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3D modeling: Cost of producing molds for textile waste reuse companies

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ABSTRACT
3D modeling is an essential technique in many areas, such as architecture, product design, games and animation. It makes it possible to create digital models that represent objects, scenarios or characters in three dimensions, with depth, width and height, much more accurately and realistically than two-dimensional images. Combined with 3D modeling, the use of a 3D printer makes it possible to create more complex shapes that would be very difficult or impossible to produce by other means. 3D printing technology makes it possible to create parts with organic shapes, smooth curves and fine details, thanks to its high precision, which expands the possibilities for design and production. In addition, 3D printing is a faster and more automated technique. Using a 3D printer, it is possible to produce a large number of molds in a short time.

Keywords: 3D modeling, Molds, Reuse, Textile waste.

INTRODUCTION

3D modeling is an essential technique in many areas, such as architecture, product design, games and animation. It allows you to create digital models that represent objects, scenes or characters in three dimensions, with depth, width and height, in a much more accurate and realistic way than two-dimensional images. Combined with 3D modeling, the use of a 3D printer makes it possible to create more complex shapes, which would be very difficult or impossible to produce by other means. 3D printing technology allows you to create parts with organic shapes, smooth curves and fine details, through its high precision, which expands design and production possibilities. Furthermore, 3D printing is a faster and more automated technique. Using a 3D printer, it is possible to produce a large number of molds in a short time.

3D Printing has been widely applied in different segments, in particular, in the manufacturing sector of thermoplastic injection molds. Currently, metal additive manufacturing requires a solution that combines high performance with low cost to make this technology more applicable. (FERIOTTI, et al 2021).

Molds have different characteristics such as material and time for the same. In these cases, costs are directly related to the production process and business development. Nakagawa (1991) highlights that

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strategic cost management provides information to support strategic and operational decisions, using productive resources efficiently and effectively. Assaf Neto (2015) highlights that through economic indicators it is possible to measure the company's own capital with the profitability of its operational activity.

With the advancement of technology, the mold sector may undergo significant changes in conventional manufacturing methods (Pegas, 2017). Therefore, strategic cost management must be aligned with the company's strategy, organizations tend to present higher performance (Vizzotto, Motta and Camargo, 2019). Some sectors have advanced in 3D printing mold technology (FERNANDES et al., 2014).

Some companies that work with the reuse of textile waste from factory disposal create new sustainable products using 3D printers, having as part of their strategy the use of this new tool for the development of molds used in their production process and acquiring a new strategic ally for customizing products in favor of differentiation. As the mold market is still a topic with room for analysis, knowing the different types of possibilities is a field to be evaluated.

Therefore, this work seeks to provide answers to the question: what is the cost of producing molds in 3D printing in relation to alginate and silicone materials? The objective is to analyze the cost of producing molds using a 3D printer in relation to alginate and silicone materials.

Studies have shown that in the 3D printing process, mold designers must take care in the ideal positioning of 3D mathematical models (PLESSIS et al., 2016; FERIOTTI, et al 2021). Other studies also seek to verify relationships with 3D printing and its costs. (ABREU, 2015).

Morandi & Del Vechio (2020) highlights that 3D printing has enormous potential for the use of this technology, whose resulting products or objects are increasingly complex, cheap and quick to produce. Perhaps there will come a day when, in the industry, even parts of the human body are printed, in addition to people being able to have equipment like this in their own homes.

This file is intended to present an example of a complete article, which may be useful in clarifying any doubts (Describe the study in a clear and objective way, highlighting the relevance of the problem investigated, based on the literature, and the main objectives of the work).

THEORETICAL FRAMEWORK

COSTS AND EXPENSES

The cost is recognized when production factors (goods and services) are used to manufacture a product or perform a service. [...] Expenses are items that reduce Net Equity and have the characteristic of representing sacrifices in the process of obtaining revenue. (MARTINS, 2003, p. 17-18). Expenses represent the amount used in activities not directly related to the production of goods and services, with

the purpose of maintaining the company's activities, and can be considered as non-operational expenses. Costs relate to what is directly necessary for the production of goods and services, that is, it is the value of the inputs and materials used in the production of the good or service (BEHR et al, 2017).

According to Santos (2018), by default, the expense represents something predictable and budgeted, having no relation to the company's product or production process, but rather to a specific period, being a sacrifice of assets for the maintenance of business activities, not necessarily generating revenue. Cost, according to the author, represents something that does not change the company's net worth, as it reflects the use of resources to generate services and goods.

