12 Digital Tools to Improve Aesthetic and Functionality of Fashion Products: Footwear

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1. Introduction

Product design is a creative task that implies new ideas or improvements of existing ones. Creating products that are functional or fulfill consumers' requirements is a process that involves following various steps to meet these requirements. The whole process of product design includes all the steps followed from market research to the final product. All the steps from 2D sketches, 3D computer-aided design (CAD) modeling, simulation, etc., are needed to create a prototype/product to fulfill customer needs. These are continuously changing and linked with various applications. Highly important applications are addressed for specific users. Obviously, consumers' requirements have evolved over time, and the products offered try to accomplish not only the functional part, but to also include the aesthetic part. As a result, more and more consumers are involved in the product design process.

Footwear design and production have changed over time, thanks to technological advances at every stage of production. As a mainly manpower-based industry and, of course, considering the costs related to product development, today the integration of computer-aided design/manufacturing (CAD/CAM) systems in footwear production has brought many advantages, i.e. 3D technologies, part of product design in footwear industry as modeling, simulation, and visualization. These digital tools improve the whole process with regard to related costs, time, waste reduction, etc.

The present research introduces product design methodologies in the footwear industry. As one of the main processes of product development, it plays an important role by becoming a decisive factor in producing footwear with adequate comfort and sustainable production.

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A rapidly growing awareness of sustainability issues and impact of the footwear industry is receiving attention from companies operating in this sector and dealing with these issues. This chapter discusses the attempts to evaluate sustainability as an emerging need in the footwear industry by bringing it about through various applications. Obviously, they are linked with technological advancement, occurring continuously, and are known under the term Industry 4.0.

The most important properties of footwear such as creativity, functionality, sustainability, and customization are provided by a complex set of characteristics as described by the following statements: creativity plays an essential role in the product design process. It must meet requirements as an original design and follow the latest trends. Regarding the functionality of footwear products, they must fulfill the requirements of quality, regarding fit and comfort for consumers' feet. These last two requirements can be achieved by customization, which is a growing trend, including in footwear products. Customization can include aesthetic, fit, and comfort for individualized shapes. Moreover, customization can enhance sustainability of footwear production, by reducing the number of footwear products and the use of recycled materials. All these properties can be improved using digital technologies such as 2D/3D modeling and additive manufacturing (Figure 1).

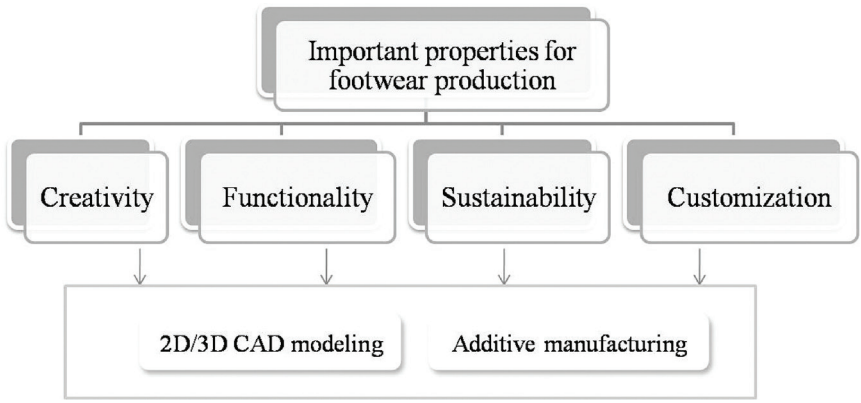

Fig. 1 Important properties for footwear production

2. Footwear Products and Role of Design in Comfort Perceived

Footwear products are considered the most important wearable items, especially related to functionality and comfort that they should offer. Comfort is a term related to subjective assessment from consumers on how they perceive it. It is linked with materials used and product shape or design. Producing footwear products with the right fit is a complicated process due to the complex geometry of the foot. Footwear products, in contrast with other items, are modeled in the same way by traditional

methods and advanced 3D modeling software over the last shape, which is even called as the heart of shoe production. It is said that should be the translated form of the shoe, but not exactly. In other words, the last shape is responsible for the fit and comfort of the produced shoes.

