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MODERN METHODS FOR CREATING CUSTOM EYEGLASS FRAMES THROUGH ADDITIVE AND SUBTRACTIVE TECHNOLOGIES

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Abstract: *The paper presents two technological processes for obtaining personalized eyeglass frames through additive and subtractive technologies, highlighting the main advantages and disadvantages specific to each technology. The authors also present the CAD-CAM modeling of a personalized eyeglass frame and its execution both through additive technologies, the FDM process from PLA materials and numerically controlled CNC machines from wood, plastic and composite materials.*
Key words: *additive manufacturing; custom eyeglass frames additive technologies; custom glasses frames obtained through subtractive technologies; CAD-CAM*

1. INTRODUCTION

Even though people have become accustomed to them, and they are even used as an accessory, eyeglasses are medical devices used to correct visual acuity. Eyeglasses with optical role are used by people who have difficulty seeing at a distance and/or up close, or by those who see blurry.

The frame of the eyeglasses is what supports the lenses and consists of the frame itself, the arms, and the nose bridge. This entire assembly helps to effectively fix the lenses and stabilize the eyeglasses on the wearer's face.

There are several models of frames in function of geometry, material and style. Full-frame frames support any type of lens, while half-frames are lighter and rimless frames reduce the visual barrier effect. Plastic frames are lighter, while metal frames are very resistant [1, 2].

In addition to their role of correction and protection, eyeglasses are also an important accessory. When choosing them, style and personality must also be taken into account, as well as the fact that there are glasses with frames for men, with special frames for women, and glasses with unisex frames.

The size of the eyeglass frame must consider 2 parameters: the size of the lens and the overall size of the frame. If the width of the frame is too small and the arms are bent outward, this can cause anything from minor discomfort to injuries to the temples or ears [3]. The most used criterion for choosing eyeglasses is the physiognomy of the face (the face can be round, oval, elongated, triangular, square or even trapezoidal), but also hair color, frame material, design, and personal preferences in terms of frame color [4]. A pair of glasses must first and foremost fulfill their role, which consists of fixing the lenses at a distance of 12 mm to the eyeball, correspond to the optical axes of the client and the glasses, and not damage the field of vision. The purpose of the glasses must also be considered, whether they are for distance, for reading, for various physical work, for sports, or as sunglasses from an aesthetic point of view. The optician must be careful when choosing the shape of the frame so that it benefits the wearer.

The wooden frames are unique and ecological and with a natural look. Each pair has a distinct natural pattern due to the wood fibers used. Lightweight and durable, bamboo is often used for eco-friendly glasses. Frames made of maple, walnut or other hard woods offer a rustic and sophisticated look but can be more fragile compared to other materials. To prevent wooden eyeglass frames from cracking over time due to the change in temperature and humidity, the material of choice for wooden eyeglass frames is usually veneer. This material is no lower quality than one-piece wood. When making veneer frames, several layers of wood are laid on top of each other, in different directions of the rings and glued. Made in this way, wooden glasses are much more stable. The layers of wood are made of either local materials, such as walnut or rosewood. But woods from outside Europe, such as black ebony, which is considered to be particularly noble, are also used for dark wood sunglasses or prescription glasses. Handmade wooden frames are extremely comfortable to wear and need to be sanded laboriously until they have a perfect surface. A luxury choice, natural horn frames are rare and personalized. Each pair is unique due to the variability of the texture and color of the horn [1, 2, 5].

Considering the importance of customization and the use of ecological materials and increasing their possible applications in the field [6-9], the paper presents technological examples for the realization of personalized eyeglass frames by both additive technologies and subtractive CAD-CAM technologies.

2. TECHNOLOGIES AND MATERIALS FOR CUSTOMIZED EYEGLASSES FRAMES OBTAINING USING ADDITIVE AND SUBTRACTIVE APPROACHES

Additive manufacturing or 3D printing is one of the fastest-growing technologies, attracting significant attention from specialists in various industries due to its layer-by-layer creation of objects with less waste and the possibility of complex and personalized geometric shapes. From small, relatively simple customized structures and accessories to highly complex mechanical parts used in aerospace applications or prosthetics and implants in the medical field. With regard to conventional subtractive technologies, a deep understanding of the machine's operation, its mechanics, tools (cutter) and cutting modes (speed, feed, depth etc.) is required. Selecting the inadequate tool or cutting mode can quickly result in the failure of an expensive tool, damage of the workpiece or the necessary final technical requirements will not be ensured.

