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A methodology to use digital tools for design and manufacturing of footwear parts as heels

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ABSTRACT

Offering customers custom-fitted clothing improves customer satisfaction with well-fitted products and waste reduction. Among many products, footwear plays a pivotal role in human body health and the high requirements they must fulfil in terms of fit and comfort. Designing footwear products is a complex process that merges the creative part for aesthetic purposes and the technical part for fit and comfort. The spread of digital tools in footwear production is helping companies improve their performance and align with the sustainability goals required by the footwear industry. This work presents a methodology to design heels as part of a project to use digital tools for footwear products. The first case encompasses the use of the base of a standard heel and creates new heel models. Meanwhile, in the second case, the heel designing is depicted based on the surface of the bottom part of the second half-insole. In both cases, based on the new shapes, a pattern engineer goes further by creating heel shapes as a complex fantasy. The digital tools part of 3D modelling software presents an easy and efficient way to create these new models. Direct digital manufacturing, like additive manufacturing, presents advantages such as reducing dependence on external manufacturing companies, offering product customisation, or waste reduction. They depict the important role of technology as a key driver of the fashion industry.

Keywords
methodology,
digital tools,
heel design,
shoes,
customization,
additive manufacturing

1 Introduction

Shoe products are used to support our feet, to cover them, and to protect them from weather conditions or environmental hazards. Shoe modeling is a complex process and requires advanced knowledge of the human foot, which is a very complex shape due to its free-form geometry. All the parts of the foot work together to offer the body support and mobility. But today shoes, apart from their main function to protect our feet, play an important role in a consumer's appearance. The main parts of the shoes are the upper parts, usually produced from leather or other types of materials developed after the 1960s.

Heels are an important part of the shoe and are 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 in heel models. However, the shoe pattern maker tries to approve them based on some important requirements that every heel model should fulfill. For the heel design, the top surface should be the same as the outsole. As a creative process, heel designing has limitations regarding shape, height, or the materials used for manufacturing. One of the biggest problems of high heels is the discomfort and pain of the wearers, which can be solved by assuring the right balance of modeling and materials used for production. Footwear comfort can be evaluated through factors like weight distribution, cushioning, arch support, and shock absorption. Increasing heel height results in discomfort, but the use of a shoe insert with total contact can improve it [1]. Despite these facts, there are still other, not often considered problems with comfort and foot health. Women still want them to present themselves as attractive.

In this work, the use of digital tools for footwear products is presented as a methodology to design high heels. The following section includes a literature review of digital aspects of footwear products with a focus on heels, continuing with the methodological part of this work. After that, heel designs based on two cases are presented. The first case encompasses the use of the base of a standard heel and creates new heel models. In the second case, the heel design is based on the surface of the bottom part of the second half-insole. Digital manufacturing, also known as additive manufacturing or CNC machines, presents advantages such as reducing dependence on external manufacturing companies, product customization, or waste reduction. At the end, the paper presents the main conclusions derived from it.

2 Digital aspects of footwear products – heels

Various steps involved in product development, such as production, merchandizing, retailing, and customer service, have introduced an entirely digital workflow. Among various changes happening, effects on the quality, speed up the process, and innovative technology adaptation have been key drivers in the history of e-commerce and digital business. The fashion industry has slowly adapted to new technologies, but now there is a tremendous shift, where designing, production, distribution, and retail have increased the adoption of these new technologies by changing the way today's consumers experience their purchases. Among the technologies of Industry 4.0, 3D modeling has an important role in testing product design by testing and correcting errors before its manufacturing. 3D models can later be used for marketing as a combination of 3D modeling and animation.

