# PROSPECT USE OF ADDITIVE MANUFACTURING FOR ORTHOPEDIC FOOTWEAR

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## ABSTRACT

Orthopedic footwear products show a high interest for people with various foot health problems. Their use offers support and stability for consumers' feet. The traditional way of producing orthopedic footwear products lack of accuracy buy not support various health problems of consumers feet. Advanced technologies, which are widely used in various industries, present an efficient method to produce customized orthopedic footwear. Starting from 3D foot scanning in various postures improves the fit and accuracy of these products. The digital information of the feet can also be used to analyze various foot problems and improve personalized footwear products. Their production through additive technologies as 3D printing presents a faster and more accurate way. Freedom to use various materials and 3D printing parameters helps to achieve the required physical and mechanical properties for orthopedic footwear products. Moreover, it supports the sustainable way of production through waste reduction. These case studies are shortly presented to give an overview of the disadvantages of traditional production and the advantages of the use of 3D technologies.
**Key words**: orthopedic footwear, additive technologies, customization, shoe lasts.

## INTRODUCTION

Orthopedic footwear is a product used to improve walking performance and foot stability. It belongs to the rehabilitation aids group and is included in the prosthetic and orthopedic products category.
Orthopedic shoes, even those named special shoes, are made individually for the patient and intended to prevent or correct foot or leg deformities during complex treatment. Anatomically, they ensure the correct position of the foot. Orthopedic shoes have a therapeutic or preventive effect on the human body during the entire period of wearing them, and therefore, the correctness of the shape and design of such shoes is extremely important (Werner M., & Wellmitz, G., 2001).
These special shoes have a wide target segment including children with congenital defects of the feet, children with impaired development or functioning of the feet, pregnant women, adults and children with injuries of the lower limbs, people with plegia of the lower limbs of various origins, people with diabetes, people with pathologies of the foot structure, patients after surgical interventions, patients with partial foot amputations, etc. Each case of developing orthopedic shoes is individual and requires considering all the factors that can affect the motor function of the foot.

In the practice of orthopedic production in Western European countries, orthopedic footwear is a separate important sector of footwear production, which has traditions, methods, and technologies that allow the production of decent, comfortable, high-quality, and aesthetic footwear (Seidich H., & Seidich, D., 2024).
Today, the situation in Ukraine presents new challenges to producers and scientists in various spheres of the national economy. With the beginning of a full-scale war, the need for prostheses increased dramatically due to the large number of amputations, especially of the lower limbs of the Ukrainian military. Moreover, a big part of the population suffers from orthopedic foot problems of various origins (flat feet, valgus deformity, heel spurs, hallux valgus, and others). Previously, the vast majority

of patients were elderly. However, since the beginning of the war in Ukraine, the number of people with gunshot wounds of various types has increased significantly.
The manufacture of orthopedic insoles requires the use of a special technique for manufacturing the spatial shape of the orthosis based on the shape of the patient's foot, taking into account the peculiarities of foot biomechanics, recommendations of the orthopedic surgeon, and the peculiarities of the clinical and physiological condition of the foot (Forward Motion Medical, 2023). Such insoles are complex shapes made of materials with different physical and mechanical properties, connected into a single unit. The traditional way of manufacturing insoles involves laying out materials on a prepared plaster model or pad, thermoforming and gluing them, followed by processing on a grinding machine. Figure 1 depicts the orthopedic shoes that can be produced based on the adapted standard shoe last with overlays in certain areas (left side) and based on foot plaster cast (right side).

*Figure 1: The traditional ways to create the personalized shoe last.*

More details about the main steps followed to produce an orthopedic insole are depicted in Figure 2. The traditional technique for producing such insoles includes the steps of molding parts from EVA, gluing parts of different hardness, milling, and finishing the complex shape.

