



DIGITAL TOOLS FOR DESIGN AND MANUFACTURING OF FOOTWEAR PARTS AS HEELS

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ABSTRACT: Digital tools are implemented in various steps, such as production, merchandising, retailing, and customer service. Their implementation includes the fashion industry where product development such as garments, heels, jewelry, and accessories, is essential within all steps of production. Starting with the concept of creating 3D models, simulating, and direct digital manufacturing, including complex geometry, depicts the advantages of these technologies in the fashion industry. Reducing time, waste, and the advantages of creating, visualizing, and evaluating products at the early stages of product creation improves the process of product development. In this paper we present a methodology to implement these digital tools for design and manufacturing of shoe parts as heels. Due to the important role that heels play in shoe stability, an attempt to create heel shapes by inspirations taken from solid geometries is presented. To complete the whole design of these models the same shapes are used to create the upper part of the sandals. The methodology presents accurate and convenient manufacturing of footwear products based on product customization. Moreover, it shows a sustainable way of manufacturing footwear products.

Keywords: 3D modeling, heels, accessories, simulation, 3D printing.

DIGITALNI ALATI ZA DIZAJN I PROIZVODNJU DELOVA OBUĆE SA POTPETICOM

Savez inženjera i tehničara tekstilaca Srbije



APSTRAKT: Digitalni alati se implementiraju u različitim koracima kao što su proizvodnja, merchandising, maloprodaja i korisnička podrška. Njihova implementacija uključuje modnu industriju u kojoj je razvoj proizvoda kao što su odeća, potpetice, nakit i dodaci neophodan u svim fazama proizvodnje. Polazeći od koncepta kreiranja 3D modela, simulacije i direktne digitalne proizvodnje, uključujući složenu geometriju, oslikava prednosti ovih tehnologija u modnoj industriji. Smanjenje vremena, gubitka i prednosti kreiranja, vizuelizacije i evaluacije proizvoda u ranim fazama kreiranja proizvoda poboljšava proces razvoja proizvoda. U ovom radu predstavljamo metodologiju za implementaciju ovih digitalnih alata za projektovanje i proizvodnju delova cipela kao potpetica. Zbog važne uloge koju potpetice igraju u stabilnosti cipela, predstavljen je pokušaj kreiranja oblika potpetice inspiracijom preuzetim iz čvrste geometrije. Da bi se kompletirao dizajn ovih modela, isti oblici se koriste za kreiranje gornjeg dela sandala. Metodologija predstavlja tačnu i praktičnu proizvodnju obuće zasnovanu na prilagođavanju proizvoda. Štaviše, pokazuje održiv način proizvodnje obuće.

Ključne reči: D modeliranje, potpetice, dodaci, simulacija, 3D štampa.

1. INTRODUCTION

Footwear products are a necessity for human beings. Their function is not only related to offering consumers protection and comfort but also to the aesthetic side. There are three most important factors in purchasing decision as “price”, “brand” and “product design and style” [1], where the last one is linked with long-term use [2]. Studies reveal that fit and comfort of footwear products are of great importance to improve gait performance [3], and reducing fear of falling [4]. Moreover, well-fitted, lightweight shoes with soft midsoles and curved rocker-soles are generally perceived to be most comfortable [5]. This would reduce the different problems created with ill-fitted footwear. Evidence results that 63 to 72% wearing in appropriately sized footwear based on length and width measurements [6], are associated with various foot pains as reduced mobility according to target group [7]. In addition, these findings try to attract consumers’ attention and make them more conscious about their buying decision and in the meantime provide evidence to companies and shoe pattern makers to use these data to improve their product. These products are also constantly changing in terms of their design and the materials used for production.

Shoe modelling is a complex process that requires advanced knowledge of the human foot, which is a very complex shape. All the parts of the foot work together to offer the body support and mobility. Also, heels are an important part of the shoes and used especially for women’s shoes. Usually, heels are designed based on some basic styles by making variations. However, designers try to create heels based on different shapes. Cases were presented and even implemented for heel models. However, the shoe pattern maker tries to approve them based on some important requirements that every heel model should fulfil. For heel designing the top surface should be the same as the outsole.

This paper is organized as follows: Section 2 continues with a literature review of digital tools for heel designing and production. Section 3 gives a detailed description of the a



methodolgy used to model and produce new heel models. Following the methodolgy Section 4 presents results of heel models designed and produced though digital tools. Moreover product assembly in a footwear company. At the end the conclusions of this work are presented.

