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PROJEKTIRANJE I IZRADA MODELA AMBALAŽE PRIMJENOM FDM TEHNOLOGIJE 3D ISPISA

DESIGN AND PRODUCTION OF PACKAGING MODELS USING FDM 3D PRINTING TECHNOLOGY

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SAŽETAK

3D ispis ili aditivna tehnologija neizostavni je dio projektiranja i izrade ambalaže. Zahvaljujući naprednim tehnologijama 3D ispisa, dizajnerima u ambalažnoj industriji i njihovim marketinškim odjelima omogućena je proizvodnja vizualno realističnih modela u boji, sa stvarnim teksturama i u vrlo složenim oblicima. Time se omogućuje analiza fizičkih karakteristika modela i redizajn ambalaže prije same finalne izrade što osigurava veću učinkovitost i funkcionalnost gotovog proizvoda. U sklopu ovog rada realiziran je cjelokupni projekt dizajna i izrade modela nove ambalaže u obliku plastične boce. Digitalni model kreiran je pomoću softvera Autodesk Fusion 360. 3D ispis prototipa ambalaže izrađen je primjenom FDM tehnologije, po principu uzastopnog dodavanja ekstrudiranog termoplastičnog filamenta, sloj po sloj. Na temelju analize cjelokupnog procesa i procjene kvalitete prototipa utvrđene su prednosti i nedostaci 3D tehnologije ispisa i finalnog modela. Dobiveni rezultati pokazali su da ova metoda omogućuje brzu preinaku prototipa, stvaranje modela visoke kvalitete i ubrzava donošenje konačne odluke.

Ključne riječi: *aditivna tehnologija, 3D ispis, FDM tehnologija, ambalaža, prototip*

ABSTRACT

3D printing, also known as additive manufacturing, is an integral part of packaging design and manufacturing. Thanks to advanced 3D printing technologies, designers in the packaging industry and their marketing departments are able to produce visually realistic models in color, with real textures and in very complex shapes. This allows for analysis of the physical characteristics of the model and redesign of the packaging before final production, ensuring greater efficiency and functionality of the finished product. As part of this work, the entire design and production project of a new packaging model in the form of a plastic bottle was realized. The digital model was created using Autodesk Fusion 360 software. The 3D printing of the packaging prototype was made using FDM technology, based on the principle of successive addition of extruded thermoplastic filament, layer by layer. Based on the analysis of the entire process and the evaluation of the prototype quality, the advantages and disadvantages of 3D printing technology and the final model were determined. The results obtained showed that this method enables rapid modification of the prototype, the creation of high-quality models and speeds up the final decision-making.

Keywords: *additive technology, 3D printing, FDM technology, packaging, prototype*

1. INTRODUCTION

With the advent of desktop 3D printers, completely new areas of application of 3D printing technology have opened up. Their use, i.e. the use of additive manufacturing, is developing rapidly and in all directions. Additive manufacturing is the name for all manufacturing technologies that create physical objects by successively adding materials, layer by layer [1]. More than three decades ago, 3D printing technology became available to a wide range of markets. Then these very narrowly oriented professional devices began to be used more intensively, which led to the opening of new areas of application and new users. In recent years, competition on the world market for production services and products has been increasing. It has become important, if not crucial, to bring a new product to market before competitors. Many processes, such as product design, testing, production and distribution, have become limited by time and material resources. That is why 3D printers have started to be used in the packaging industry to create prototypes, personalized packaging and for the improvement of packaging design [2]. FDM/FFF (*Fused Deposition Modeling/Fused Filament Fabrication*) is the most widespread and cheapest 3D printing technology [3]. Printers enable a computer-generated 3D model to be turned into tangible form [4]. The affordable prices of 3D printers made this technology accessible to a wider population, and 3D printers began to be used more and more in various fields of application.

The aim of this paper is to show the entire process of creating a packaging prototype, from the design of the model using CAD (*Computer-aided design*) geometry to the creation of the model using 3D printing technology. Furthermore, the goal is to investigate the advantages and disadvantages of the mentioned 3D printing technology and the final prototype.

2. APPLICATION OF 3D MODELS IN THE PACKAGING INDUSTRY

Packaging design is a very important factor when choosing and buying a product. Consumers pay a lot of attention to the packaging of the product. Therefore, manufacturers are competing for attention on shelves and in advertisements, and ecological packaging is becoming an increasingly large part of the packaging industry [5]. In today's increasingly competitive market, meeting the needs and tastes of consumers becomes the main concern of producers. Product packaging must meet consumer needs in terms of function, appearance and cost of the product. That's why packaging design plays an important role in marketing, and the goal is to find the fastest, most affordable and simplest way to produce the best possible packaging that will satisfy all aspects, from practicality, attractiveness to ecology [6]. 3D printers have a big role in this process because many companies are using them in the development of packaging.

