Concept of parametric design and fast 3D printing of individual shoes

Valentina Vladimirovna Kostyleva[1], Olga Borisovna Konovalova[2]

Art Modeling Design and Technology of Leather Products department, Russian State University named after A.N. Kosygin, Moscow[1,2]
kostyleva.vv@mail.ru, o.b.konovalova@gmail.com

Abstract. *A personalized approach to printing individual shoes is possible due to the availability of laser scanning of the feet and professional interpretation of the results. Based on preliminary diagnostics of the condition of the musculoskeletal system in areas of high pressure in the feet, it is possible to identify problems associated with pain in the joints of the lower extremities and lumbosacral, abnormalities and asymmetries of their structure. It is also possible to timely relieve ankle, knee, femoral joints, lumbosacral spine, correct posture and gait, reduce joint pain, prevent surgery on joints of the lower extremities and lumbosacral spine, monitor the dynamics of changes in the rehabilitation period.*

The task of effective prevention and early diagnosis of problems of the musculoskeletal system can be solved with the targeted popularization of individual shoes and orthopedic insoles among the population, as well as its accessibility thanks to additive technologies, databases of parametric digital models, an established production and technological cycle and a flexible client-oriented service , including protocols for remote and virtual interaction between production and the end user.

However, shoes printed on a 3-D printer, so far, are not attractive to consumers or manufacturers. Mass production of shoes is still much faster and cheaper, although initially it was assumed that the introduction of additive technologies will significantly reduce the cost and time costs, but so far this has not happened for several reasons. In our country, there is a shortage of specialists in digital technologies, 3D-modeling and printing. In addition, as elsewhere in the world, equipment for fast 3D printing has a very high cost and only giants such as Adidas or Nike can create real production of printed products. However, it is a matter of time. The area of additive technologies is attracting more and more medium and small firms, individual designers, because 3D printing allows you to achieve unexpected and revolutionary results, as well as provide customized solutions at an affordable price.

KEYWORDS*: DIGITAL TECHNOLOGIES, PARAMETRIC DESIGN, 3D-PRINTING, INDIVIDUAL SHOES.*

1. Introduction

1.1. An increase in the number of people with pathologies of the musculoskeletal system.

A more in-depth and personalized approach to printing individual shoes is possible due to the availability of laser scanning of the feet and professional interpretation of the results. Based on preliminary diagnostics of the condition of the musculoskeletal system in areas of high pressure in the feet, it is possible to identify problems associated with pain in the joints of the lower extremities and lumbosacral, abnormalities and asymmetries of their structure. It is also possible to timely unload the joints of the lower extremities and the lumbosacral spine, reduce pain in these areas, prevent operations on the joints of the lower extremities and the lumbosacral region of the spine, identify the dynamics of changes in the rehabilitation period, and adjust posture and gait [1].

1.2. The high cost of printed shoes due to monopolies in this market segment.

Shoes printed or connected on a 3D printer in our country are gaining popularity rather slowly and in a limited segment - for sports (Nike, Adidas, New balance, etc.). Initially, it was assumed that additive technologies would make the cost of such shoes low and affordability high. However, this has not yet happened (the cost of a pair of 3D sneakers of the above brands can reach from 300 - 600 dollars in retail). As a result, a third problem arises.

1.3. The growing inaccessibility of high-quality individual and orthopedic shoes.

According to Rosstat's research on the living conditions of Russians dated April 5, 2019, more than 35% of Russian families cannot afford to buy one pair of shoes for each season. It is only about everyday shoes, excluding categories of the population with orthopedic problems.

2. Background and means to solve the problem

2.1. The situation in the segment.

Despite the fact that such giants of the shoe industry as Adidas, Nick, Under armor, New balance, Reebok have long and successfully used technology for fast and economical 3D printing to produce individual parts of the upper and lower shoes. For example, layer-by-layer photopolymerization of resins in a bath (or stereolithography) - SLA, DLS, etc. However, mass production of shoes is still much faster and cheaper.

