4.0 processes.
For this reason the “on measure” principles, paradox for the mass production logics and for the deterministic role of the design approaches devoted to the unique solution and to the simple interaction between a generic expression of the user experience (globally defined), is today a principles that gives new meaning to the “design science”, going toward such “informal” processes typical for the handicraft in which the user could customize each component of the product, from the dimension to the style. In connection with the footwear sector see the affirmed tendency for the

most important brand of the sportswear and the casual outfit to the definition of an extreme customization of the shoes by the customer. This new tendency is allowed by that possibility to manage all the productive process digitally, from the conception of the object, to the production processes.
These include from the one hand the definition of a design process that includes the direct interaction of the user in the contest of the conception of the product/service; from the other hand the same user experience methods become to be integrated to the more general theme of the big data in the contest, going towards a user data experience (Costa, 2016, pp.20-21). This last aspect is originated bot from the data flux generated by the network interaction in the contest of the IoT, and also thanks to the use of the trans-receiver e trans-sender systems implemented on the product.

3. Study case

3.1 Shoes last

The study case that is proposed is the project of the shoe, investigating the possibility of interface the research focused on product design with the industry standards, thought the virtual prototyping methods[2].

Traditional practices for the on measure and customized shoes, once destined to hand made production, could nowadays combine the laser scanner tools for the definition of the anthropometric data, and the baropodometric tools for the postural data, in order to design new ergonomic shoes. The possibility that this phase of data acquisition could takes place remotely and could be downloaded in any manufacturing system connected by internet, revolutionizes the same conception of the shoe[3].

The definition of the style for the sole or the upper sole has been experimented using an interactive parametric methodology. The texture definition (which design is adaptive and customizable by the end user) has been adapted to the shoe last and the shoe design. The production, thanks to cad cam systems has provided both additive and cutting experimentation.

The ergonomics for the project can be defined as a philosophy of intervention that, starting from the principles and content of the User-Centred Design, focused on the user and his own needs, the starting point of the design process, uses a methodological approach that can identify the complexity and specificity of these needs and translate them into the project intervention capacity, in order to improve user satisfaction and the set of system performance. So, after obtaining a digital model of the foot (human factor), as faithful as possible to reality, it moved on to modelling the anthropometric curves that trace the main morphological and biomechanical characteristics of the foot.

These curves have the peculiar characteristics, in fact, in addition to serve as a starting basis for the modelling of surfaces perfectly coincident with the morphology of the foot, especially in the arch area, the more sensitive to the comfort, are curved parameterizable, and they may be associated with parameters that vary from foot to foot, making the subsequent modelling process a procedure adaptable to any user.

2 All the prototype proposed have been developed with different industry actor in the sector of footwear, component production, specialized decorative and finishing works.

3 Particularly those comparison has been carried out thanks to support given by the Kasucci, a farm with its core business based on medical on measure shoes.