3D printers can be used to improve the design and functionality of packaging products. By printing a 3D model of the packaging, before making the final product, it is possible to analyze the physical characteristics of the model and, if necessary, changes can be made [7]. Decisions about making the necessary changes that could increase the efficiency and functionality of the product can be made before production on a commercial scale. In such a way, the entire design and planning cycle of new packaging can be shortened, and some of the errors that may appear on the final product can be eliminated using the 3D model [8]. The personalized packaging trend is particularly significant for the food and beverage industry, where customized birthday cakes and liquor bottles are highly desirable gifts for family members and friends [9].

3D printing technology, due to its precision and functionality, as well as significant savings in money and time, has enabled great progress in the field of prototyping. With the help of CAD geometry and the creation of a packaging model with the help of a 3D printer, it is possible to avoid certain errors in the design or functionality of the packaging at an early stage of prototyping [10]. In this way, it is possible to achieve solutions that fully satisfy technical and aesthetic requirements in a faster and more favorable way.

All sectors in the packaging industry have recognized that product packaging is as important as the product itself, and perhaps even more.

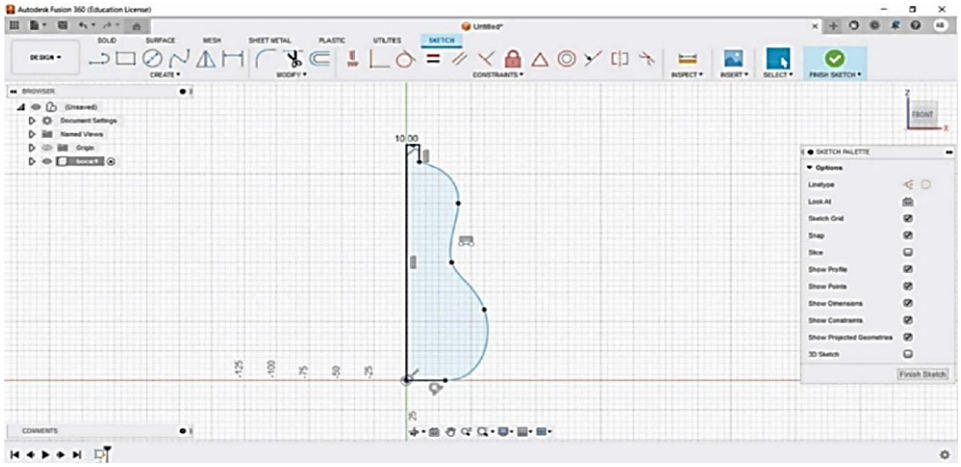

Figure 1 *Creation of the first half of the bottle model*

Before bringing a product to market, it is crucial to first prototype it to get feedback and to ensure that the final product meets the exact requirements of the target customers. Because 3D prototypes can be produced quickly and cost-effectively, this speeds up the time and costs required to bring products to market, and the flaws can be spotted in early stage. [11]. Conventional packaging manufacturing methods such as injection molding, thermoforming and blow molding are expensive for short production runs and require more time to produce a finished prototype [12]. Using 3D printing, a prototype can be made from a CAD drawing to a finished product in a few days. The printed prototype can have all the characteristics as well as the real packaging and gives us the feeling as if we are holding a finished product in our hand.

3. THE PROCESS OF PROTOTYPING A PLASTIC BOTTLE FOR THE BEVERAGE INDUSTRY

In this chapter, the entire process of creating new bottle-shaped packaging will be presented, from design to model printing. The 3D model of the bottle was created in the Autodesk Fusion 360 software, and it was printed on the Creality Ender 3 V2 3D printer.

3.1. CREATION OF 3D MODELS IN AUTODESK FUSION 360 SOFTWARE

Fusion 360 is a relatively new product from Autodesk, designed as a powerful software package for 3D modelling with an integrated CAM module (*Conditional Access Module*). Autodesk Fusion 360 connects the entire product development process into a single cloud-based platform. Autodesk Fusion enables easy movement between 3D design, manufacturing, simulation, drawing and photo-realistic rendering environments. The tools in the software enable quick and easy exploration of design ideas with an integrated concept into a suite of manufacturing tools [13].