Additive manufactured personalized eyeglass frames is a promising approach that successfully combines personalization, innovation, and high technical performance. 3D printing brings multiple technical benefits in the production of glasses, compared to traditional methods. Unlike mass production, 3D printing allows designers to create unique, complex shapes and geometries that are impossible or very expensive to produce using traditional methods. Customers can choose not only the design, but also the color, texture, and even add personalized elements, making each frame unique. This level of customization ensures superior comfort compared to glasses manufactured by conventional methods, which are often less ergonomically precise.

The reduced weight is another major advantage of the new materials. Due to the low density, glasses manufactured by this additive technology are extremely lightweight, considerably reducing discomfort during long-term continuous use. This aspect is particularly appreciated in the sports field, where comfort and weight play a critical role. Another special technical aspect of glasses manufactured by 3D printing technologies is their very good dimensional stability. The materials used for 3D printing high-quality personalized eyeglass frames are designed to ensure durability and performance in a variety of environmental conditions (temperature, humidity, ultraviolet radiation). Thus, the glasses do not deform or deteriorate prematurely, having a significantly longer lifespan than conventional thermoplastic materials. They are also biocompatible materials that allow direct contact with the skin, respecting strict biocompatibility standards. These characteristics make it ideal for glasses, protective equipment used in the medical field or personal devices for daily use, minimizing the risk of allergic reactions or skin irritations. Glasses printed by additive technologies have many applications in various areas thanks to their excellent mechanical and operational properties. Some possible examples: industrial field – it can be created safety customised glasses that are perfectly tailored to each worker's facial features, increasing comfort and protection effectiveness; sport – the frames can be precisely adjusted to the athlete's face for maximum comfort and to prevent slipping while moving and athletes can enjoy unique and comfortable frames made of lightweight materials that combine functionality and individual style; fashion industry – creation of unique, personalized, and aesthetically sophisticated frames that meet the individual needs of customers; medicine – due to the possibility of the personalization and maximum compliance with the anatomical features of the patient's face and also for protective and specialized glasses for medical personnel.

Processing eyeglass frames using CNC machines allows for simultaneous automation of the process with high precision, making eyeglass frames with complex geometries and models, ensuring fast and repeatable production with the possibility of using a wide range of raw materials (for example wood of different types) and minimizing material waste through precise machining paths, CNC machining supporting sustainable production practices.

3. REALIZATION OF CUSTOM GLASSES FRAMES USING ADDITIVE MANUFACTURING PROCESS AND CNC MACHINING

The manufacturing process of personalized eyeglass frames through additive technologies as well as obtaining personalized eyeglass frames through CAD-CAM technologies takes place in four stages: design, programming, processing, control. Computer-aided design (CAD) is a software package that creates the graphic representation of the final eyeglass frame similar for both additive and subtractive technologies, in 3D.

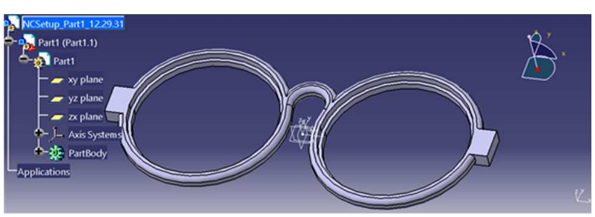

Fig. 1. CAD model of personalized eyeglasses

In the pre-printing stage, the CAD model generated in a specialized CAD system is introduced into a special slicing program that gives the code and the main printing parameters – Fig.2. The slicer program performs a key function in the 3D printing process and namely translates the digital 3D model into a set of specific instructions that the 3D printer can understand. The main function of this program is to virtually divide the model into a stack of flat two-dimensional layers according to the set thickness. The program also allows positioning and orienting the model in the virtual workspace (printer's work platform), generates the print nozzle movement trajectories, sets important working parameters and estimates the printing time. In the case of printing the structure for this paper, a layer thickness of 0.2 mm was used with a 0.4 mm extrusion nozzle. The QuickSlice option with the help of Ultimaker Cura software [10] realizes the paths for the extrusion nozzle in order to deposit the section of the part, fig. 2 [11, 12].