Traditionally, lasts shapes are created by experienced people working in this sector and having good knowledge of human feet. But due to the introduction of digitalization, the process of last designing is much shorter, more precise, and includes virtual simulation. It is of high importance to have a preliminary evaluation of the products prior to their production. It allows the pattern maker, also known as technical designer, to add extra features that include various changes to achieve the right fit required by the consumers.

Wearing shoes without the right fit impacts our health. Evidence found by various researchers identifying the role of shoes and their impact on our health demonstrates problems that are evident in various parts of the body. The nature of the foot and its linkage with other parts of the body confirm this evidence.

Consumers have become more aware about the role of shoes regarding foot comfort and whole-body health by changing or using products that are more comfortable such as sport shoes.

3. Factors Affecting Footwear Comfort

Various consumers experience different problems with footwear products during their lifetime. There are different factors that indicate footwear comfort. These factors are related to the last shapes and materials used for their production. But, on the other hand, comfort is defined as perceived sensation from the user. It can be affected by shoe microclimate, such as temperature and humidity (West et al., 2019). Studies conducted to evaluate comfort for shoes indicate various characteristics such as suitable heel height (Goonetilleke and Karwowski, 2016), good fit in the forefoot region, and attractiveness as well (Au et al., 2005).

Shoe inserts are another part of the shoe responsible for comfort. Their texture can change gait pattern and can be important to determine movement strategies (Nurse et al., 2005). Comfortable shoes are the ones with the correct shape of the last. It is mandatory to create a last with the correct shape based on the anthropometric data of consumers' feet. A shoe last is a complex shape due to its free form geometry. To model a new shoe last, an existing shoe last can be used as a reference and its virtual copy can be created based on reverse engineering method. Later, using digital tools, the shape of the virtual last is merged and compared with the shape of the consumer's foot. The parameters of shoe lasts are generated by features based on the results of 3D scanning, and considering the practical experience, the most important footwear products are fashionable footwear, everyday comfort footwear, orthopedic footwear, and special footwear for increased comfort. Figure 2 depicts the shoe last design according to two different ways. The first one is based on the adapted shape of shoe last that is designed according to the main foot parameters. Meanwhile, the second case

creates individual shapes of shoe lasts that are designed according to the shape and all measurements of the foot (Figure 2).

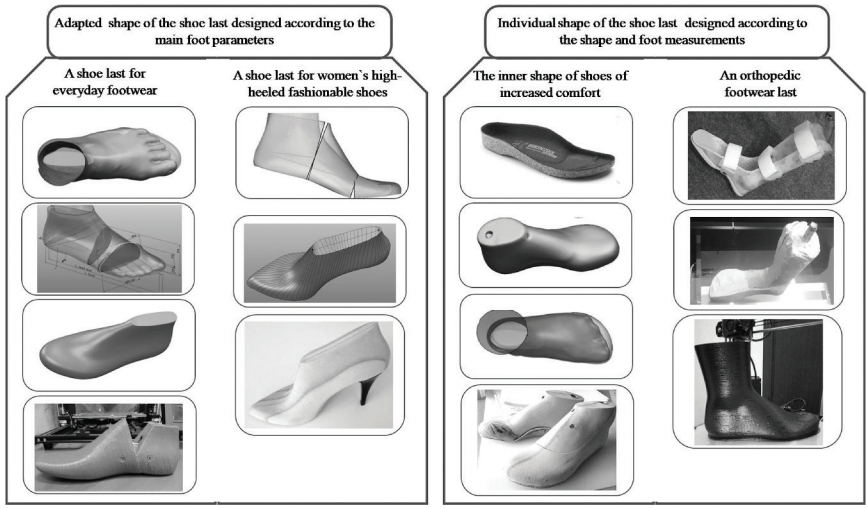

Fig. 2 Shoe last design according to foot parameters and according to shape and foot measurements

Analyzing foot pressure distribution is crucial for data collection to improve human performance. These data provide important information about static and dynamic weight distribution of our body under different activities performed during our daily life. The technology used helps to register and analyze these data reported in real time not only for athletes but also for people with various foot problems. Figure 3 depicts pressure maps of the feet taken with T-Plate for two different participants.