MOLDS

According to Garcia (2009), a mold can be understood as a structure that consists of a set of plates or plates where the functional systems are installed or the material to be filled is added. These systems, as the name suggests, are responsible for enabling the mold to perform its functions properly.

To create the mold, to be used to obtain the desired part, different materials can be used such as silicone, alginate, liquid plastic, as well as the use of a 3D printer and other materials depending on the specific production needs of the material. The molds can be made of silicone, alginate and 3D printer. These will be included in the next chapters.

Silicone

According to the Filament2print portal (2020), silicone molds are molds used in the manufacture of parts, objects or products in which great precision and detail are required in the reproduction of the original mold. They are made of silicone, a flexible and resistant material, which allows the creation of molds with complex shapes and textures. The use of silicone for molding consists of simple and economical manufacturing, and can be flexible to facilitate the demolding process. However, to make a silicone mold, you need to have a piece ready to serve as a model.

According to the silicone mold manufacturer Gummies (2023), the silicone mold is capable of facilitating the production of varied parts, where it is possible to obtain, in large quantities, the construction of modeled parts with the exact same shape as the original model. In turn, this generates a reduction in production cost and time, benefiting mass production and service quality.

Alginate

According to the Sanar portal (2020), alginate is an easy-to-use material that, when mixed with water, undergoes a gelation process. In addition to being easy to use, its main characteristic is its low cost, however, the same product may present low reproduction fidelity and dimensional stability.

Alginate is a material mostly used in the dental industry, according to Capel (2017), it is used to copy teeth and adjacent structures, and alginate is a cheaper product than elastomers. However, it does not have very good passive copying power and only allows one leak. Additionally, alginate has low tear resistance, but it is not a critical factor for work carried out with it.

3D Printer

According to 3DLAB ebook (2019), the 3D printer is considered an aspect of industry 4.0 and is known as digital manufacturing, the 3D printer allows the creation of unique objects by creating a model, slicing the part and printing the final part . As one of its main characteristics is the flexibility and diversity of filaments (such as PLA, ABS and PETG) as raw material, the use of 3D printers can be used to obtain mechanical parts of high strength and rigidity, as well as simple decorative pieces.

The use of a 3D printer to build molds is part of a process called additive manufacturing where, according to Zaparolli (2019), this method where the material is added in layers as defined in a project built within a computer platform, giving more freedom for designers and enabling the production of parts with complex geometry and also hollow, different from traditional machining processes.

METHODOLOGY

This research is applied in nature, with a quantitative approach, with exploratory objectives, with a case study being carried out using the data analysis technique. According to Kauark et al. (2010), applied research seeks to provide knowledge to solve specific problems, with practical application. The quantitative approach seeks to classify and analyze information that can be quantified through statistical techniques. Still according to the same author, the exploratory objective of the research seeks to generate information that allows greater intimacy with the subject addressed in the research problem.

Finally, the case study (Yin, 2001) is responsible for detailed and broad knowledge of one or a few research objects. In this work, only one specific company was analyzed, as the research consists of evaluating the theme within the business sector of this small company that currently produces various objects through the reuse of textile waste and also participates in national and international fairs and exhibitions. The owner's objective is to ensure that all of the company's processes are strongly aligned with sustainable policies.

Therefore, to carry out this work and achieve the proposed objectives, initially a classification of the molds used will be made based on their own mold and the product to be made from this mold. After this first step, a mold/product will be selected for each defined degree of complexity and subsequently the values needed to produce the same mold for each type of material described in this work will be quantified.

Having quantified the production costs of each mold according to the materials studied, a comparative analysis of these costs will begin, also taking into account the characteristics of each material and difficulties/facilities encountered. Two molds were selected for analysis, where:

Mold 1 - This is a mold whose objective is to allow the production of a covering for the seat of a stool, where this covering is produced from textile waste.

Mold 2 - This is a mold whose objective is to allow the production of a solid piece in the shape of the letter I, composed entirely of textile waste

In summary, the work will be carried out in 4 stages as summarized below:

1st - Selection of molds - In this phase, the most impactful characteristics of the molds already used by the company were analyzed and thus defined the need to study molds with the characteristics of: allowing the production of a solid part and allowing the production of a piece to be attached to a product.

2nd - Analysis of the materials that make up the mold - It was made up of the analysis of which materials are commonly used in the market for the elaboration of molds in general and then selecting those that suit the company's production process, as well as the company's own knowledge about of these materials.

3rd - Cost survey - Stage where the values necessary for the production of the respective molds were sought according to each designated material. To collect the values, the prices of the company's current suppliers were taken into account and compared with other options available on the market.