The creation of the model began with the creation of the body of the bottle. First, the height of the bottle and the width of the bottom (base) were determined using the *Line* tool. At the beginning, half of the bottle was drawn (Figure 1) and then using the *Spline* tool, the rounded shape of the bottle was created. Later, the bottle could be reshaped with the help of sketch points. The top of the bottle was created using the *Line* tool, and in that step, the size of the bottle opening was set.

After creating half of the bottle, the other half was created using the *Revolve* tool, and thus the 3D shape of the bottle was made. The *Revolve* tool creates a solid body by rotating the selected bottle profile or model geometry around its axis in the Fusion 360 software. If we want to change the shape of the bottle again, we use the *Edit sketch* option to return to the 2D shape and change the shape using the sketch points. In Figure 2, the shape of the bottle obtained after using the *Revolve* tool is shown on the left, while the final shape of the bottle, after editing the initial sketch, is shown on the right.

Figure 2 *Appearance of the final bottle shape after editing the initial sketch*

In order for the bottle to have an opening on the top, a simple opening was defined in the solid body of the bottle with the help of the *Hole* tool (Figure 3). A point in the middle of the opening is selected to define its center. If necessary, the settings of the size, shape and position of the bottle opening can also be adjusted.

During the creation of the model, various dents or bumps can be added to decorate the bottle. With this bottle, indented lines have been added around one part of the bottle so that the body is not completely flat. This can be done in several ways, one of which is shown below. Using the *Fit Point Spline* tool, a line was drawn on the body of the bottle and duplicated using the *Rectangular Pattern* tool. When duplicating, it is necessary to determine the axis along which the line will be distributed. We can also specify the total number of lines, the distance between them and in which direction they are duplicated. In this example, there are five lines in total (Figure 4).

Then, the body of the bottle is divided into parts based on the drawn lines using the *Split Face tool*. This is done to achieve the desired indentation around the entire bottle, not just on one side. After that, using the *Pipe* tool, indentations were made in the bottle so that lines of precisely determined thickness and depth were