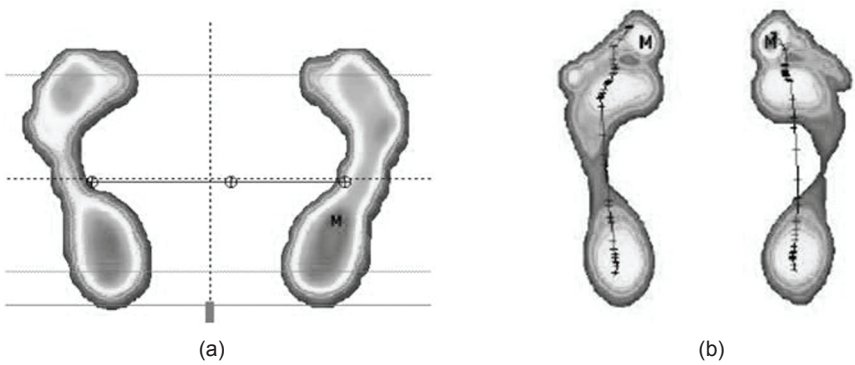

Fig. 3 Static analysis of the feet (a) participant 1 and (b) participant 2

Figure 4 depicts the dynamic analysis for both feet for the second participant. This measure is valuable in terms of forces, which act in various parts of the foot.

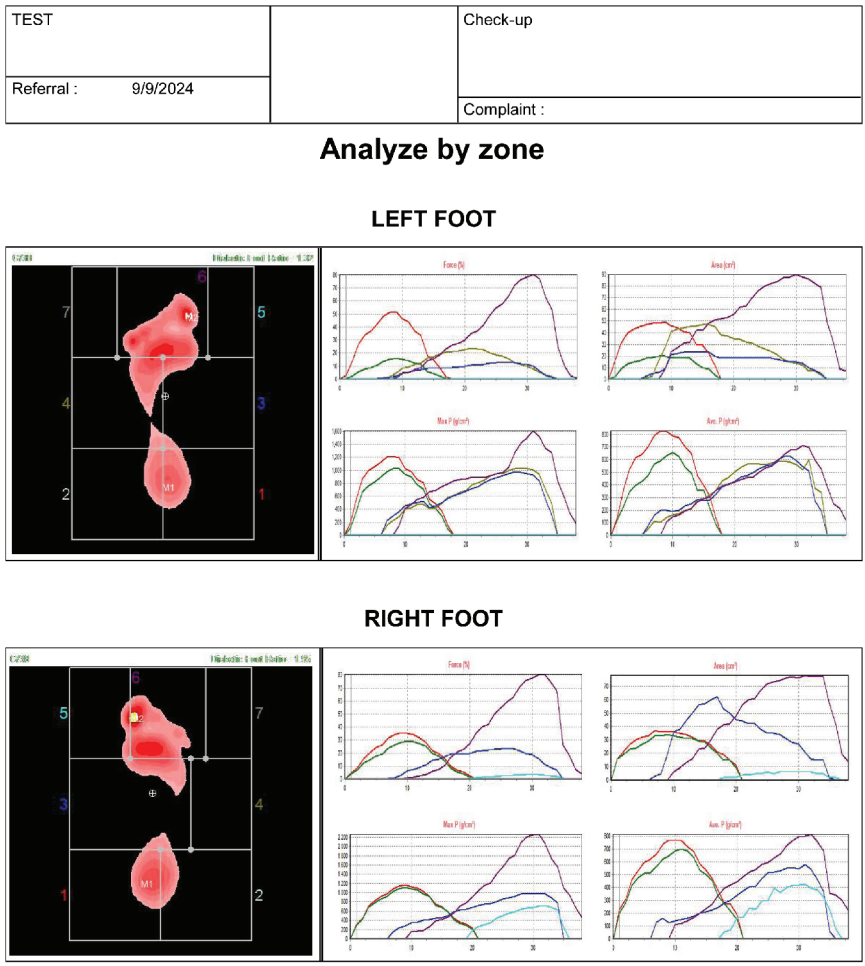

Fig. 4 Feet dynamic analysis of the second participant

During the gait process, the higher the pressure points that the feet apply on the walking surface, the higher the discomfort. To overcome the discomfort, the insoles should be designed considering two design schemes: (a) the pressure map showing the force distribution during static pose of the participant and when walking bare foot, and (b) based on specific forces on the foot (the force sensors were used at nine different points of the foot area) (Almeida et al., 2019). During this process, the participant wore casual shoes (Figure 5). From the first test conducted on the static analyses, the resulting pressure distribution map is presented in Figure 6. In the design process, the insole was divided into nine parts (Figure 5b). This division was important to evaluate for each single part the mechanical characteristics

according to the pressure distribution by changing material used for production or manufacturing parameters. The resulting insole produced was later tested by the participant to evaluate their comfort. During the evaluation process, from the study, the participant exerted less force during the gait analysis of the left foot and the force values were reduced from pick values.