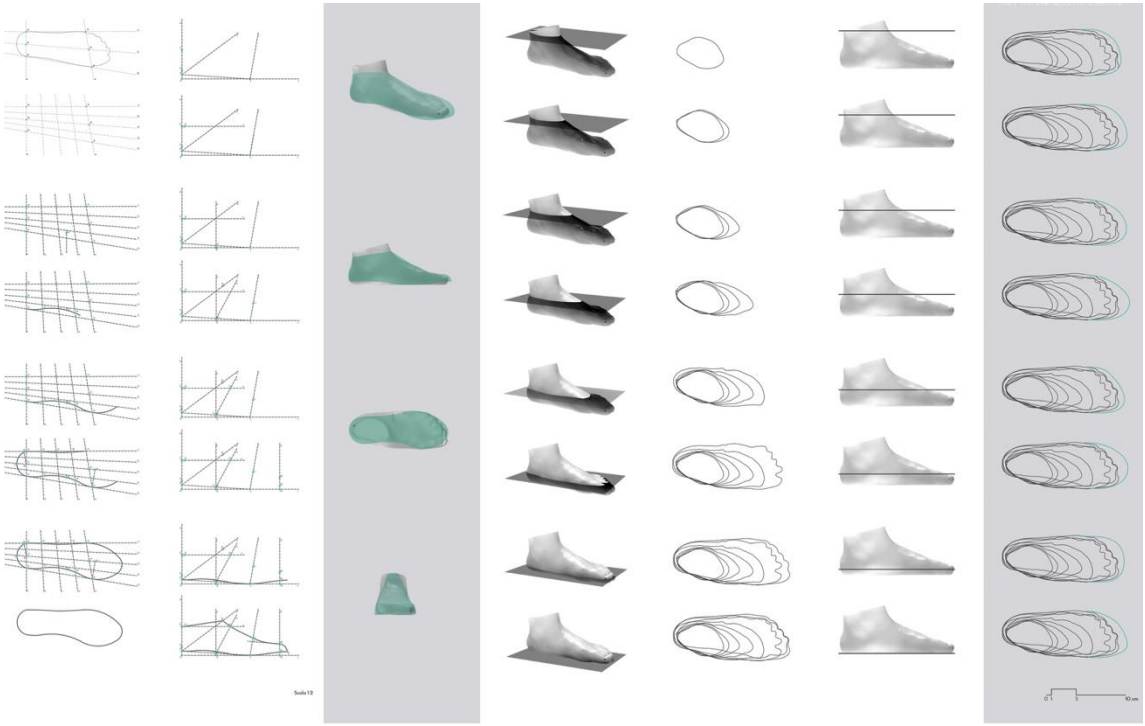

Figure 1. Comparison between traditional analogical and contemporary digital methods for the definition of the on measure shoe last. The first one is based on a geometrical bi-dimensional model defined on the basis of the principal measure of the foot. The second one is the three-dimensional model of the foot by laser scanner. Authors: Giorgio M, Sciancalepore, M. Degree Thesis in Industrial Design. Advisor, Di Roma, A.

The figure 1 shoes the comparison between the traditional analogic methods for the definition of the "on measure" shoes and the digital model taken by the laser scan system. The comparison between the green shapes and the grey one shoes some inconsistence that could be more or less important for the comfort of the shoes. The traditional shoe last is fitted to address the style of the shoes and not to be necessary confortable. The definition of a shoes fitted on the real shape of a foot is addressed to be ergonomic and confortable.

3.2 Virtual modelling

Starting from the 3d scan of the foot the three-dimensional model of the shoes is parameterized on the base of the real geometries. So the ergonomic cross sections are addressed to the confortable style line and network of 3d curves produces the definition of the shoe last.

The evolution of the aesthetic and the functions of the product design express the role of technologies and production processes adopted. In the field of traditional craftsmanship and fashion this development resulted in a mutual integration of the "hand made" techniques with the electronic systems for the large-scale production processes. These new introductions in the field of shoes, textile, clothing are developed in the phases of cutting, assembling and finishing of the product, and are combining the artisan and manual dexterity of the workers with the cnc machines.

3.2 Parametric modelling approach

Through parametric software you can organize projects in associative systems based on the logic of the relationship between parties, with the possibility of altering the overall configuration of a system, acting on the parameters set at the base of the design process, according to the change propagation logic.