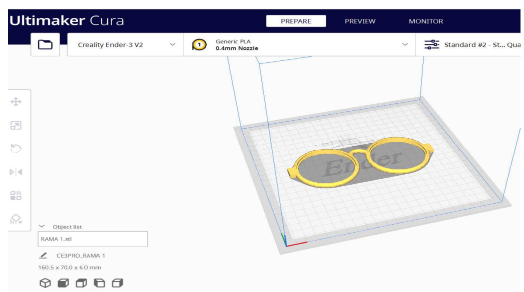

Fig. 2. Orienting the eyeglass frame on the 3D printer bed

During the realization of the part in the case of FDM technology, the extrusion device of the printer deposits a thin wire of material accordingly to the perimeter of the section. Practically, the extrusion head first outlines the boundaries of the current section. Next comes the laying of building material in areas corresponding to the full area (filling). After the outer contour is created, the printer fills the inside of the layer with either solid material (if 100% fill is set) or a specific pattern as configured in the slicing software. After this, the platform is lowered to the height of the section of the virtual model (one layer) and the processes are repeated until the entire 3D model is ready. Fig. 3 presents the 3D printing process of realizing personalized eyglass [11, 12]. The last stage refers to post-processing actions in which the part is separated from the platform, all sacrificial materials are removed and, if necessary, finishing processes are applied.

Fig. 3. Realizing personalized eyeglass frame through 3D printing

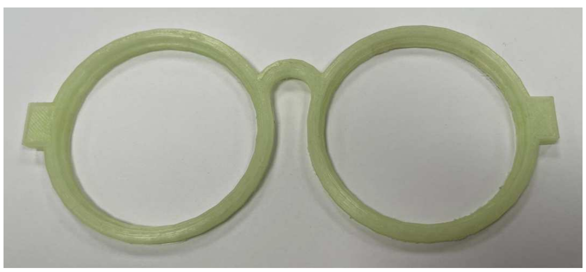

Fig. 4a. Personalized glasses frame made of PLA filament material

Computer-aided manufacturing or CAM (Computer-Aided Manufacturing) systems can be considered as a software bridge between the digital model of the product (CAD) and the physical production equipment (CNC machine). In other words, CAM uses numerical codes to quickly convert CAD-generated models into physical products. CAD/CAM software programs help us design and produce prototypes and finished products in a short time.

Below is a sequence of CAM operations to generate an NCCode program used by the 3-axis numerical control machining machine used for processing a custom wooden eyeglass frame [13, 14].

The desired machine tool is selected by pressing the corresponding icon, fig. 4, the characteristics of the machine tool will be presented, and the accompanying parameters can be selected depending on the type of machine tool used, for example: numerical control parameters, tool rotation parameters; parameters for tool change; tool corrections; feed rate.

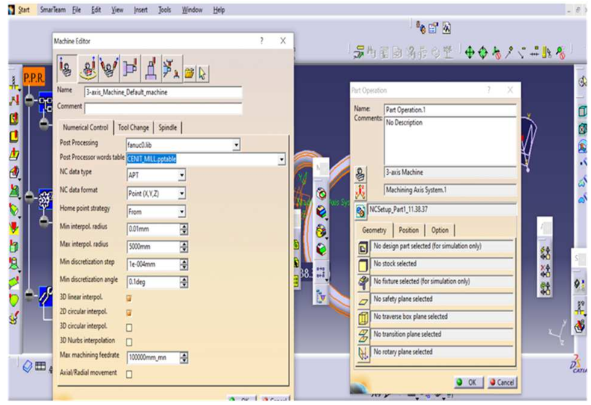

Fig. 4b. Definition of Machine Editor and Part Operation operations – the working parameters of the 3D processing system