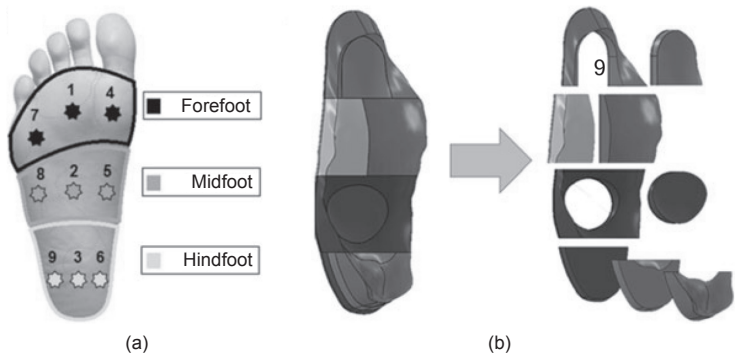

Fig. 5 (a) Division of foot plantar sensor positions outlines and (b) Insole design (Henrique Amorim Almeida, 2019)

The classical methods of making orthoses/insoles will remain relevant for a long time. The layer-by-layer lamination of materials with different densities, followed by thermal and mechanical processing, requires relatively high material costs (a variety of materials and tools are needed) and proper technical equipment. 3D printing of custom orthopedic insoles may offer advantages, such as reduced time costs, automated production, potential long-term cost reduction through equipment usage, and the ability to produce insoles that better match the contours of the foot. By using a single material, our goal was to achieve different physical and mechanical properties in different areas of the product. The insole shape modeling was done in Rhinoceros™ according to the following algorithm:

- designing the upper surface of the insole based on the 3D scan of the foot imprint on the foam;
- fitting the constructed 3D surface into the contour of the inner sole of the footwear;
- aligning the resulting model with the foot pressure map to determine areas with high pressure;
- creating counters that limit areas with high pressure;
- constructing surfaces to slice the 3D insole model into individual areas;
- save the individual areas of the insole;
- convert and import them into Cura™ slicing software; and
- selecting 3D printing parameters according to each individual area.

Figure 7 presents pictures during the process for insole modeling. The first step includes creating a digital copy of the bottom part of the foot. The second step deals with the elaboration of the 3D model of the bottom part of the foot and