This situation occurs for several reasons:

• In our country, there is a shortage of specialists in digital technologies, 3D-modeling and printing.

• We, as well as around the world, have equipment for fast 3D printing at a very high cost, and only giant companies such as, for example, the American concern Carbon can create real mass production of printed products.

However, it is a matter of time. The area of additive technologies is attracting more and more medium and small companies, individual designers, because 3D printing allows you to achieve unexpected and revolutionary results, as well as provide customized solutions at an affordable price.

In addition, engineering thinking is evolving, leading to the introduction of new design methods, such as parametric design.

2.2. Fashion tech.

The beginning of the XXI century is characterized by a large number of scientific studies and discoveries. The technological breakthrough did not pass by the world of fashion. The development of the Fashion Tech trend in the variety of its manifestations is associated with the enormous opportunities that modern digital technologies provide the industry with. The origins of these phenomena are the 20th century, which has overturned the generally accepted notions of life on our planet, its forms and development. Such theories, for example, as chaos theory, complexity theory, quantum field theory, etc., have formed a new synergistic picture of the world. Researchers have identified such qualitative changes in the paradigm of public consciousness as the transition: from a picture of the sustainable development of society to a vision of its metastability; from order to chaos; from evolution to co-evolution of complex systems; from independence to dependence; from dimensionality to proportionality or fractal replication by the world of itself. Parametric design, which came into practical use at the beginning of the XXI century, basically reflects the entire spectrum of emerging ideas about the world as a complex system of interdependent elements, changes in one of the parameters of which leads to a change in the whole system, as well as the basic algorithms that lie in basis of this system.

2.3. Parametric design.

In the process of designing a new product, or customizing an existing one, many tasks arise for combining data of different generation and characteristics that are dependent and independent from each other. Thus, the process of designing a complex product can be delayed, and making changes to an existing project can give rise to a series of self-replicating errors, significantly complicating

the process of further work. Especially, in a situation with a predominance of "manual" operations in the project.

The undoubted advantage of automation of technological processes is a significant reduction in time spent on product development. However, specialized CAD systems require the involvement of experienced technical professionals, who, unfortunately, are not enough to meet the needs of the industry. Thus, specialized CAD systems are ineffective or inaccessible to small enterprises or private practitioners. At the same time, the active expansion of additive technologies in all branches of industry allows us to implement the most ambitious ideas in the material, which, of course, attracts the attention of specialists from various fields (designers, marketers, etc.).

Against this background, parametric design seems to be attractive, allowing you to create algorithms for objects or processes of any complexity based on the analysis of data arrays, as well as their interaction in real time, which serves as a universal mechanism for creating both individual objects and entire systems. The scalability of projects is the most important property of this approach, which enables the specialist to manage the complexity of the project, to build any hierarchical structure [2, 4-7].

One of the most important properties of the parametric approach is its adaptability to environmental factors. Using the method allows you to create objects consisting of groups of autonomous elements. Some of these groups respond to the influence of external factors by changing the properties of the groups associated with them and, as a consequence, the system as a whole. For example, in response to a change in pressure force, the texture density and surface pattern of the material change.

2.4. "Rhinoceros & Grasshopper."

Universal parametric design tools such as Rhinoceros and Grasshopper allow a creative specialist to realize ideas that are difficult to understand, easily translating them into an algorithm language and expressing them in a visual modeling environment. It is the creator of the concept that can choose from a variety of design parameters that are most important for the full implementation of his plan. Also, any number of changes are made quickly and clearly, without requiring the replication of repeated operating cycles.

For example, the motive of the collection is a cellular fractal structure, in which each element, having its own set of parameters, is part of another cellular fractal structure, being one of the parameters for its element. Generally speaking, this is a kind of grid located inside another grid that is inside the third grid, etc. And, thanks to additive technologies, such as 3D printing on fabric, collections of this kind, including scalable parametric motifs, are now not uncommon (Atlantis Plato, Alexander McQueen).