4th - Analysis of manufacturing costs and benefits - This consisted of comparing prices taking into account the manufacturing characteristics of the mold according to each material, such as production time, reuse of the mold and the need for a pilot part.

The research was carried out during the period from August 2022 to September 2023 and other necessary information was obtained through surveys with the company.

DEVELOPMENT

The development stage of this project will be divided into 3 stages, where each stage represents the collection of production data for each mold according to the three materials defined as feasible for the company. It should be noted that these 3 steps will be carried out for each mold studied,

For the purposes of this work, some considerations need to be made about the materials studied.

The survey of the material needed to create the alginate and silicone molds will be done using the mass formula, composed of $m = dv$, where d represents the density, m represents the mass and v represents the volume. The volume will be obtained through the design created for the 3D printer mold and the density obtained from the technical information of the material. In this way, when we apply the density formula, we will obtain the mass necessary to create each mold.

The density of alginate, which is a common type of irreversible hydrocolloid used to make impression impressions, generally ranges between 1.1 g/cm³ and 1.3 g/cm³. This means that the density of alginate is slightly greater than that of water, which has a density of around 1.0 g/cm³. Therefore, for calculation purposes for this work, the alginate density will be considered to be 1.2 g/cm³. Furthermore, alginate needs to be mixed with water in a proportion of 10 grams of powder for every 17 ml of water. As for the density of the silicone, 1.3 g/cm³ will be considered, as this information was provided by the seller of the silicone already purchased by the company at other times.

Additionally, for both the alginate mold and the silicone mold, it will be considered for calculation purposes that the mold wall will be 1 cm, considering that the majority of silicone molds already acquired by the company have this thickness.

Regarding the mold for 3D printing, it was designed using the Solid Edge tool (a tool whose objective is to offer solid modeling in 3D, the assembly of modeling and the elaboration of functionalities for mechanics) and subsequently the slicing of the design for insertion into the printer was carried out using the Ultimaker Cura tool (this tool aims to carry out open source slicing for 3D printers, that is, transforming the Solid Edge design into a file to be processed in the 3D printer), obtaining the necessary time from this slicing for printing as well as the necessary material. For the preparation of the 3D mold as well as cost calculation, Premium PLA filament will be considered (it is a thermoplastic polymer that is produced from lactic acid, derived from renewable raw materials, and due to its origin in organic, PLA is biodegradable, meaning it can be broken down naturally, making it compostable and recyclable) 1.75mm.

The values for each material as well as quantity will be summarized in the following table, including the cost of shipping for delivery of the material:

Table 1 - Materials and values/kg

MATERIAL	AMOUNT	PRICE R$)
ALGINATE	1 KG	R$ 127.10
SILICONE	1 KG	BRL 76.71
PLA FILAMENT	1 KG	R$ 124.90

Source: research data

In the table above it is possible to summarize the materials to be used in this work, as well as the value per kilogram of each material. It should be noted that alginate is sold in packages of 400 grams, however proportional calculations were carried out to obtain the value per kilogram in order to be able to compare the price of each material considering the same quantity. The values of these materials were

collected during the month of September 2023, where it was possible to verify that alginate is the most expensive material and silicone is the cheapest material among the 3 studied.

MOLD 1 - BACKPACK

The first product to be studied in this work is the mold for the production of a textile covering added to the seat of a stool, as can be seen in the image below of the product after the inclusion of such a covering.

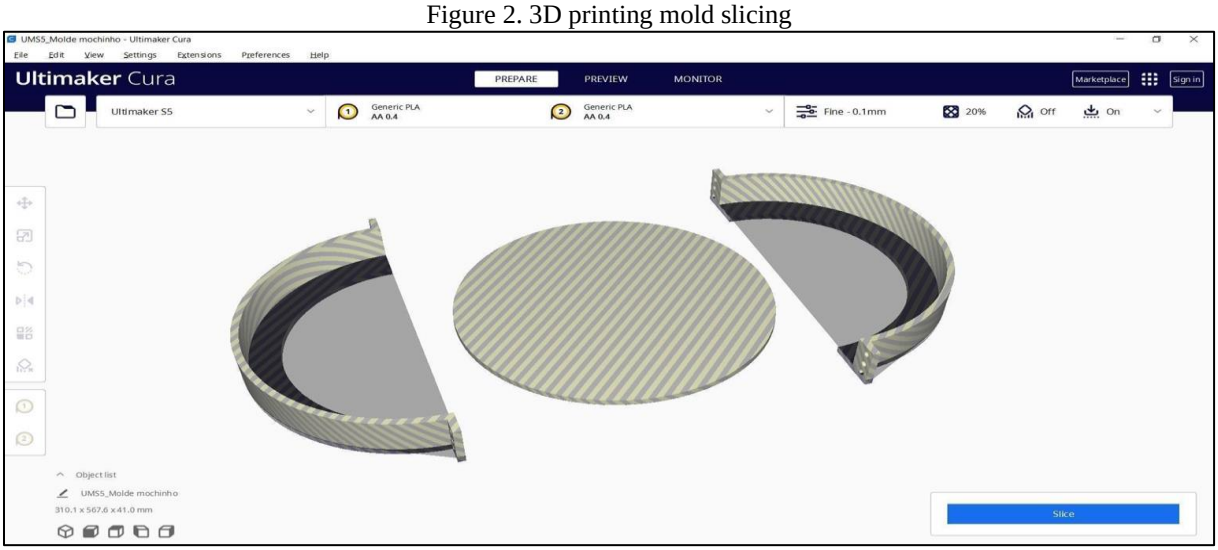
Figure 1 - Backpack with textile covering