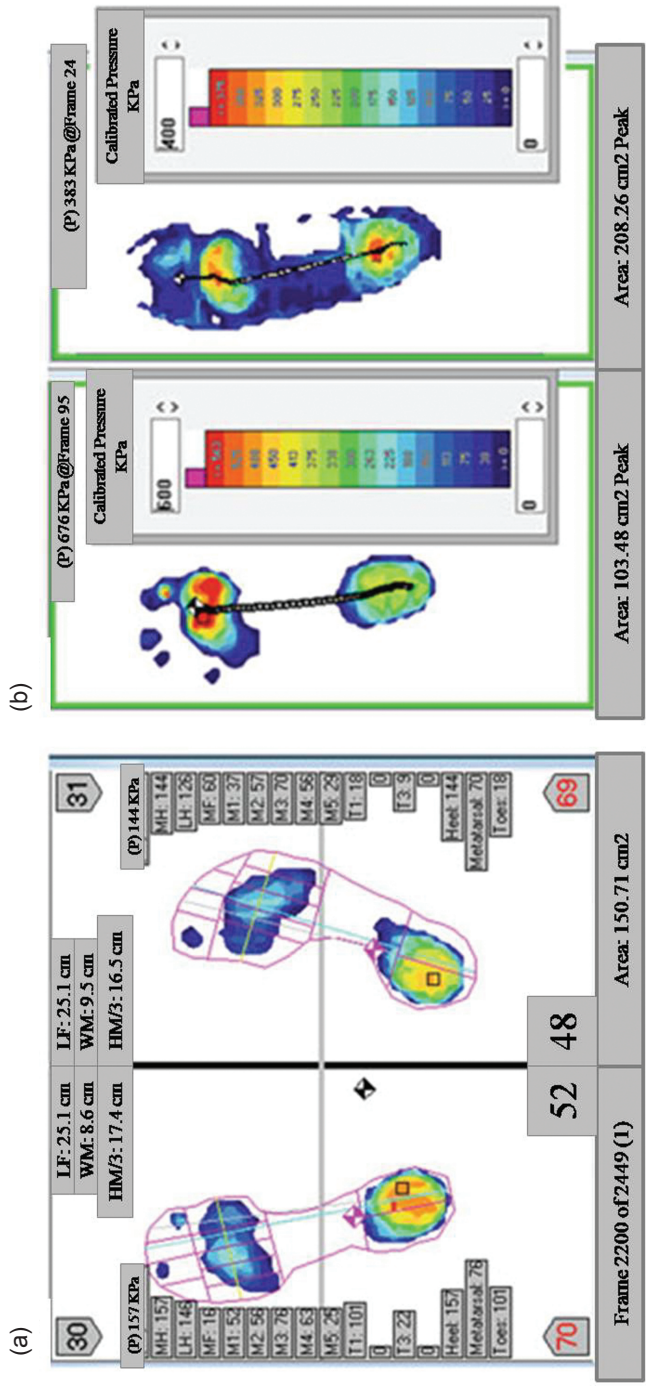

Fig. 6 (a) Plantar pressure distribution mapping of the foot during static state and (b) Plantar pressure distribution mapping for the left foot during walking analysis without insole (left) and with the produced insole (right) (Henrique Amorim Almeida, 2019).

preparing it for the 3D printing process. The last steps include preparing the model for 3D printing machine and its final production.

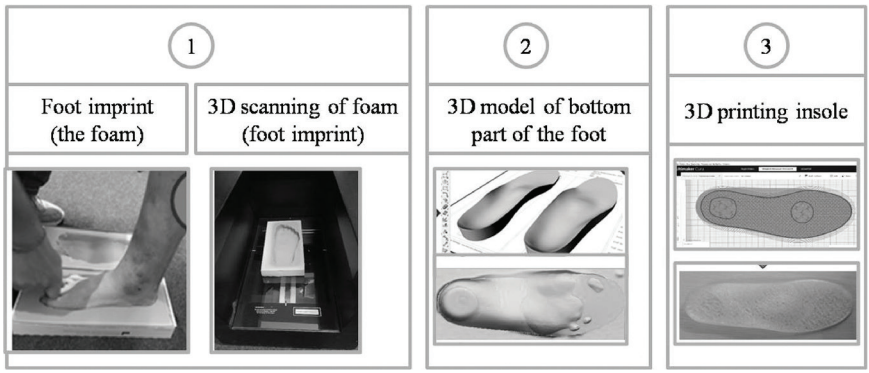

Fig. 7 From foot imprint to 3D printed insole

4. Sustainability as an Emerging Need in Footwear Production

Sustainability is a common goal for people all over the world, and its various definitions have a common task—to make people aware of their actions so as not to have a negative impact on the environment in the future. Developments in technology have brought about overproduction; the various materials used, and the means of product distribution, retailing, and usage—in other words, the whole product life cycle—play a role in contributing to environmental pollution. To maintain sustainable production, the design process plays an important role, as the core of the circular economy. It is evaluated that 80% of sustainable production is defined at the design phase (Ellen MacArthur Foundation, 2022) by underlying as the most important process in product development. The United Nations has defined various goals that should be considered for securing sustainable development. Among them, the goal related to industries, innovation, and infrastructure plays a key role in sustainable production, including in the footwear sector (United Nations, 2021). As one of the industries ranked among the top for the negative impact on environment, textile production is responsible for about 20% of water pollution. This is especially related to the dyeing process and finishing (European Parliament, 2024). Meanwhile, business is expected to increase and grow to 147 million tons in 2030 (Geneva Environment Network, 2024).