The synergy of the designer's creative intent and capabilities of digital design technologies allows us to take a fresh look at the growing role of form and its embodiment in the modern fashion industry. The development of the natural sciences shows us the evolution of complex objects of animate and inanimate nature, as, kind of, derived from the processes of fusion, division and transformation, fueling the interest of scientists and designers in biomorphic and topomorphic objects. Complex objects of living nature undergo significant transformations under the influence of many laws throughout the life cycle, providing a vivid example of the parametric principles of shaping in the environment.

2.5. "Wearable technologies".

Such project logic implies reaching a fundamentally different level of creating clothes and shoes - the level of formation of the vital membranes of the human body, its "small infrastructure". According to some scientists, in the near future it will be possible to design complex objects and systems in those areas of life where shells created or built according to the principles of molecular synthesis will arise directly at the object of application of their functions, and shape and design correction will occur by changing the software code. Outdated or faulty elements of such an infrastructure will be able to be updated or self-repaired according to the same algorithmic principles. Futurologists believe that clothing and the environment, united by a unity of functions, will have their own ecosystem, harmoniously integrated into the surrounding nature.

"Wearable technologies" - clothing (from underwear to shoes and accessories), is directly related to such a thing as metamaterials, which can change their properties by changing the spatial structure. Thanks to them, dimensionless textiles became a reality. So, the Royal College of Arts recently introduced the development of children's dimensionless clothing. Increasingly, they are announcing products based on nanotissues that respond to light, ambient temperature, human condition, and the nature of their activities. Spray clothing technology has already been developed by Imperial College London. Due to the availability and versatility of properties, the material is predicted a great future in various fields of application, from fashion to medicine.

Modern materials containing natural fibers, such as silk, as well as nanoparticles of an electrical conductor, flexible sensors, etc., make smart fabrics a reality. Sports and physical activity are not always equivalent to "health" and "safety". Therefore, intelligent sportswear for diagnosis and prevention is included in everyday life. However, the inclusion of technological components in clothing requires a change in the thinking of both manufacturers and consumers. Therefore, for integration into our everyday life, "smart clothes" is becoming more and more like everyday clothes.

The increase in the density and concentration of the urban environment, the acceleration of social processes, the need to provide protection and comfort at various standards of consumption, forces engineers and designers to use new adaptive parametric technologies and materials.

3. The solution to the problem

We see that the problems of increasing the availability of individual shoes, as well as effective prevention and early diagnosis of disorders of the musculoskeletal system, can be solved by:

• targeted popularization among the population of individual printed shoes and orthopedic insoles,

• the advent of inexpensive domestic equipment for 3d printing,

• established production and technological cycle;

• flexible client-oriented service, including protocols for remote and virtual interaction between production and the end user.

3.1. Hypothesis - the production of affordable individual shoes printed on a 3D printer is possible due to the availability of available equipment, supplies and software, as well as:

• a well-developed base of parametric models;

• algorithmic design in real time for customization of models from this base;

• mobile client service and VR / AR technologies (mobile offices, virtual fitting and mobile application).

3.2. Goal

The purpose of the work is to increase the efficiency of technological processes in the domestic shoe industry and the quality of manufactured products.

3.3. Tasks of work:

• create an algorithm for converting graphic data of foot pressure force to the surface obtained as a result of scanning into a digital model of upper and lower parts of shoes made of 3D-printed material with a reconfigurable relief structure, the density and height of which depend on the pressure force;

• analyze the properties and behavior of the digital model of the upper and lower parts of the shoe;

• create prototypes and samples of a digital model;

• analyze the change in their elastic properties depending on the materials used;

• implement the results in the form of a working module of the technological complex of parametric design and quick 3d printing of individual shoes in the format of a mobile salon.