Footwear products should fulfill requirements such as fit and comfort for our feet due to the huge impact they have on the human body's health. Problems created by ill-fitted footwear can be found in various research studies. In addition, these findings not only give evidence about these problems but also try to attract consumers' attention and make them more conscious about their buying decisions. In the meantime, this evidence serves the companies and shoe pattern makers to use these data to improve their products. Findings reveal that comfort, fit, and characteristics of design constructively need to be customized to fulfill customer needs [2]. There is a need for older people to find shoes that offer stability and make doffing and donning easier, especially for older people, including aesthetics [3]. Even at the national level, the situation might be the same for other countries. Shoe design and production are based on the 3D shapes of the last, which is the main part of the shoe modeling process and is anatomically the converted shape of our feet. Sizing systems used for footwear production are based on anthropometric data taken by anthropometric studies. Even though they try to accommodate all foot sizes regarding length, width, and girth, 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 to take digital information of the foot and further elaborate on the 3D foot model aligned with a standard shape of the last; a new last model personalized according to the customer's foot is created. Furthermore, the custom last is used for shoe modeling [4]. However, due to the high number of lasts derived from the variety of customers' feet and different shoe styles, removable toe parts between lasts with similar dimensions depict the ways to reduce the shoe last number. Meanwhile, it assures a high level of conformity between last-shape customers' feet dimensions [5].

It is a well-known fact that high heels are attractive. Research comparing females in high heels with females in flats results in high heels increasing femininity of gait and being more attractive [6]. But, despite being attractive, problems are created with the distribution of foot pressure and displacement of the center of pressure [7], leading to discomfort [8], and evidence shows that pathological alternations are found even in younger users [9]. Increasing heel height results in the raising of the fourth and fifth metatarsal-phalangeal joints and migration of the small toe towards the lateral side [10]. To keep both fashion and comfort, researchers have developed an adjustable heel with low and high heights.

Simulation is one of the pillars of Industry 4.0, which is called the heart of Industry 4.0 and the main driver of it [11]. It is a process that tries to mimic the product or the system to evaluate and avoid mistakes, reducing labor costs and materials waste by improving it at the first steps of designing. The simulation process is found for product and process, including assembly lines where an increase of production can result [12]. The results taken from 3D finite element analyses depict the higher stress in the soft tissue related to high heel height [13]. Finite Element Analysis (FEA) is evaluated as an alternative means to solve biomechanics problems for the design of high-heeled shoes. The data are used to define appropriate parameters for the design of high-heeled shoes [14]. Simulating footwear products in a virtual environment to analyze the biomechanical response of high-heeled shod walking through computational modeling based on finite element analyses is foreseen as a step to be followed in footwear modeling [15].

The methodology developed based on synergies existing between parametric designs, design optimization, and additive manufacturing is presented as a case for heel modeling applicable from an ergonomic and mass customization point of view [16]. Design is the first phase of footwear production that includes this paper, which explores how Design for Additive Manufacturing (DfAM), Design for Assembly (DfA), and Design for Disassembly (DfD) strategies, along with Additive Manufacturing's (AM) capability to produce intricate parts, can contribute to the fashion industry's shift towards a Circular Manufacturing model [17]. A study presented to design high heels shoes exploits the synergies between modeling and experiments to improve and optimize the shoe-designing process [18]. Reducing the negative impact of high heels, especially when used for an extended period, is possible. Researchers have designed insoles that can effectively reduce the deformative torque of big toes [19]. Even in the case of inserting a heel cup, it effectively reduces heel pressure and impact force by improving perceived comfort during walking conditions [20]. Other findings on the effect of heel height show that elevating heel height results in larger dimensions for girths and smaller dimensions for lengths, but when applying an increased height of the forefoot results in less deformation and discomfort [21]. All these data, taken with digital foot as 3D modeling, simulation, or 3D scanning, provides insightful results to be used as a reference to improve the fit and comfort of footwear products while assuring aesthetic parts too.

Heel models differ from shoe models, and designers present a wide range of them, from the normal shapes to the strangest ones. Taking inspiration from nature helps designers to create various fashion products [22,23]. Even heel models are items that express individuality and at the same time should fill the requirements to withstand body weight. Here we present the cases of shoe customization through heel models.

3 Methodology

The 3D modeling software programs used are TinkerCAD, ShoeMaker 2016 and PowerShape 2016 (Autodesk, San Francisco, USA). They are equipped with digital tools used for modeling, identification, modification, etc., for shoe modeling purposes. The user can load default models that are part of the digital library or can import them from other software to create a personalized library of shoe lasts or other parts of footwear products [24-26].