The increased focus on sustainability is perceived as a boost for the adoption of new technologies, which are sustainability-enablers in footwear manufacturing. Footwear production is mainly a power-based industry due to the nature of footwear products. Of course, over time, the advantages offered by the integration of CAD/CAM systems in footwear production have brought about many advantages. At first, they were mainly focused on 2D patterns and have evolved with time by

including 3D technologies for the process of product development in the footwear industry. Modeling, simulation, visualization, and so on, offer digital tools that improve the whole process regarding costs, time, waste reduction, etc. There is a growing number of well-known companies operating in footwear production that are trying to push further the integration of sustainable processes and materials in the footwear industry. In this scenario, product design becomes a decisive factor to produce footwear with adequate comfort and sustainable production. Understanding consumer behavior on the role of sustainability in buying decisions has been the focus on several researches. Consumers exhibit a positive attitude toward sustainability and eco-fashion but these factors are less important than other factors—i.e. price, value, size, quality, style, convenience of purchase, materials, and many others—that prevail while making their buying decisions (Mandarić et al., 2022). Based on other studies, this can be attributed to lack of information, education, and transparency among consumers, where companies can play a crucial role in educating consumers to implement sustainability in their buying choices (Pereira et al., 2021). The correlation between educational level and knowledge of sustainable fashion shows a high purchase intention for these products (Han et al., 2024). These highlight the need to enhance the efforts toward consumers' education for the high impact of their purchases on sustainability (Papamichael et al., 2024) and the need for strategies to support environmental consciousness (Lopes et al., 2024), where marketing sustainable fashion can contribute to consumer awareness and reduce the negative impact of their buying choices (Ray and Nayak, 2023).

The findings may differ for the footwear industry with sustainability being one of the main factors taken into consideration or ranked as the least important factor (Polese et al., 2019) or not considered at all by the new generation (Bernardes et al., 2018). Among the three pillars of sustainability, studies have found that social sustainability has resulted in the most important impact on the supply chain of the footwear industry (Munny et al., 2019).

In the footwear industry, leather processing through chrome tanning releases waste that has a negative impact on the environment. Among the various ways to achieve sustainable production in the footwear industry, one of the steps is developing a new tanning technology and using the waste generated in cosmetics, agriculture, etc. (Deselnicu, 2014). Solutions can be found by focusing on design principles and circular economy to come out with reduced waste and negative impact at a high level (Marques et al., 2017).

Changes in footwear production are also related to the materials used that contain of materials like plastics, rubber, leather, and textiles, which in most cases makes it impossible to recycle them. Running shoes, for example, contribute to waste generated due to their use for a short time.

To have a more sustainable production of shoes, plantar pressure maps were used together with topological optimization schemes to develop soles with the best material design according to the feet's pressure, while maintaining biomechanical performance and aesthetics. The design process considered the feet's plantar

pressure maps (Figure 8a) which were then converted into numerical simulation data for the topological optimization scheme (Figure 8b). After undergoing the topological optimizations, an optimized biomechanical sole was obtained with the best material design (Figures 8c and 8d) (Spahiu et al., 2021).

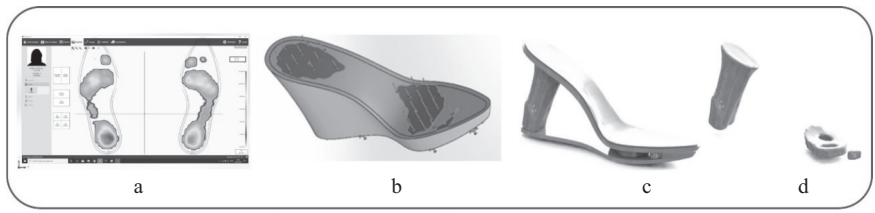

Fig. 8 (a) Plantar pressure maps; (b) boundary conditions for the topological optimization and illustration of the optimized designs; namely, (c) the design region and (d) the optimized sole (Spahiu et al., 2021)

Conclusions

Designing process is a crucial step in product development by including new ideas or improving existing ones. Creating products that are functional or fulfill consumer requirements is a process that includes various steps followed by 2D sketches, 3D CAD modeling, simulation, etc. These are continuously changing and linked with various computer-based applications. Consumers requirements have evolved over time including the aesthetic part too, which includes consumers in the process of product designing. Highly important applications are addressed for specific users.

The role of digital tools is indispensable in product development due to their numerous advantages. The manufacturing part through additive technologies as 3D printing present an efficient technology to transform 3D models into a physical product by reducing time, costs and realizing 3D structures that can not be produced using traditional technologies.

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