2. DIGITAL TOOLS FOR FOOTWEAR PRODUCTS

Shoes are garments worn by feet but with high requirements compared to other items. Shoes design and production are based on the 3D shapes of the last, which is the main part of the shoe modelling process and anatomically, the converted shape of our feet. Sizing systems used for footwear production are based on anthropometric data taken from anthropometric studies. Even though they try to accommodate all foot sizes regarding length, width and girths, there are still problems that lead to ill-fitted footwear. This is related to foot shapes which are different. As a result, companies try to offer consumers personalized products.

Advanced technologies such as 3D foot scanning systems offer the possibility of taking digital information of the foot, and further elaboration of the 3D foot model aligned with a standard shape of the last, a new last model personalized according to customer's foot is created. Furthermore, the custom last is used for shoe modelling. Nowadays, designers have the necessary tools and capabilities to create more efficient and customized designs [8]. It is evident that integration of digital transformations can strongly drive waste reduction to support sustainable production [9]. Up to 80% of a product's environmental impacts can be determined at the design phase [10]. CAD designers can integrate design simulation in their projects. Known as the heart of Industry 4.0 and the main driver of it [11], simulation is a process that tries to mimic the product or the system to evaluate, avoid mistakes, reduce labour costs and material waste by improving it at the first steps of designing. The simulation process is found for product process, including assembly lines where an increase of the production can result [12]. In the footwear digital prototyping can significantly contribute to environmental and economic sustainability [13].

Here we present the cases of shoe customization through heel models. Heel models differ from the shoe models and designers present a wide range of them, from the normal shapes to the strangest ones. It is well-known fact that high heels are attractive but the problems are created with the distribution of foot pressure and displacement of the centre of pressure [14] by leading to discomfort [15] and evidence shows that pathological alternations are found even in younger users [16]. To keep both fashion and comfort researchers have developed an adjustable heel with low and high height. The results taken from 3D finite element analyses depict the higher stress in the soft tissue related to high heel height [17]. The methodology developed based on synergies existing between parametric designs, design optimization, and additive manufacturing presented as a case for heel modelling applicable from an ergonomic and mass customization point of view [18]. A study presented to design high-heeled shoes exploits the synergies between modeling and experiments to improve and optimize the shoe design process [19].

Taking inspirations from nature approach help designers to create various fashion products [20]. Even heel models are items that express individuality and, in the same time should fill the requirements to withstand body weight. Bearing in mind the weight of customer and material selection according to the manufacturing technology chosen for heel production, 3D heels models have undergone structural simulations and topological optimization.

This study evaluates or analyses the 3D modeling, simulation, and 3D printing for fashion products as heels of the shoes. Three heel models are designed based on various geometries.

3. METHODOLOGY

The methodology followed in this work includes 3D modeling and 3D printing of heel models. Figure 1 depicts the main steps from 3D modeling to additive manufacturing of footwear products.



Figure 1: From 3D modeling to additive manufacturing of footwear products.

The shoe's last shape is designed based on the anthropometric parameters of the foot, and the heel shape is directly related to the last which is the support of the foot in high-heeled shoes. When lifting onto a heel, the foot is in an unnatural position, which causes a change in the relative position of the bones of the foot [21] and a redistribution of the load. Figure 2 depicts an x-ray showing the anatomical position of foot structures in a high-heeled shoe. To ensure the stability and normal functioning of the heeled structure, we need to consider the main parameters that must be taken into account during the design. When standing on a heel, body weight is distributed between the metatarsal-toe area and the center of the heel.

Proper design of the heel is especially important since it accounts for a significant portion of the total body weight.