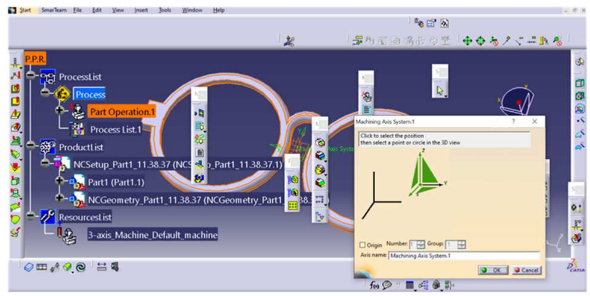

Fig. 5. Defining the orientation system

The red dot is pressed, a point that symbolizes the origin, the window disappears momentarily, and the user selects a corner of the blank. The selection window reappears, and the axis system is positioned on the model of the blank in a certain orientation. If the user wants to change the directions of the axes, he must select one of the axes on the symbol in the window, and it will disappear again allowing the choice of a new orientation. Finally, the axis system must have the vertical Z axis, with the + direction upwards and the X and Y axes in the plane of the upper side of the blank, fig. 5, the proper orientation of the system resulting to the change of the color of the components of its symbol (axes, planes, origin) to green.

For the processing of the personalized eyeglass frame, Zlevel processing was chosen depending on the type of technological operation, which is specific to the processing of vertical surfaces along the axis of the milling cutter to be processed to define a contour of the part and specify the number of processing paths, fig.6.

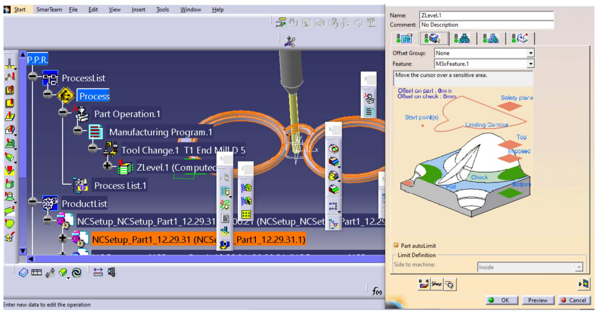

Fig. 6. Defining the ZLevel milling operation

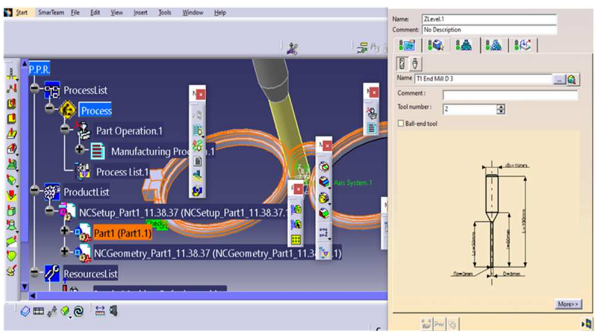

Fig. 7. Defining the geometric parameters of the cylindrical face milling cutter for machining

Visualization of the simulation of the machining operation, fig. 8, both the machining specification tree, the semi-finished product and the finished part, the milling cutter with the defined dimensional parameters, its path as well as the animation controls and visualization of the simulation are presented.

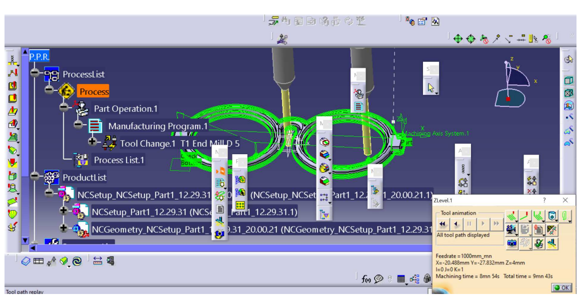

Fig. 8. Viewing work paths

In another display mode in which the tool trajectory is visible, fig. 9, the control window presents various information regarding the machining process, feed speed, the position of the tool at a certain time (X, Y and Z coordinates), the effective cutting time and the duration of the simulation.

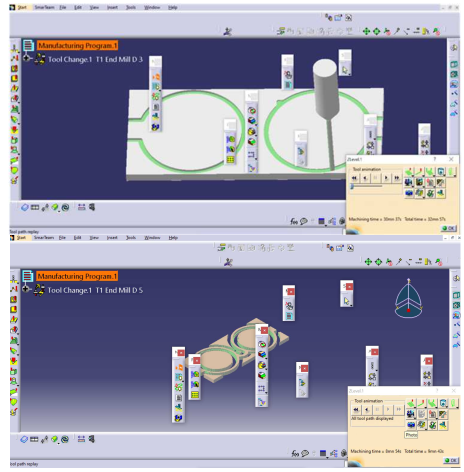

Fig. 9. Simulation of the processing of the customized eyeglass frame, outer contour