The digital information of the last is taken from the foot scanning system 3D scanner InFoot3D (Lithuania). This is an optical 3D scanning device for creating digital replicas of the human foot, analyzing foot shape, and extracting foot dimensions based on the reference points. The scanner uses the laser triangulation technology combined with 2D color image. It is equipped with 8 cameras that, together with the red laser plane, sweep the foot or the last by creating their 3D information. It has a short scanning time of 2 seconds, and the digital data taken can be exported in different formats used for modeling or direct manufacturing.

In this work, a shoe last of size 38 (for a foot length of 245 mm) with a bottom length of 260 mm and a heel height of 100 mm was used to be scanned. Figure 1 presents a view from 3D scanning and the 3D last model generated.

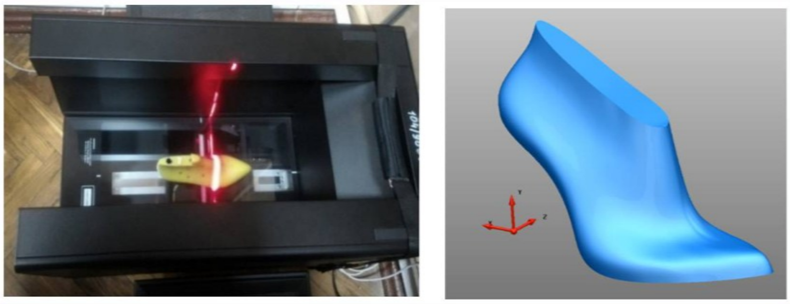


Fig. 1 Last scanning with InFOOT 3D and the resulting 3D last model.

4 Results & discussions

4.1 Heel designing

The first case encompasses the use of the base of the standard heel and the creation of new heel models. In both cases, based on the new shapes, a pattern engineer goes further by creating heel shapes as a complex fantasy. The software used is Tinkercad by Autodesk, which is a free web app for 3D design of various products. The digital tools present an easy and efficient way to create these new heel models. Digital manufacturing presents advantages such as reducing dependence on external manufacturing companies, product customization, or waste reduction. They depict the important role of technology as a key driver of the fashion industry.

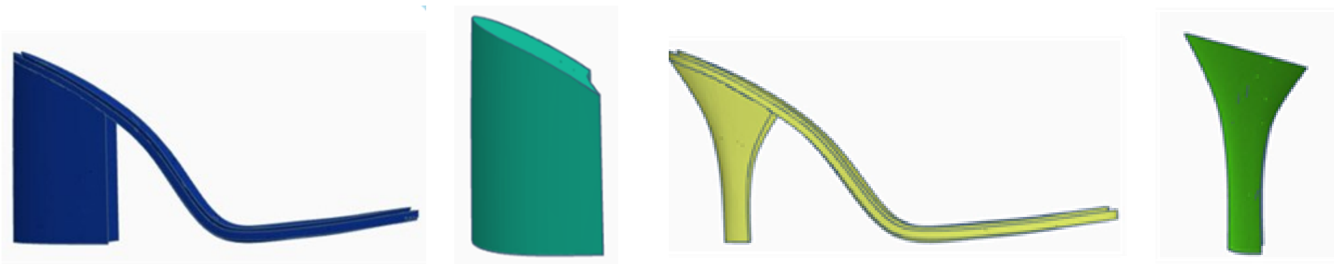


Fig. 2 3D model of heels and insoles used for creating new heel models with Tinkercad by Autodesk.

In Fig. 3, different heel models are modeled based on the standard heels presented in Figure 2. Inspirations can be taken from various sources. Moreover, the figure presents the 3D model of the last and the heel created by the 3D models of numbers 0 and 1 [26].