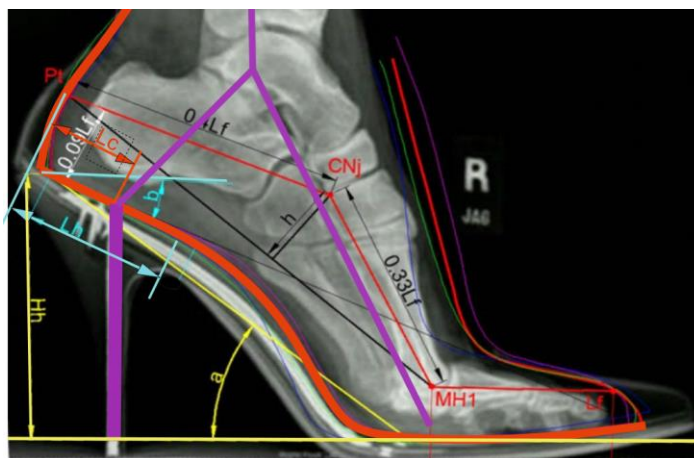


Figure 2: x-ray of the foot wearing high heels

The top surface of the heel depends on the shape of the heel area of the shoe's last bottom surface. The most important design parameters for a stable heel structure are the wedge angle (the angle of the top surface of the heel) and the location of the vertical axis of the heel. The heel axis should be located under the center of the heel, that is, at a distance $L_c = (0.16 \div 0.18) L_f$ (L_f - foot length, mm) from the Pterion point. While the wedge angle depends on the height of the heel $WedgeAngle = 0.25H_h - 2$. Figure 3 depicts shoe last measurements with a high heel.

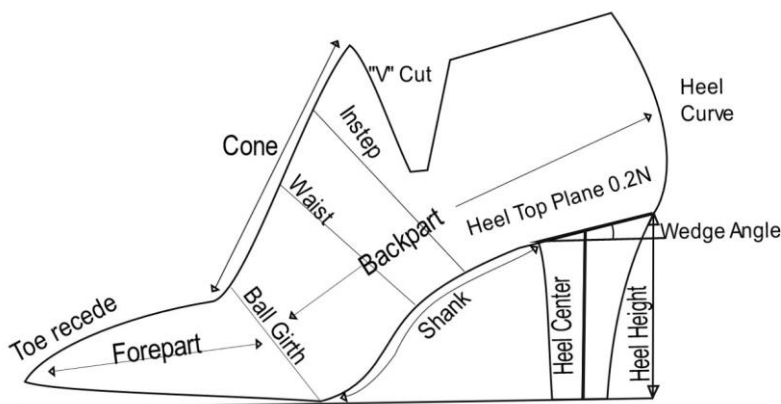


Figure 3: The high heel shoe last measurements

To design the shape of a heel for 3D printing, several methods can be used:

- 1) Solid modeling based on functions of extrusion and rotation of designed projections with next application of Boolean operations of subtraction and intersection
- 2) Solid modeling based on a set of flat horizontal sections



- 3) Surface modeling, during which the side, top, front and bottom surfaces of the heel are designed, which form a closed 3D body
- 4) Solid modeling using simple geometric bodies, Archimedean solids, etc. - for fantasy heel shapes.

In the current work, the software used for 3D modelling shoes is ShoeMaker 2015 R2. The software for heel shape design – is PowerShape. The 3D heel models were converted to STL file for next preparing in slicer software Ultimaker Cura 4.5 for 3D printing. Heel production is realized on a FFD 3D printer GEEETECH A30 3D and the material used is PLA. Table 1 depicts the main parameters used for 3D printing.

Table 1: The main 3D printing parameters

3D printing parameters	Value
Material	PLA(Polyactic acid)
Layer thickness	0.2 mm
Bed temperature	60°C
Nozzle temperature	220°C

4. RESULTS

4.1. Heel designing and manufacturing through additive manufacturing

In recent years, we have often seen unusual fantasy heel shapes on fashion catwalks, which have expressive plasticity based on complex 3D shapes. In fact, the shape of the heel is the freest spatial element of the shoe, which has limited parameters only in the top part, attached to the shoe last. In this work, at first, we attempted to customize the bottom of the shoe using different heel shapes, modeled based on the same parameters of the heel part of the last and half-insoles. Heel shapes can be designed using solid or surface modeling functions.

Inspirations taken from solid geometries are implemented for shoe heel designing. First, the last model is modified according to heel height and the standard heel is used as a base for the new heel models. Heel height is personalized with the value of 10.5 cm and the modified last is then 3D printed, which can be further used for shoe production. All models are based on the 3D cube solid geometry at the lower and upper parts of the heel. In the middle of all models are included the Archimedean solids which are well-known for having a very high symmetry. The solids of Icosahedron and Rhombicuboctahedron models are included in the heel models. Figure 4 presents the view in the front side, side view and 3D view of both heel models. Moreover, these models are produced with an FDM printer with PLA material. Produced models arranged with the personalized last according to heel height are also presented in Figure 4.