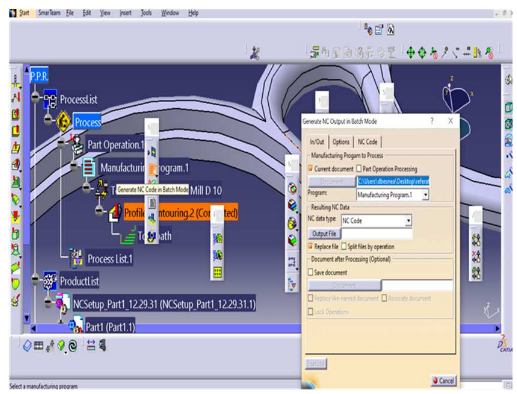

Fig. 10. Generating NC Code

Once the simulation is completed, the user must generate the numerical control program compatible with the machine – tool, fig. 10. The processor of the machine tool is chosen, in our case a 3-axis milling machine, equipped with FANUC equipment. An NC and APT code file is generated, the APT code being more explanatory but longer, while the NC code uses the specific meaning and syntax using the G, M, F, and S codes, (for example G0 – rapid movement at the chosen point; G1 linear interpolation; M5 – spindle stop, F – feed mm/min; S – spindle speed rpm). Fig.11 presents the results obtained regarding the personalized wooden eyeglass frame realized by CNC machining.

4. RESULTS AND DISCUSSIONS

If the two manufacturing methods for eyeglass frames are compared in terms of economic impact and sustainability, it can be said that the

3D printing method is a more sustainable and economically viable solution, especially if we consider the elements of customization and the reduction of material waste because it uses a layered additive approach. In addition, additive technology allows for the creation of complex structures, as well as rapid production and prototyping.

Fig. 11. Personalized wooden eyeglass frame obtained by CNC machining

At the same time, there are some disadvantages of 3D printing, including rougher surface finish and more limited material options. On the other hand, CNC machining offers better precision, a better surface finish and can work with a wider range of materials (for example, natural wood materials), but at the same time costs are higher (for small series) and produces significant material waste.

To compare the characteristics of the models, a total of 5 eyeglass frames were made, as follows: three on a 3-axis CNC equipment - realized of wood, Plexiglas and a composite material, and two on a Creality Ender 3D printer using FDM technology - PLA (Yellow Green) and PLA (Panchroma). Dimensional accuracy tests were performed on the deviation from the nominal thickness at 10 different points of the eyeglass frames in the arm fixing region by simultaneous determination on an experimental stand with an accuracy of 0.0005 mm – Fig.12. Also, for all types of frames, the diameters of the left-right lens slots were determined with a digital calliper – 0.01 mm.

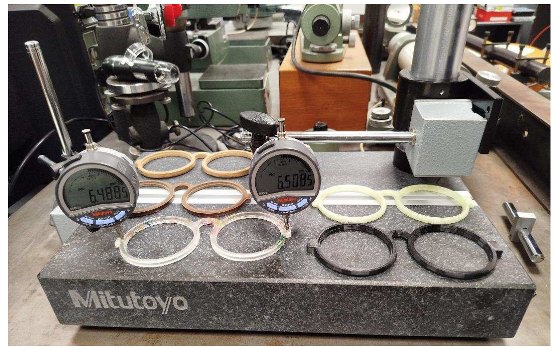

Fig. 12. Determining the dimensional deviations of the frames obtained

Table 1. Results obtained regarding thickness deviations of the realized eyeglass frames

Material	**h_l [mm]**	**h_r [mm]**
Wooden CNC – 7.5 mm	7.6972±0.05293 ε_{rl}= 2.629%	7.5465±0.03873 ε_{rr}= 0.620%
Plexiglas CNC – 6.5 mm	6.4706±0.02485 ε_{rl}= 0.452%	6.5034±0.03364 ε_{rr}= 0.052%
Composite CNC – 6 mm	6.1879±0.00509 ε_{rl}= 3.132%	5.5771±0.00752 ε_{rr}= 7.048%
PLA 3D printing Y.G. – 5.5 mm	6.0248±0.01508 ε_{rl}= 9.542%	5.3542±0.033783 ε_{rr}= 2.651%
PLA 3D printing Panchroma – 6 mm	6.2726±0.04713 ε_{rl}= 4.543%	6.1821±0.0206 ε_{rr}= 3.035%

Table 1 shows the results obtained regarding thickness deviations of the realized eyeglass frames, where h_l and h_r are the thicknesses in the arm fixing area – left and respective right, with standard deviations, ε_{rl} and ε_{rr} are the relative errors to the nominal value (left and right). The nominal thickness for each material is specified in the material column.