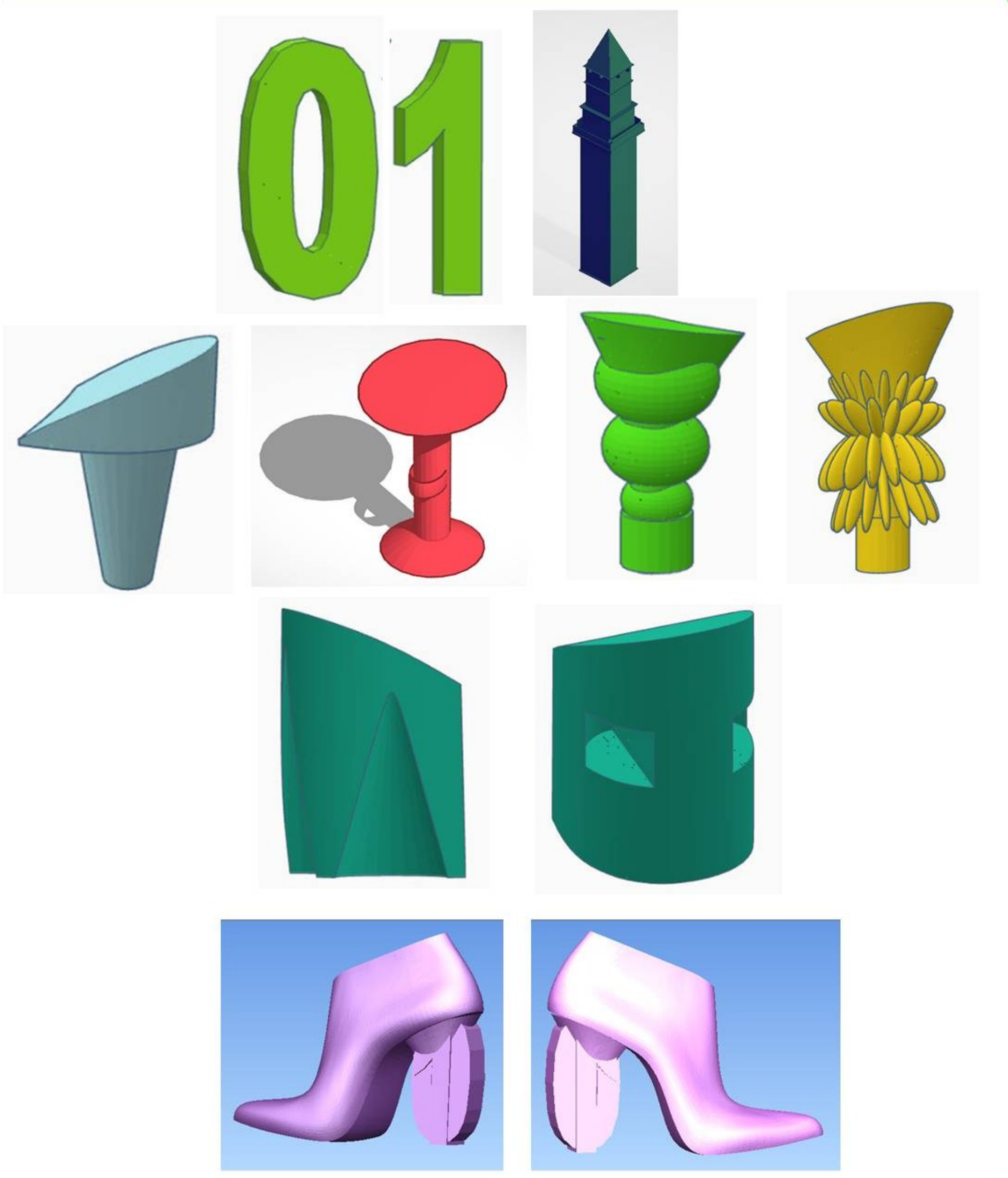


Fig. 3 Different heel models modeled based on the standard heels with Tinkercad by Autodesk.

The second case depicts the heel design based on the surface of the bottom part of the second half-insole. The 3D model taken by the 3D scanning process is a point cloud that should be elaborated, and different sequences for obtaining a vector model of the surface of the last bottom surface must be taken.

First, a CAD model is created and imported to the graphical software, and its orientation must be relative to the coordinate system by considering the height of the heel elevation.

After that, the process of heel designing includes defining the contour of the feather edge that will be used to design a grid of transverse curves to model the shape of the bottom surface.

In Fig. 4 the nodal points that are formed at the intersection nodes of the feather edge contour and transverse curves are visible. These nodal points need to be corrected. At this step, checking the resulting contours and bringing the transverse contours to a single number of points and a single direction needs to be performed.