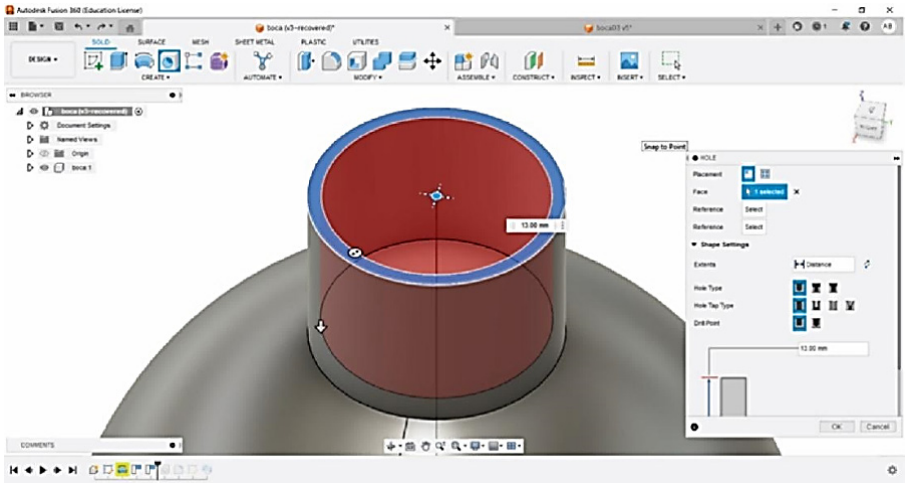

Figure 3 *Making a simple bottle opening*

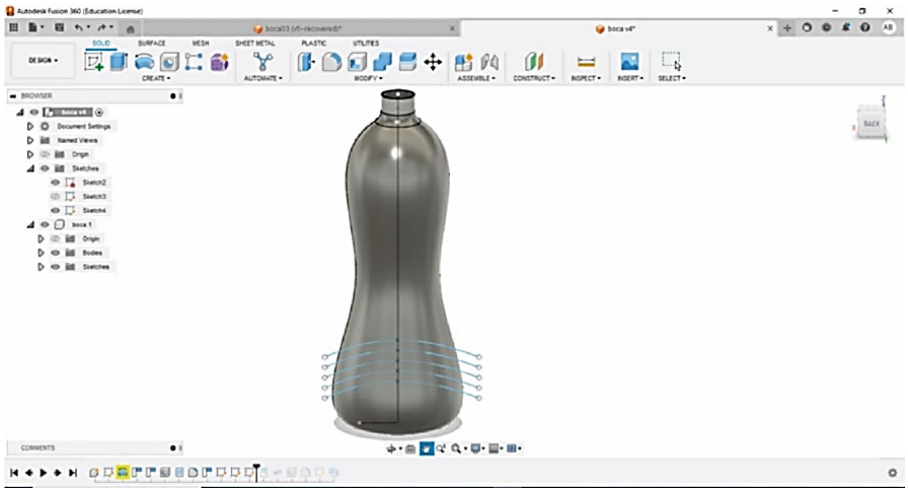

Figure 4 *Adding lines to further decorate the bottle*

cut from the body of the bottle (Figure 5).

For each line separately, using the *Fillet* tool, the edges of the dents on the bottle are rounded so that they are not sharp. In this way, the edges of the solid material are rounded by removing material from the outer edges or adding material to the inner edges. When using this tool, the rounding radius is defined or the rounding is done manually by dragging the arrow shown on the element (Figure 6). After the final creation, the model is saved as an STL file.

3.2. SLICING 3D MODELS INTO THIN LAYERS IN SOFTWARE ULTIMAKER CURA

Using the Slicer tool, the 3D model is cut into thin horizontal layers of a precisely determined thickness (Figure 7) and then generates these lines over which the printer must pass during the printing of the model [14]. The starting point is determining a 3D printing strategy that will enable faithful reproduction of the model in physical form. Slicer tools can generate patterns that have the internal geometry of the model filled so that they have additional strength and stiffness. They can also generate support structures for models so that better 3D printing results are obtained. An SLT file for 3D printing only represents the geometry of the model and is difficult to edit when changes are needed. The increasingly popular AMF 3D file format contains, in addition to model geometry, other characteristics such as color and texture data.

The primary purpose of any 3D printing cutter is to generate instructions for the 3D printer, and in most cases, these instructions will be printed as G-code. The software also allows multiple models to be opened and placed on the print