*Figure 2: Main steps to produce an orthopedic insole.*

However, the traditional method, which is still used nowadays, has some disadvantages, due to the low accuracy compared with the advanced technologies used nowadays as digital technologies. Data accuracy is one of the main requirements to be fulfilled to assure stability and comfort. It is worth mentioning here the number of different issues and difficulties encountered during the process of orthopedic shoe production as follows:

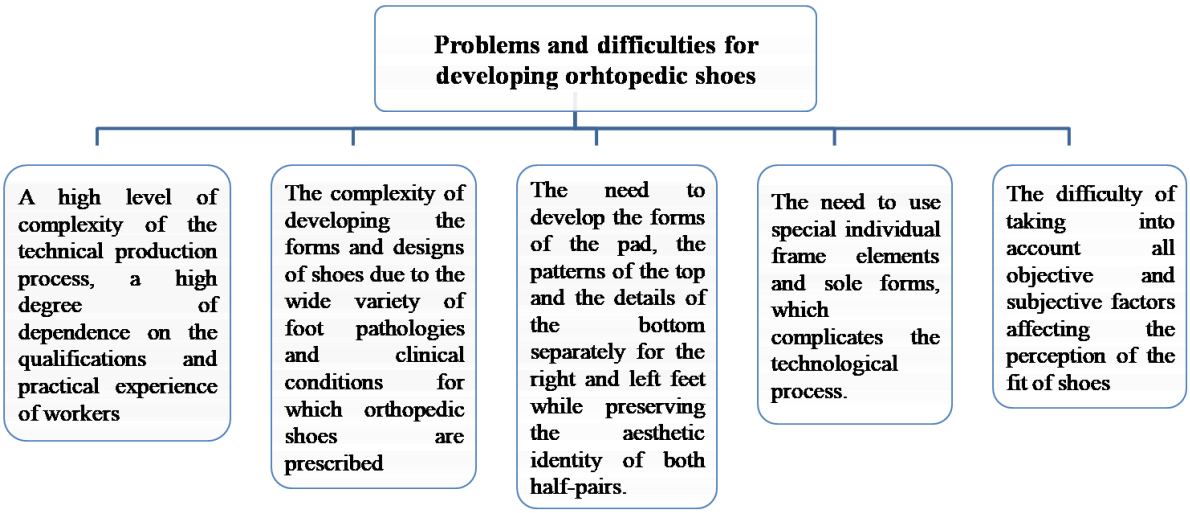


*Figure 3: Key issue in producing orthopedic footwear.*

## 3D TECHNOLOGIES AS NEW SOLOTIONS FOR ORTHODPEDIC FOOTWEAR

The implementation of digital technologies in various industries has improved product manufacturing. Digital technologies not only increase the accuracy of design processes but also reduce time and avoid complex technological operations performed manually.

Unequivocal advantages can be seen in the use of 3D technologies for the development of inclusive products, orthopedic shoes, orthoses, and special products for people with disabilities; as such products require an exclusively individual approach and high accuracy of product parameters.

In a study done (Walker K.., et al.,2023) based on information about the foot's shape and relief, 4 pairs of individual orthopedic insoles were manufactured: a pair of supportive and regular insoles made traditionally, and a pair of supportive and regular insoles made using 3D printing. Participants assessed forefoot and heel cushioning, arch support, overall insole condition, and overall shoe fit (size, width, etc.). The comparison of the results demonstrates the possibility of using 3D printing for the production of supporting and unloadin insoles because the participants of the experiment did not find a significant difference in the assessment of comfort. There are preliminary studies indicating that orthopedic insoles manufactured using additive production are effective in reducing pain sensations in the heel area (Xu R., & Wang Z., 2019 - Grat A., et al., 2018), and in altering the biomechanics of the lower limb (Mo S., et al., 2019). At the current level of development of additive technologies and 3D printing materials, helps to achieve the needed physical and mechanical properties of footwear parts (Iacob M.C., et al., 2023).

The bottom of the shoe, consisting of the sole, orthopedic insole, and frame elements that fix the heel and heel part of the shoe, ensures the correct installation and biomechanics of the foot. The upper part of the shoe should wrap around the shape of the foot, without creating discomfort.

One of the main elements that ensure the correct shape of shoes is an orthopedic last. That can be modeled based on the 3D foot model generated by 3D scanning, or a plaster cast by the method of reverse engineering. 3D foot scanning is an important method to take the digital information of the feet that can be later used to analyze foot shape and its dimensions. The accuracy of digital data and their use at every moment without the need of the subject offer practical use of these data for shoe last or footwear personalization. Moreover, digital data on the feet can be used for analyzing the clinical condition of the feet of individual consumers or population groups (Kaptiurova D., et al., 2024 - Chertenko L., et al., 2023). Following are some of the 3D foot scanning uses:

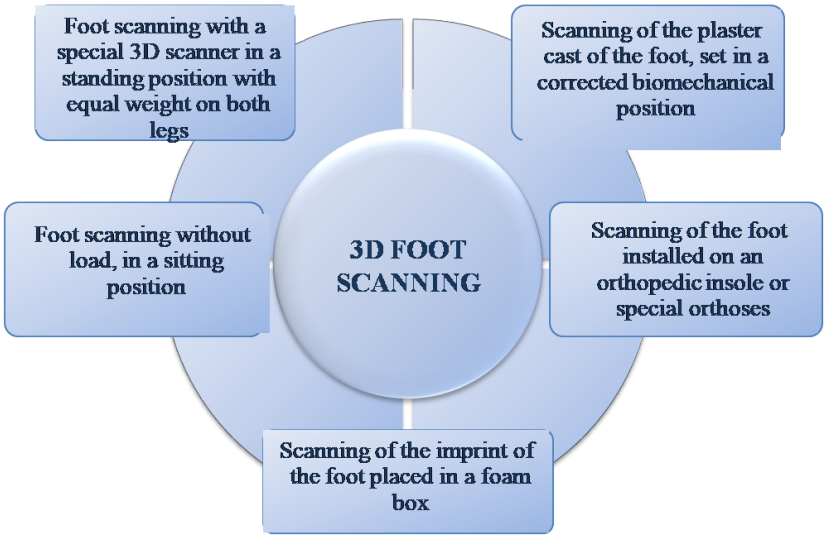


*Figure 4: Uses of 3D foot scanning for various purposes.*

The resulting file can be loaded into the environment of 3D CAD software for designing an individual shoe last. At the same time, in cases of simple deformations of the foot, we can modify the standard shoe last by adapting it to the parameters of the patient's foot according to the following parameters (Fig. 5).

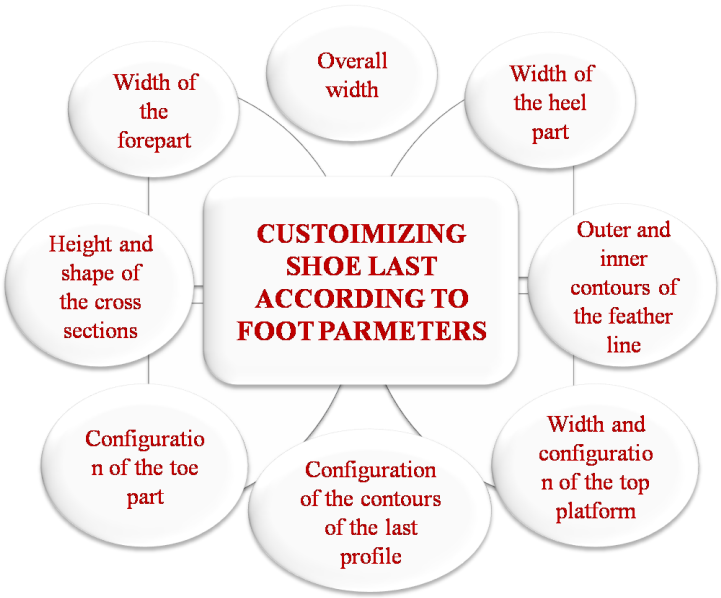


*Figure 5: the main operations of the shoe last modeling in the 3dCAD using reverse engineering.*

The bottom of the shoe, consisting of a sole and an orthopedic insole, performs a corrective or supporting function. For this, the shape of the bottom of the shoe can have one or more of the following shape elements, depending on the necessary adjustments (Fig. 6).