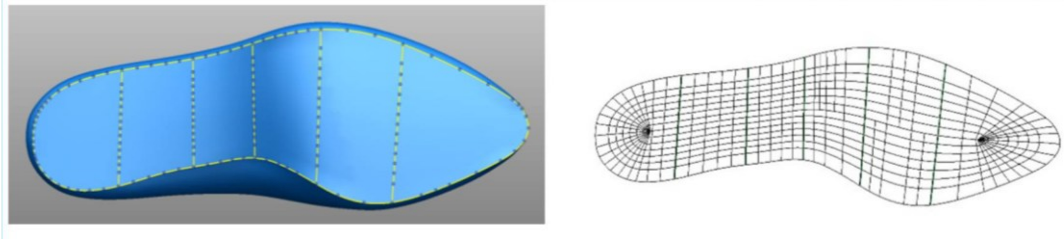
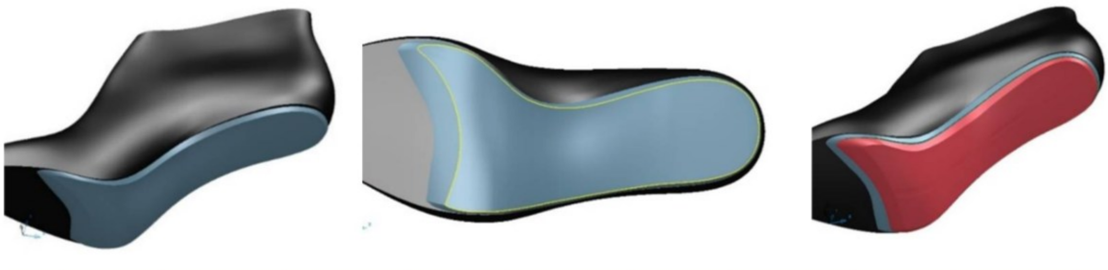


Fig. 4   Designing the surface of the last bottom based on a grid of 3D contours with PowerShape 2016 by Autodesk.

The shape of the bottom of high-heeled shoes includes a shank with a stiffening rib and a block of half-insoles that provide the necessary strength to the arch structure. Such block insoles can be manufactured by 3D printing in small-scale production and a personalized approach. Their design is carried out based on the surface of the bottom of the insole block.

Figure 5 depicts these steps followed to model the first and the second half-insoles starting from the surface of the bottom last. So, this process of designing the main parts of the shoe bottom occurs in the following sequence:

1) Modeling the base of the first half-insole (thickness 3 mm). Creating an edge cut at an angle depending on the curvature of the side surface of the last.
2) Design of the bottom contour of the half-insole obtained after constructing the side section.
3) Repeating operations for the second half insole.



1 2 3

Fig. 5   Steps followed to model the first and the second half-insoles starting from the surface of the bottom last.

Following the heel design, its top surface is based on the surface of the bottom of the second half-insole. Construction of the axis of symmetry of the heel based on the inside contours will be used further to design the basic vertical of the heel. This is presented in Fig. 6 with the purple triangle. This vertical surface is the basis for constructing the 3D shape of the heel.

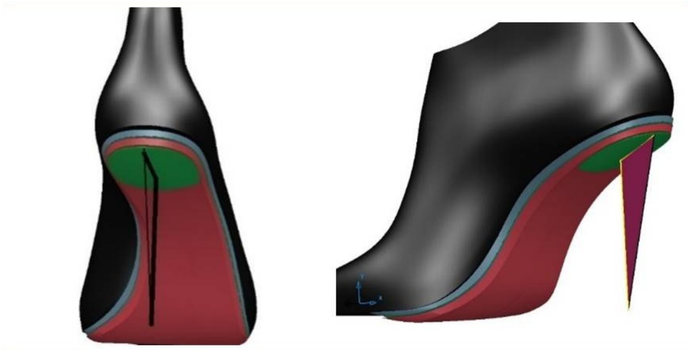


Fig. 6   Vertical surface used for modeling 3D shape of the heel.

Based on this vertical surface, the process continues with modeling the shape. During this step, it must be considered even the upper surface of the heel. Figure 7 presents the heel modeled accordingly.