4. What is planned to be achieved:

1. Create an effective algorithm for converting the data of scanning the pressure force of the foot onto the supporting surface, into a digital model of the upper and lower parts of the shoe with a reconfigurable relief structure for quick printing of individual shoes in the format of mobile salons;

2. Create a database of digital models of upper and lower shoe parts;

3. Create a work module for the technological complex of parametric design and fast 3d printing of individual shoes in the format of a mobile salon.

5. Methods and tools for implementation:

Methods of data collection and analysis:

- This work analyzes sources on the topic, the results of laser foot scans, conducts experimental studies to create digital models of materials with a reconfigurable structure and simulate their behavior, as well as studies of real materials (sheets and filaments).
- Prototypes are created, and their elastic behavior is analyzed taking into account the properties of real materials and boundary conditions.

Tools and equipment:

- BY,
- 3d printers,
- results of 3D scans,
- sheet materials,
- filaments.

6. Proposed solutions.

6.1. The optimal network structure of the 3D shoe printing mobile showrooms, in our opinion, should include:

1. One head office, in which there is one designer, one technologist, one orthopedist, as well as a base of models, blocks, soles, materials.

2. N-number of mobile salons equipped with all necessary equipment, in which there is one operator who controls a 3D scanner, a 3D printer, communicates with customers, courier service and head office, receives and issues orders.

3. Logistics department-warehouse, connecting the network with the supply center, delivering orders to customers involved in transportation.

4. The client communicates with the designer and orthopedist remotely. Mobility allows you not to get attached to the location and move the salon to the points of maximum concentration of the target audience (various social centers, events, etc.)

6.2. The basic technological cycle will consist of the following steps:

1. The only appeal: the client comes to the mobile salon, where he selects a model from the catalog or develops an individual one together with a specialist who conducts a topological analysis of the distribution of foot pressure on the supporting surface and interprets the results of the study. The client receives a digital scan model of their feet on digital media; if necessary, additionally consults with the designer and orthopedist.

2. After receiving the order, the specialist conducts a more detailed

morpho-functional analysis of scan results.

3. Next, the selection of materials for printing is carried out depending on the configuration of the three-dimensional structure and the number of its layers, the pressure value.

4. The algorithm of the interdependence between the pressure zones and the density of the relief pattern is established.

5. Relief modeling is carried out, the vector model is converted to a solid model to be sent to the preparation program for 3d printing.

6. A new design for the details of future shoes is being created. If necessary, customization of the finished design solution from the catalog is performed.

7. Directly in the salon or in the central office (depending on the complexity of the project), 3D printing of the upper and lower parts of the shoes is performed, their connection.

All clarifications with the client are carried out remotely through instant messengers or the company's information portal in 24/7 mode. It is also possible to develop a virtual application for trying on a product before delivery or during production / alteration.

Shoes are delivered to the client by courier or mail, (pickup possible).

6.3. Expansion Technology Cycle:

1. Products can be equipped with additional tools, for example, nanospray-preventive disposable socks, for gentle and comfortable use of shoes and protect the foot from scuffs and calluses.

2. Depending on the polymers used, micro-offices may provide services for collecting used 3D shoes for further processing.

3. As a marketing move, as well as a scaling element, you can offer customers a kind of “designer” of individual elements (soles, upper parts, individual pads, 3D models of feet), 3D handles and the corresponding polymers for independent amateur customization of individual shoes at home.

4. In addition, it is possible to integrate systems of elastic sensors into shoes for timely diagnosis and prevention of diseases according to the position of the body in space and the difference in pressure of the foot sections to the surface. And with the help of its own mobile application, “smart shoes” will instantly inform its owner about an error in the distribution of load on the joints during training or in ordinary life.

7. The expected result and directions of its practical use.

It is planned to create an effective algorithm for converting graphic data of the pressure force of the foot to the surface, obtained as a result of scanning, into a digital model of the upper and lower parts of shoes with a reconfigurable relief structure, the density and height of which depend on the pressure force, in order to quickly print individual shoes in the format of mobile salons .