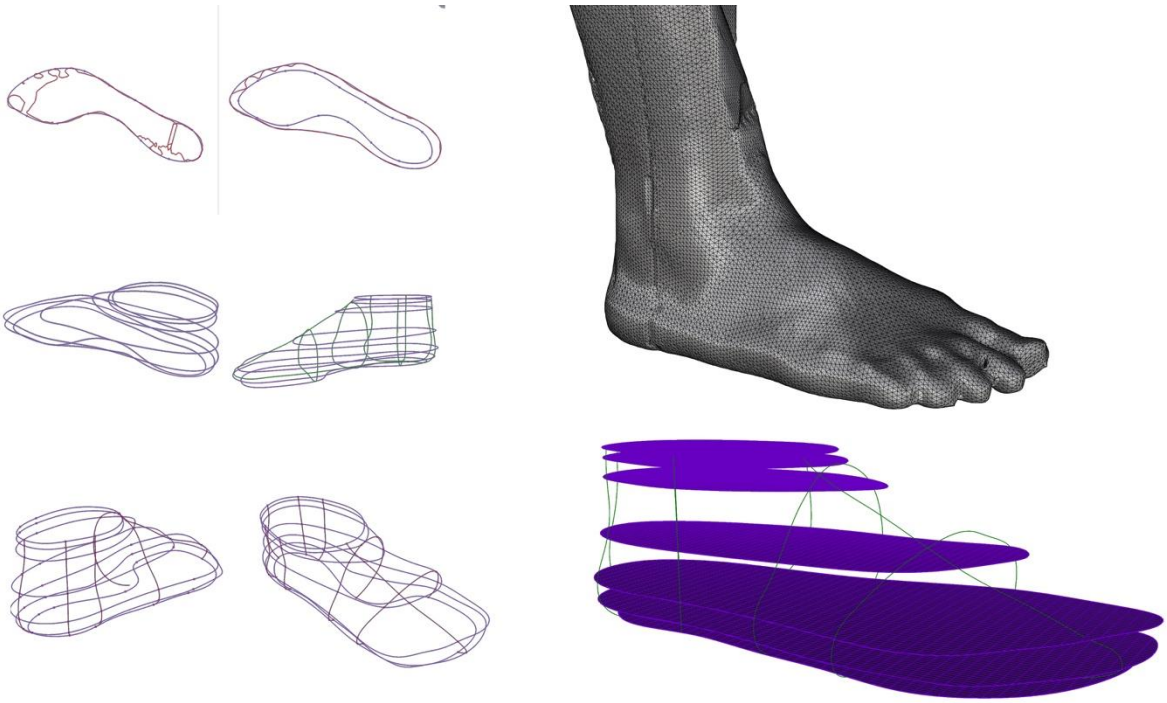

Figure 2. Starting from the three dimensional model of the foot by laser scanner, the virtual 3d model of the shoe last could be designed using parametric software in order to define ergonomic customizable models. By the author.

A parametric model could better approach the theme of the customization of the shoes, both regarding the "on measure" and the sizing, both regarding the style and the typology. Virtual prototyping is generally used, in fact, to simulate aesthetics and ergonomics. Complex free form and multibody geometrical modeling can help the designer to integrate in optimal way electronic devices and textiles into the shoe structure. Multiple designs can be quickly reviewed, different foot size and shapes can be simulated and the contact area can be investigated using different industrial floors textures. Virtual and augmented reality technologies will be applied for interactive 3D design review.

In terms of aesthetic one of the most complex contributions is due to the introduction of digital parametric-generative processes, which are associated with rapid prototyping and manufacturing techniques, controlled electronically.

The digital revolution, in fact, during the last two decades has contributed to the acceleration of the modification of the design tools and in order to produce open and customizable models.

The algorithms modelling allow designers to overcome the limitations of 'traditional' software and obtain a level of complexity and control significantly higher. In algorithmic modelling the user has the ability to create three-dimensional objects through the description of the system of relations at the base of any complex geometry. Such description is given by the development of a diagram nodes (visual algorithm) according to an associative logic, within a specific editor that operates in parallel to the modelling software. Therefore what is listed is not the object, but the process of its construction and its data.

The traditional mathematical instruments for the surface design through the tessellation theories are implemented by algorithmic modelling tools for creating and managing complex shapes in any scale: from architecture to design. The pattern developed with parametric software are dynamic systems

modified in real time, by varying the parameters defined during the construction of the diagram: this means immediate benefits for formal exploration, control and rationalization of the geometrical model.