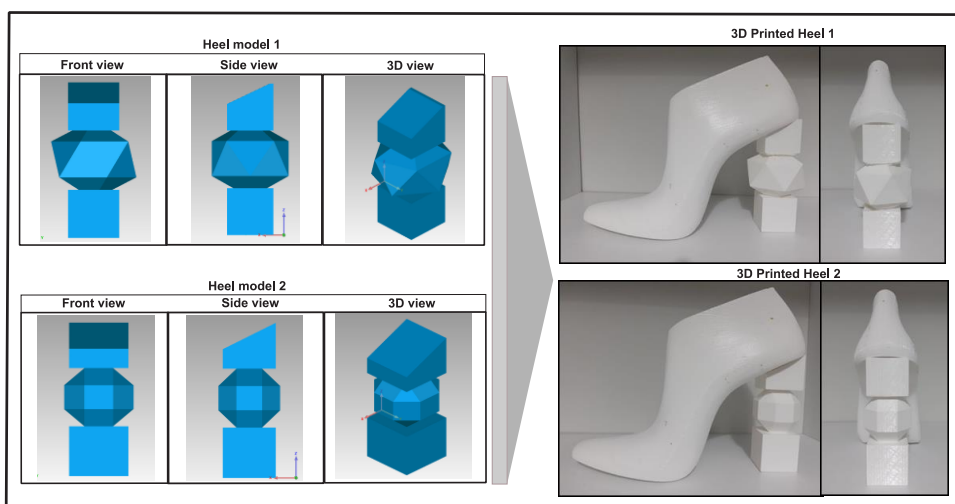


Figure 4: 3D heel models in front, side, and 3D view, modelled and produced in 3D using solid modelling.

4.2. Sandals manufacturing

Based on heel models and 3D printed last, the following step includes footwear production. In this work three different sandal models are selected, where the upper part is modeled by considering the same geometric models of the heel on the 3D modeling software ShoeMaker 2015 R2. Figure 5 depicts 3D models of numbers 0 and 1 merged, where the upper part or heel seat is from the standard heel (22).

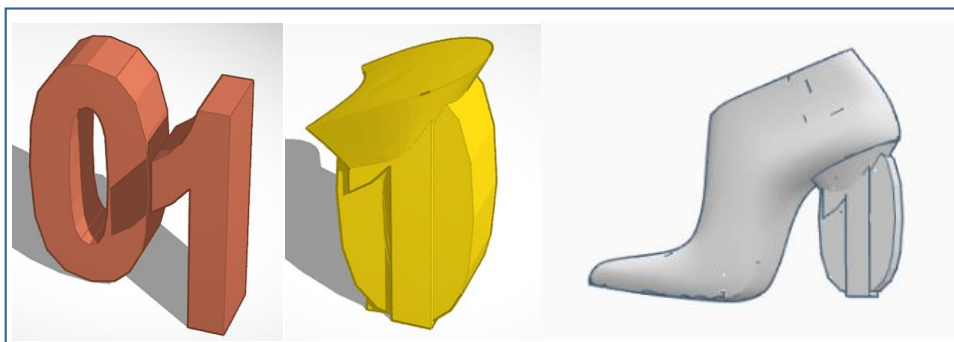


Figure 5: New 3D heel model: left) 3D models of numbers 0 and 1; center) new heel model and right) last and the new heel model.

From Figure 6 is evident that the upper part of the sandal is modeled based on the heel geometry where are visible 0 and 1. This is a semi-finished product where the assembly with the sole part must be taken.



Figure 6: Different views of sandal model 1 during production process over 3D printed last.

Following, Figures 7 and 8 depict the other two sandal models during the production process. Even here, the upper parts are modeled based on heel geometries, such as the solids of Icosahedron and Rhombicuboctahedron models.



Figure 7: Different views of sandal model 2 during production process over 3D printed last.



Figure 8: Different views of sandal model 3during production process over 3D printed last.

5. CONCLUSION

The work presented here brings back case studies from the fashion industry on the use of digital tools. The key study presented here depicts the importance of implementing these digital tools in the modelling and production of these models. Product customization presents the benefits in terms of time and material waste management. This workflow can be used by different companies that would like to offer customized products.

As part of future work, the authors intend to focus on utilizing parametric design tools to create personalized footwear products as the sole, based on foot pressure maps. By employing appropriate design software and leveraging modern technological tools, it is possible to develop customized products tailored to the preferences and needs of individual users. Additionally, conducting research to select suitable materials can further optimize the final product, ensuring it meets the highest standards of quality and functionality.

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