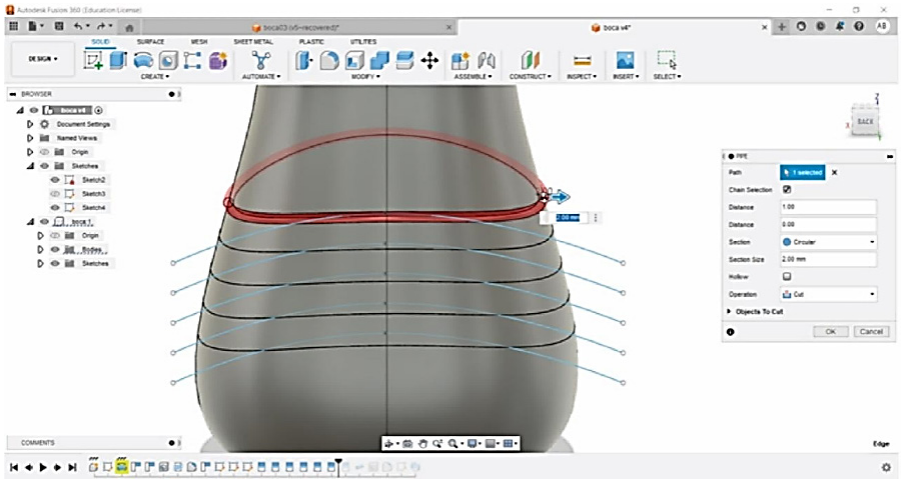

Figure 5 *Creating a dent in the bottle of a certain depth*

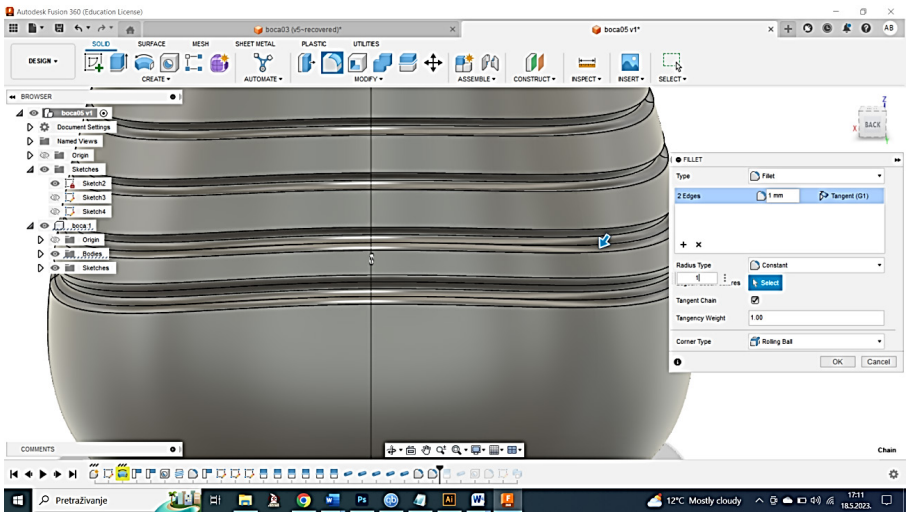

Figure 6 *Rounding the edges on the decorative parts of the bottle*

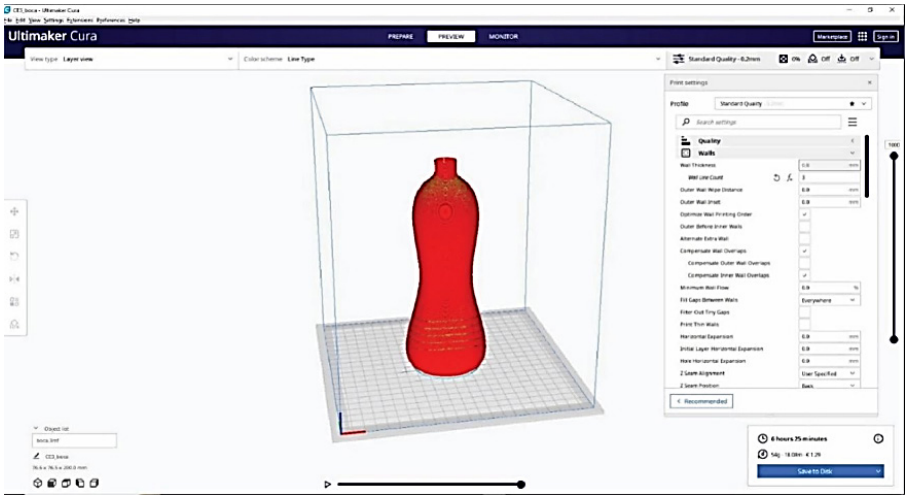

Figure 7 *Slicing the bottle model into thin layers using the Slicer tool*

stand (each with different cut settings if needed). Thus, several models are printed simultaneously, and the management of the printing process is simpler. For printing the 3D model of the bottle, the wall thickness of the bottle was set to 0.8 mm, the nozzle temperature was 230 °C, the bearing temperature was 66 °C, and the printing time was 6 hours and 25 minutes.

3.3. PRINTING A BOTTLE MODEL USING THE CREALITY ENDER 3 V2 3D PRINTER

A G-code file of the designed 3D model is used to control the printing process. G-code is a programming language used to instruct a 3D printer on how to perform tasks. It includes a series of commands, known as G- and M-commands, that direct the movement of components within the printer and determine the actions to be taken during the printing process [15]. It can also be useful to edit the G-code manually when we need to solve problems that occurred in the 3D printed code. The instructions (Figure 8) contain data on the speed of movement according to the given coordinates (F), that is, they tell the printer how fast or slow the printer head should be moved. The E mark tells the printer how much filament will be ejected from the extruder. There are also some additional notations used for M codes: T indicates which extruder will be used, and S indicates the temperature (°C) for the particular extruder. Once the 3D model is ready for printing, the G-code is sent to the 3D printer via communication software or using an SD memory card.

Creality Ender 3 V2 3D printer was used for printing (Figure 9). The printer has a printing surface of 220 × 220 × 250 mm, and its maximum print resolution is 100 μ [30]. It is characterized by easy handling and adjustment of printer settings and information about them at every moment of model printing. The printer has improved accuracy despite the increased print speed. The work surface is made of carbon glass and aluminum, which enables the uniform spread of heat over all parts of the surface. It also improves the adhesion between the printed