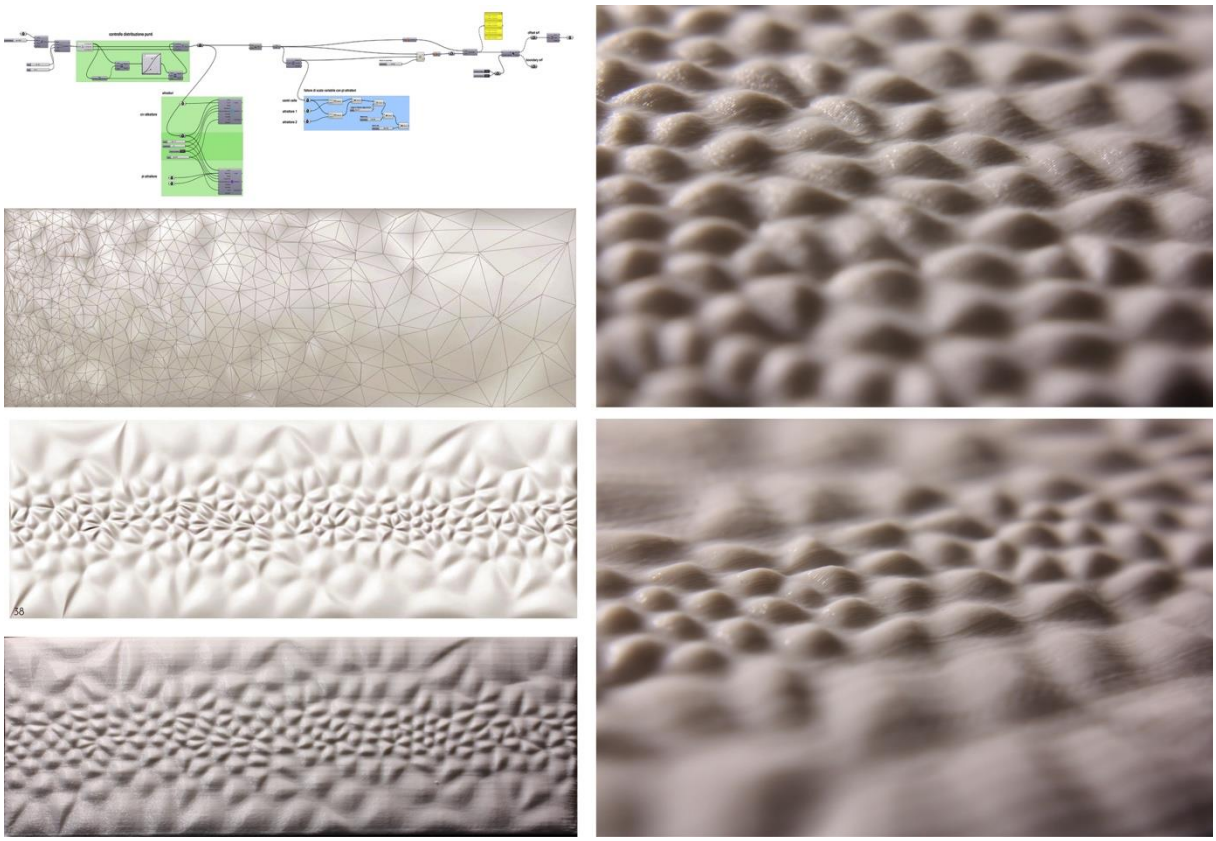

Figure 3. On the left: parametric texture for the sole, virtual prototype and 3d printed prototype in TPU. On the right details of the 3d printed soles. Author: Fasano, F. Degree Thesis in Industrial Design. Advisor, Di Roma, A.

3.3 Laser cut and laser engraving

The laser processing involves the use of a laser beam to cut different types of materials and finds wide application within manufacturing industry. The machines that use this technology avail themselves, precisely, of a high power laser beam which is directed by appropriate optical lenses and CNC (Computer Numerical Control). The focused laser beam is then directed on material that will be worked, which then melts, is burned, vaporized or eventually washed away by a jet of gas, leaving a sharp edge with a finishing quality surfaces. It's possible cut flat materials as well as more structured materials or piping.

For the realization of the prototype[4] has been used a machine with a plotter, equipped with a large flat processing (up to 1.5 m wide) and a mobile laser lens in the xy plane, and galvanometer systems, equipped with plates of approximately 500 x 500 mm but able to make incisions Ultra-fast and with two mirrors mounted on galvanometric heads (deflecting the laser beam in two dimensions).

The laser is those at carbon dioxide CO2, which emit a beam of infrared light to continuous wave.

The use of this technology, in recent years, grew rapidly especially in the field of fashion design. Especially for texturing clothing, footwear, bags, belts and apparel. This texturing process is made for subtraction of matter, unlike other methods that provide for the addition of material (inserts of

4 The prototypes has been realized by Revolution Shoes s.r.l.

various types and materials , displayed in fabric, prints, etc.) or their manipulation (story lines, lace embroidery, macramé, embossing etc.)