Table 2. Results obtained regarding lens housing diameters

Material	**Diameter [mm]**	**σ [mm]**	**ε_r [%]**
Wooden CNC	59.877	0.305	0.205
Plexiglas CNC	60.028	0.158	0.047
Composite CNC	59.542	0.207	0.763
PLA 3D printing Y.G.	59.069	0.433	1.552
PLA 3D printing Panchroma	59.595	0.363	0.675

Table 2 and Fig.13 show the results obtained regarding lens housing diameters, where σ is standard deviation and ε_r is relative error to the nominal value of the diameter (60 mm in all cases).

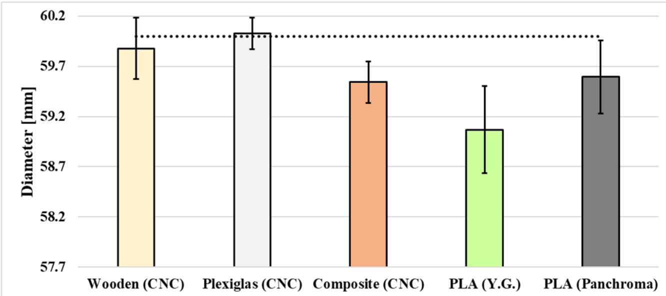

Fig. 13. Comparative diagram regarding the results obtained for lens housing diameters

According to experimental determinations, it turned out that CNC processing gave the largest errors for wood and composite materials, due to the properties of the materials, the working regime, the composition and condition of the semi-finished product, and the best results were obtained for Plexiglas. In the case of 3D printed structures, a bowing of the frame was observed due to contraction and deformation during cooling (temperature differences in the working area), which left its mark on the resulting dimensional deviations. Similarly, in the case of subtractive technologies, due to cutting forces, the material curved (especially in the case of wooden and composite materials). To obtain better results, semi-finished products with better properties, more efficient cutting tools and more precise processing systems can be used. Regarding 3D printers, increasing printing precision can be achieved by using equipment with closed working chambers for rigorous control of the temperature gradient.

5. CONCLUSIONS

Custom glasses made by 3D printing represent a successful symbiosis between technological innovation, functionality and sustainability. Due to its remarkable properties – excellent thermal and chemical resistance, low weight, dimensional stability and ergonomic-adaptive customization capacity, these unique advantages of new 3D printing materials over traditional alternatives (acetate, nylon, titanium) are changing the approach to the manufacturing of high-value products, especially in medicine and optics. 3D printing also uses only the amount of material needed to create the finished part. This is not only environmentally friendly but also cost-effective when using expensive engineering materials and flexible adaptation to specific needs. Choosing 3D printed glasses ultimately means participating in a cutting edge, durable product perfectly adapted to the demanding requirements of different fields such as medical, industrial or sports. Custom wooden frames made on numerically controlled machines are extremely comfortable to wear and have a very fine surface. In addition to the tactile experience, it facilitates the approach of man to nature through personalized wooden eyeglass frames that can be unique and ecological. The technologies for making personalized eyeglass frames presented in the paper use biodegradable materials which are materials that help preserve the environment and correspond to the trend of using organic materials worldwide.

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Cercetări privind metodele moderne de realizare a ramelor de ochelari personalizate prin tehnologii aditive și substractive

Lucrarea prezintă două procese tehnologice de obținere a ramelor personalizate de ochelari prin tehnologii aditive și substractive, evidențiind principalele avantaje și dezavantaje specifice fiecărei tehnologii. Autorii prezintă, de asemenea, modelarea CAD-CAM a unei rame personalizate de ochelari și execuția acesteia atât prin tehnologii aditive - procesul FDM din materiale PLA, precum și prin mașini CNC cu comandă numerică din materiale lemnoase, plastic și compozite.

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