The final product, in essence, is a complex consisting of prompt customer service, affordable technology, environmentally friendly materials and high-quality individual shoes for all categories of the population at an affordable price.

8. A wide target audience.

Accessibility, efficiency, the possibility of cheapening by ordering standard models from the catalog, unlimited possibilities of customization, as well as providing quality service to customers with special needs and orthopedic problems make the product suitable for all categories of the population.

9. A scalable commercialization plan.

• The modular structure with reduced labor costs enables both remote service and business scaling to the regions, regardless of their economic and environmental conditions, as well as the sale of franchises.

• In addition, the development of hardware, software, mobile applications, integrable "smart" blocks, materials, both for business and for the end user, provides an opportunity to develop in these areas.

Separately, it is necessary to mention the target audience with special needs.

The estimated competitive advantages of the methodology for the target audience with problems of the musculoskeletal system:

• unloading of the ankle, knee and femoral joints, lumbosacral spine, and, as a result, reduction of pain in them;

• posture and gait correction;

• the ability to track the dynamics of changes;

• prevention of surgical interventions on the joints of the lower extremities and lumbosacral region [3].

10. Explanatory Note

11.1. Purpose and scope:

- for a wide consumer of affordable individual shoes;

- for the target audience with problems of the musculoskeletal system.

11.2. Specifications.

Algorithm for translating graphic data obtained by scanning the foot into digital models of the upper and lower parts of shoes with a reconfigurable relief structure, the density and number of layers of which depend on the foot pressure on the surface.

11.3. TEP.

Based on assessments of the results of the practical implementation of parametric design tools in related fields, we can assume a significant reduction in the following indicators:

- 12-15% reduction in the cost of paying for production downtime, as well as energy consumption by reducing downtime in the technological cycle, its acceleration and simplification;

- the residual carbon footprint from shoe production will be reduced by 30-35%;

- the development and customization of the product will be reduced by 50-60% due to the base of parametric digital models.

11. Conclusion

Currently, the work is at the stage of developing an algorithm for converting graphic data obtained as a result of scanning into digital models of upper and lower parts of shoes with a reconfigurable relief structure, the density and height of which depend on the force of the foot pressure on the surface. But it is already possible to draw a preliminary conclusion that the unification of this process, with the receipt of a library of such samples, will several times reduce the time spent on the development of prototypes and their customization.

Directions for further research:

• Parametric programming algorithms;

• Latest software and algorithmic design technologies;

• 3D printing technology;

• 3D scanning technology;

• Consumables, filaments.

12. *Literature*

1. Li and Tanaka. Feasibility study applying a parametric model as the design generator for 3D–printed orthosis for fracture immobilization. 3D Printing in Medicine (2018) №4.
2. Steven S. Skiena. The Algorithm Design Manual. Second Edition. Springer. 2008.
3. Bekk N. V., Kostyleva V. V., Lapina T. S. Customizing of the techniques used for designing of the orthopedic footwear. New Technologies, Development and Application II. Springer Nature Switzerland AG 2020 I. Karabegović (Ed.): NT 2019, LNNS 76, pp. 803–807.
4. Miura and Tachi. "Synthesis of Rigid-Foldable Cylindrical Polyhedral." (Symmetry: Art and Science, International Society for the Interdisciplinary Study of Symmetry, Gmuend),
5. Yasuda and Yang. "Reentrant Origami-Based Metamaterials with Negative Poisson's Ratio and Bistability." (Physical review letters 114:18 (2015), 185502),
6. Yasuda, Yein, Tachi, Miura, and Taya. "Folding behaviour of Tachi–Miura polyhedron bellows." (In Proc. R. Soc. A, 469, 469, p. 20130351. The Royal Society, 2013),
7. Yasuda, Chong, Charalampidis, Kevrekidis, and Yang "Formation of rarefaction waves in origami-based metamaterials." (Phys. Rev. E 93 (2016), 043004. doi:10.1103/PhysRevE.93.043004)