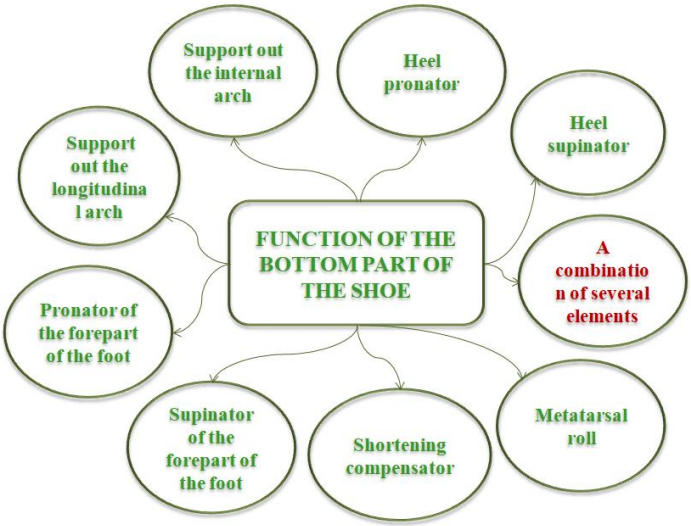


*Figure 6: Functions of different types bottom part of the orthopedic footwear.*

The basis is a digital model of a standard orthopedic insole with all standard elements. A scanned image of the baropodometry, and a 3D scan of the foot are imported into the modeling environment. Next, all these elements are combined, and aligned according to the dimensional zones. After importing a 3D scan of the plantar surface of the foot into the workspace we edit the shape of the orthotic insole according to the foot's bottom shape.
The inner filling of the insole must be different in separate areas depending on needed requirements. The unloading insert elements are modeled in the insole body in the areas of high pressure (in the heel area and ball area) and have distinctive filling parameters.
After modeling the shape of the shoe last and orthopedic insole, the designed shapes are saved in STL format and further processed in slicer software for preparation for 3D printing. The general algorithm of the improved process of developing and manufacturing orthopedic shoes looks like this:

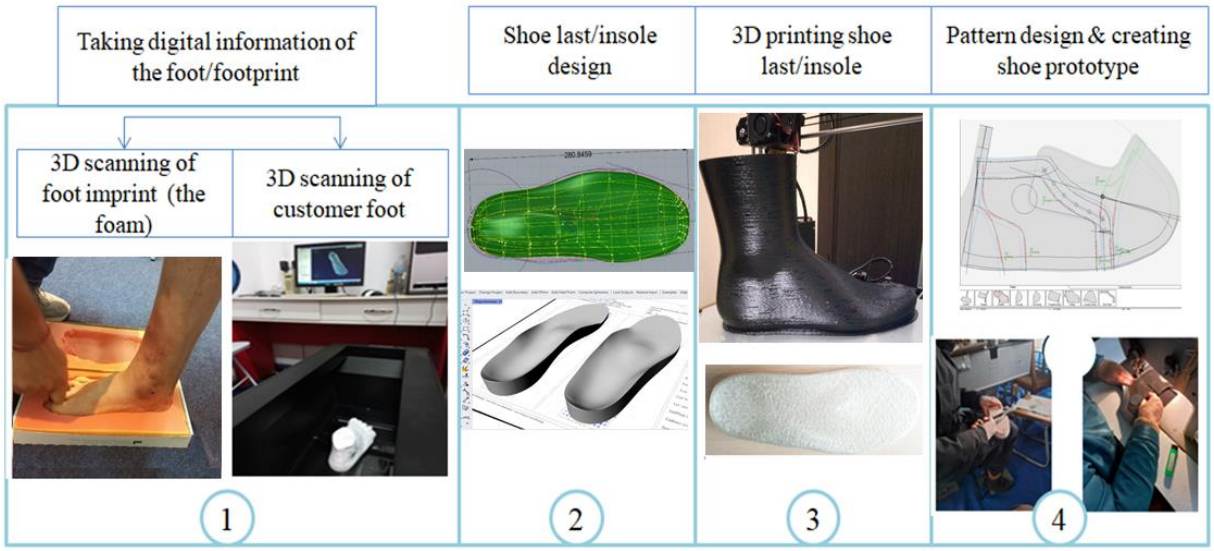


*Figure 8: The main stages of process of creating the personal orthopedic footwear.*

## CONCLUSIONS

An effective solution to the production of orthopedic shoes can be found in the wide application of advanced digital technologies. The possibility of developing products in online

mode presents a great advantage. Advanced technologies, such as 3D foot scanning are important methods for creating virtual copies of consumers' feet used for shoe modeling. Moreover, the digital information of the foot can be used to study the clinical condition of the feet of various consumers or population groups. Additive technologies, such as 3D printing help to produce personalized footwear parts as shoe lasts, insoles, and orthoses, which are modeled based on individual feet models. The freedom of using different materials and 3D printing parameters depicts an efficient way to achieve the required physical and mechanical properties of footwear parts, highly required for the production of prosthetic and orthopedic products.

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