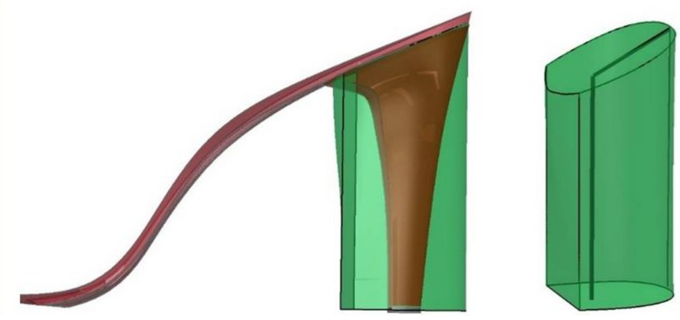


Fig. 7 The heel modeled based on the vertical surface.

4.2 Modeling more complex heel shapes

Creating more complex heel shapes requires the use of surface modeling features. Thus, in this work, an attempt was made to develop a complex fantasy heel shape using such functions as Extrusion Surface, Surface from Network, Bead Surface, Blend Surface, Fillet Surface, etc. All these functions are part of PowerShape 2016 by Autodesk. The following picture depicts the new heel modeled as a fantasy heel shape based on these functions.

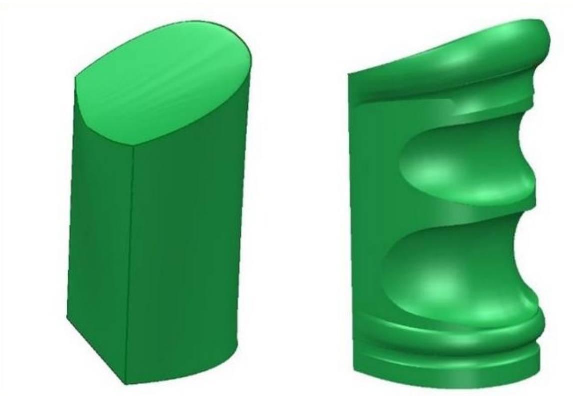


Fig. 8 Heel modeled as a fantasy heel shape with PowerShape 2016 by Autodesk.

In recent years, we have often seen unusual fantasy heel shapes on fashion catwalks, which have expressive plasticity based on complex 3D shapes. 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's last.

The software used in this work for 3D modeling of heel models are both from Autodesk company, well known for developing software for modeling different products. Depending on the purpose or specific needs of the users, choosing software for 3D modeling is not a difficult task. Tinkercad is a user-friendly design software with 3D models of different products or shapes that can be easily modified to create or adapt to new models. Meanwhile, PowerShape is a powerful CAD modeling program for advanced users. It facilitates the preparation of complex models for different products. It is based on surfaces, solids, and meshes that are highly required to model complex parts and prepare them for various types of manufacturing.

5 Conclusion

The role of Industry 4.0 in the fashion industry is evident in production, merchandising, retailing, and customers. The work presented here brings again case studies from the fashion industry. The implementation of advanced technology as one of the pillars of Industry 4.0 shows again the short time to realize fashion products, from concept to 3D model, by taking inspiration from various sources. Reducing time and waste, as well as the possibilities of creating, visualizing, and evaluating products at the early stages of product creation, are some of the advantages of these technologies as part of Industry 4.0 in the fashion industry. In this work, 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.

In this work, the use of digital tools for footwear products is presented as a methodology to design high heels. The first case encompassed the use of the base of the standard heel to create new heel models, and in the second case, the heel design was based on the surface of the bottom part of the second half-insole. The digital tools part of 3D modeling software presented an easy and efficient way to create these new models. Direct digital manufacturing, like additive manufacturing, presents advantages such as reducing dependence on external manufacturing companies, offering product customization, or waste reduction. This highlights the important role of technology as a key driver of the footwear industry. As the new heel models have limitations in terms of height, geometry, and material used for production, the work will continue with testing them by simulation according to the pressure maps of individual customers and materials to be used for their production.

Author Contributions

Author contributions statement: T. Spahiu, Y. Kyosev and L. Chertenko: conceptualization, methodology, software, validation, writing – original draft preparation; T. Spahiu and Y. Kyosev: investigation, writing – review & editing; L. Chertenko: software, visualization; H. Almeida and E. Shehi: writing – review & editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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