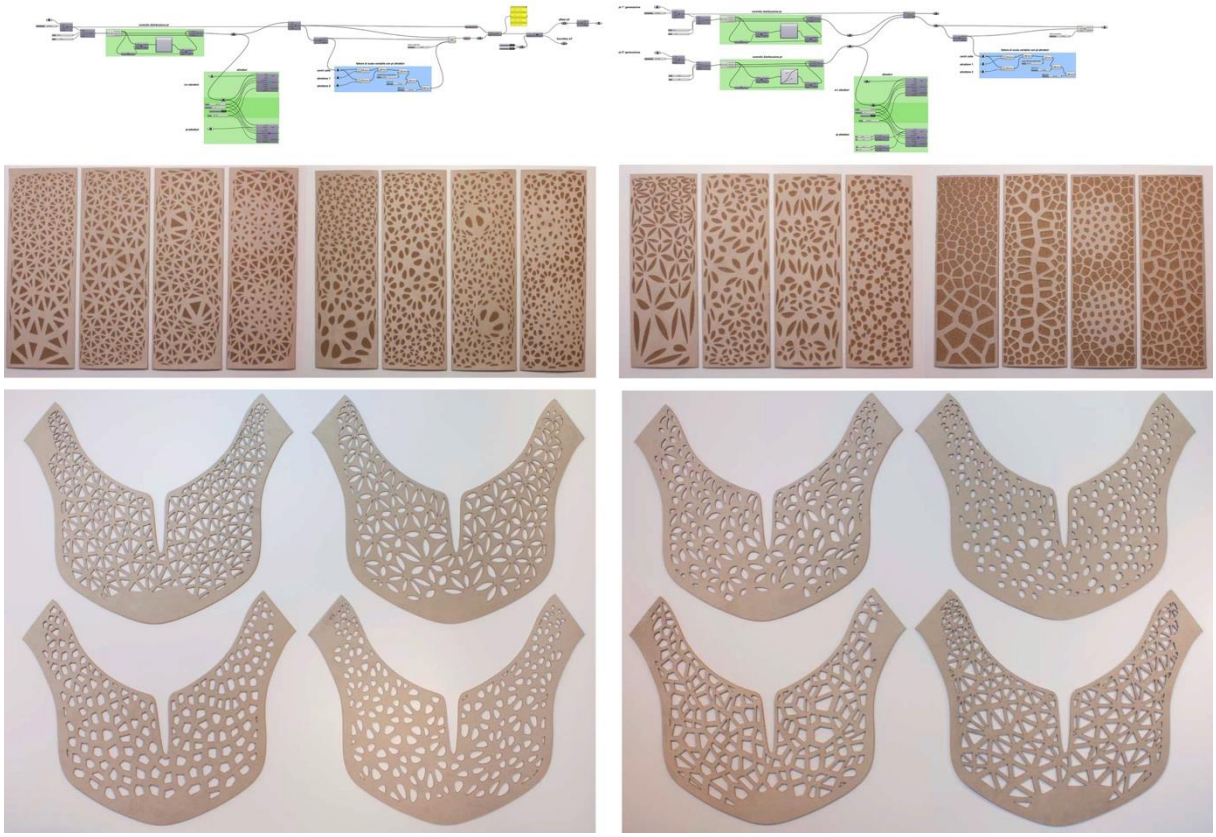

Figure 4. On the top: parametric texture for the upper-sole. In the middle: variation of the parametric texture based on Voronoi tessellation and Delaunay triangulation. Production by Revolution shoes. Author: Fasano, F. Degree Thesis in Industrial Design. Advisor, Di Roma, A.

Two different types of processes have been used:

- Cut laser (laser cutting);
- Laser engraving (laser engraving adjustable depth).

Results:

- Attention to detail;
- Ability to cut all kinds of leathers and fabrics, including synthetics, silks, cottons (and even latex, rubber, sweet wood and steel);
- Repeatability (produces large quantities of identically processing);
- Rapidity of realization;
- Very low production costs;
- The laser beam seals the edges, and avoid fraying;
- The treated materials are not contaminated and have minimal burns.

3.4 Prototyping

Contrary to previous, it is a form of additive manufacturing, that created three-dimensional objects by the progressive addition of successive layers of materials.

There are different technologies, which differ in the way in which the layers are printed and for the material used: SLS (Selective Laser Sintering) which fuses the material to create the layers; DLP

(Digital Light Processing) which provides a liquid / polymer resin bath that hardens when exposed to the light of a DLP projector with a light; FDM (Fused Deposition Modelling) which release, through a special extrusion nozzle, movable in XYZ directions and controlled by special CAM software, a molten plastic filament. Among the filaments: PLA (biodegradable plastic), ABS (rigid thermoplastic polymer), PVA (water-soluble fi lament), FLEX (flexible thermoplastic elastomer) and a number of their variants that may simulate wood, glass, bronze, copper.

This technology is more and more often adopted in the footwear industry.

The prototype of the flatten shoes has been produces using a FDM machine and a FLEX filaments. The dimension of the shoe (size EU 39) is compatible with the dimension of the most used 3d print machine available in many Fab Lab and 3d Print service. It has been produced having the bottom of the sole placed on working plan of the machine.