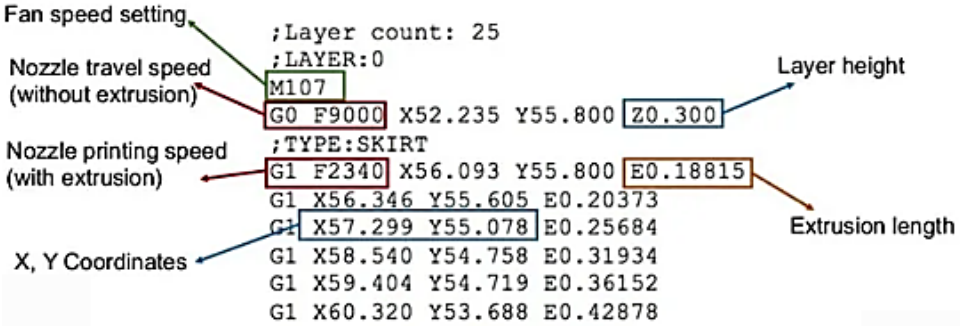

Figure 8 *View of part of the G-code file with a description of individual marks in the code (https://www.researchgate.net/publication/327760995_Watching_and_Safeguarding_Your_3D_Printer_Online_Process_Monitoring_Against_Cyber-Physical_Attacks)*

model layer and the printer substrate, which reduces the possibility of the printed model detaching from the substrate during printing.

Figure 9 *Creality Ender 3 V2 3D printer*

A filament made of polylactic acid (PLA) material was used for 3D printing of the bottle model. During printing, the following information is visible on the screen: printing time, remaining time until the end of printing, nozzle and hot plate temperature. At the beginning of the print, the molten plastic is extruded onto the base using a nozzle located on the 3D printer head. Furthermore, by moving the base and the print head, the next layer of filament is laid down, and the extruded plastic material is merged with the previous layer. Thus, the entire model is printed layer by layer. Increasing the extruder temperature shortens the printing time. Figure 10 shows the three-phase process of printing the bottle model.

Printing the bottle model took 9 hours and 47 minutes, and one layer of plastic is 0.2 mm thick. After the print is complete, all support structures are removed if necessary.

3.4. ANALYSIS OF THE CHARACTERISTICS OF THE ENTIRE PROTOTYPING PROCESS

Based on the analysis of the entire process and the assessment of the quality of the plastic bottle prototype, the advantages and disadvantages of 3D printing technology and the final model were determined (Table 1). Designing packaging in Autodesk Fusion 360 software is a very simple process and enables quick adaptation of the model to the required criteria. FDM printing technology is also a suitable method for inexpensive and relatively fast prototyping of various packaging containers. The 3D model of the packaging is tangible, unlike the 2D model, so that all the advantages and disadvantages can be seen before mass production. All defects can be corrected before making the final mold, for example, a bottle mold. Making a mold is expensive and time-consuming, and a new bottle model can be printed very easily with a 3D printer at lower costs and in a shorter time frame. As shown in this paper, the bottle model can be made on a home 3D printer and does not require a large investment for printing. The printing time of one bottle takes several hours, and with the design of the bottle itself, everything can be done in just a few days. After analyzing the 3D printed bottle, it is easy to see defects that can be corrected before mass production.

Figure 10 *The bottle model printing process shown in three stages*

Table 1 *Advantages and disadvantages of the FDM printing process and the final model*

	Advantages	Disadvantages
PROCESS	clean technology and suitable for offices	longer prototype printing time
	relatively inexpensive prototyping process	for larger volumes - print quality decreases
	reusable filament	rough surface finish
	environmentally sustainable printing materials	does not support complex model geometry
PROTOTYPE	the packaging development cycle is shortened	average prototyping accuracy
	rapid modification of the packaging prototype	temperature fluctuations can lead to delamination of the product
	variety of material choices	prints have visible layer lines
	different wall thicknesses: 0.4 – 1.6 mm	support structures are needed

4. CONCLUSION

FDM technology is the most successful and popular additive technology that uses thermoplastic materials as raw material for 3D printing. Due to some disadvantages, such as lower quality surface treatment, this technology has not yet been implemented in all possible areas of application. By applying additive manufacturing, various complex shapes and structures can be created with proper material management, which results in less waste and various other advantages compared to conventional manufacturing, making it increasingly popular. Using 3D printing technology, it is possible to produce a range of personalized items so that each product can be different while keeping the production cost low. It does not require additional costs of making molds and tools to make custom products.

3D printers can simplify prototyping processes in packaging design. The technology is capable of producing models in almost any shape, and a wide range of filaments can be used to mimic different target materials. The use of 3D printers in packaging design is completely acceptable and is increasingly being used.

This paper presents the tools that can be used for 3D modeling of a packaging product in the Autodesk Fusion 360 software. Different bottle shapes can be created, with different bumps and dents, depending on the designer's wishes. As the Creality Ender 3 V2 is a low-budget printer, on printers that are more expensive and have quality printing, you can get an even better prototype of some packaging, and it is even easier to see the flaws and good sides before production.

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