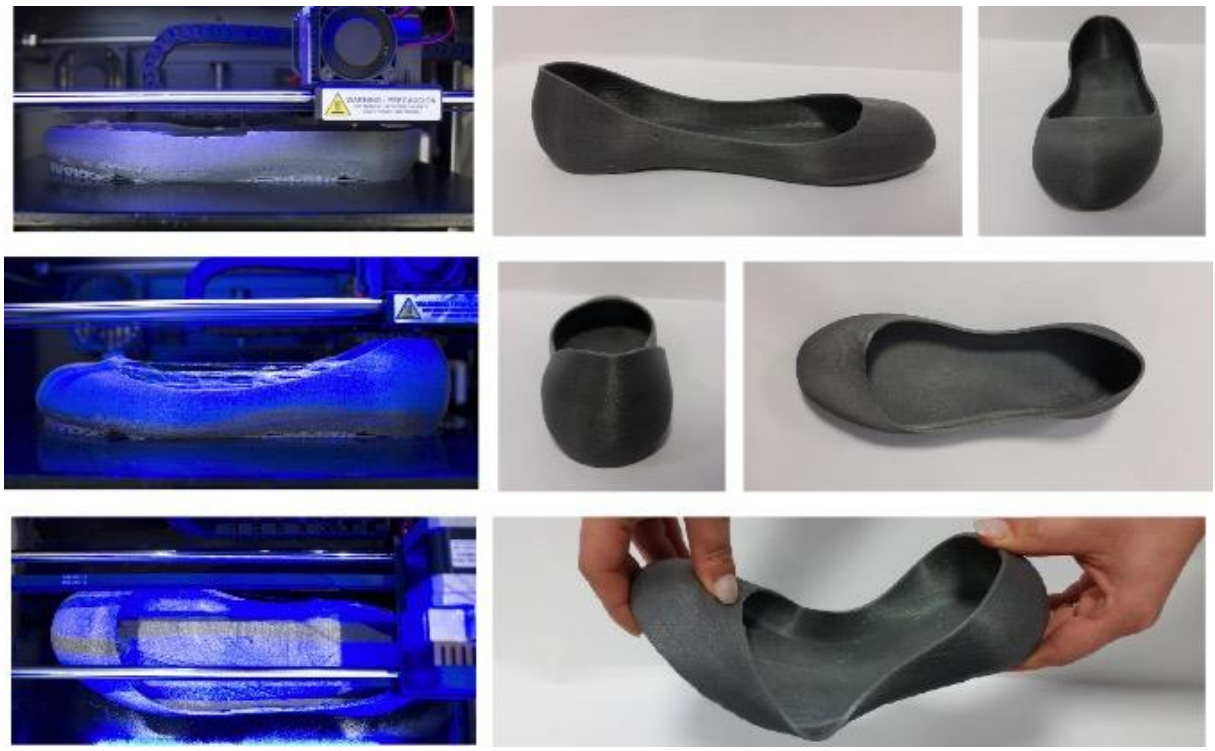

Figure 5. On measure flat shoes in TPU. Additive manufacturing using FDM technology. Authors: Giorgio M, Sciancalepore, M. Degree Thesis in Industrial Design. Advisor, Di Roma, A.

Results:

- Cost effectiveness and speed of implementation (by eliminating the high costs of traditional production and shortening of the normal long process time for the prototype production);
- Containment of waste;
- Possibility to interact during the manufacturing phase and customize the product;
- The realise of the prototypes in hours allows for immediate feedback, coming back on the concept design, and repeat the prototyping;
- The prototype allow the fast test for size, comfort and style as well

4. Conclusions

Re-locating the hand made know how and the traditional industrial methods in the context of the advanced production methods and processes, is aimed to the enhancing of the cultural matrix of a territory, able to define a new cultural economy approach, enabling new competitiveness keys for footwear market. Contemporary scene shows that artisan work is now one of the most important figures of culture and the Italian economy; bet on it, contaminating it with "new knowledge" technological and opening it to the international market would be reflected in his hands a powerful tool for growth and innovation. As evidenced by some Italian companies (Geox, Tod's, and so on) "know how" remains an indispensable ingredient for the entire Italian manufacturing. That, in the end, is one of the few vital sectors of our economy (Micelli, 2013).

As well as for the manufacturing methods this scenario has effect on the product innovation and defines an innovation of the meaning of the shoes thanks to new parameter *user centred,* in term of design, comfort, interactivity and safety.

The production of the shoes made to measure at distance, the customization, the production of small series, are not more a paradox but a concrete possibility for the innovations of a sector traditionally tied on the one hand on standardized production practice, and on the other hand on handmade on measure systems.

The so-called fourth industrial revolution, associated to the 4.0 industry contemporary standards, expresses the horizons of a new and more complex adaptivity and interactive product design and manufacturing process, connected thanks to the IoT, directly to the end user and the environment.

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