Source: Research data

To carry out this project, the mold was developed through 3D printing, resulting in a mold with 3 pieces.

In Figure 2 you can see the design of the 3 parts, which make up the mold designed for 3D printing, to make it easier to understand the information previously exposed and summarized in table 2. This figure is a capture of screen of the Ultimaker Cura program where the pieces are sliced to transfer the information to the 3D printer.

Figure 2. 3D printing mold slicing



Source: research data

In the table below, you can check the production time and material needed for each part of the 3D printing mold, where both the time and material information was provided by the program itself after slicing the 3D design. The cost in reais of each piece was calculated based on the required quantity of filament and the cost of such filament as shown in Table 1 - Materials and values/kg.

Table 2 - 3D printing PLA backpack

PART	PRODUCTION TIME	REQUIRED MATERIAL	COST IN REAL
BASIS	24h22min	132.5g	R$ 16.55
SIDE 1	11:46 am	60 g	R$ 7.49
SIDE 2	11:38 am	59 g	R$ 7.37
TOTAL	1d23h46min	251.5g	R$ 31.41

Source: research data

Based on the table above, it can be seen that the total production time is 1 day, 23 hours and 46 minutes, with a total cost of 31 reais and 41 cents to create this mold through 3D printing.

To create a replacement for this mold using alginate and silicone, you will need 479.25 grams and 519.19 grams of material, respectively. This information was obtained by applying the mass formula and considering the mold wall to be 1 cm, as previously described.

To be able to make both of the molds above, you need to have the mocha on hand to use as a reference when creating the mold. In this way, the information used to calculate the required mass was:

Mochila:	Mold:
Diameter - 24 cm	Diameter - 25 cm
Radius - 12 cm	Radius - 12.5 cm
Height - 4 cm	Height - 4.5 cm

In this way, by calculating the total volume of the mold and subtracting the volume filled by the mold, the volume required to be filled to create the mold was obtained. Thus, having the density and volume information, it was possible to apply the mass formula to discover the necessary amount of material for each mold, as initially informed (479.25 grams of alginate and 519.19 grams of silicone).

These costs can be seen more clearly and summarized in table 3:

Table 3 - Mold x material comparison

MATERIAL	COST/KG	NECESSARY AMOUNT	COST OF THE MOLD IN REAL
ALGINATE	R$ 127.10	479.25 g	R$ 60.91
SILICONE	BRL 76.71	519.19g	R$ 39.83
PLA FILAMENT / 3D PRINTING	R$ 124.90	251.5g	R$ 31.41

Source: research data

Table 3 summarizes the information, in which the quantities for alginate and silicone were calculated using the mass formula and the quantity for 3D printing was obtained by slicing the 3D design. The table presents the cost of producing the mold using silicone at R$ 39.83, with alginate calculated at R$ 60.91

Still on table 3, it was possible to note that both alginate and silicone, as they have a similar density, require a similar amount, however, differing significantly in the final cost due to the cost/kg of each material, with alginate being the more expensive production. 3D printing, although it has a higher cost/kg than silicone, as it requires a smaller amount of material, due to the use in executing its design, has become the best option in terms of cost for making this mold.

MOLD 2 - LETTER I

The second mold to be studied corresponds to the production of a piece entirely made from textile waste.

As it is a project made exclusively with textile waste, it is possible to design and produce your mold through 3D printing without the need for additional information. However, so that the same mold can be produced with silicone or alginate, it is necessary to first produce a pilot piece to be used in the production of the molds.

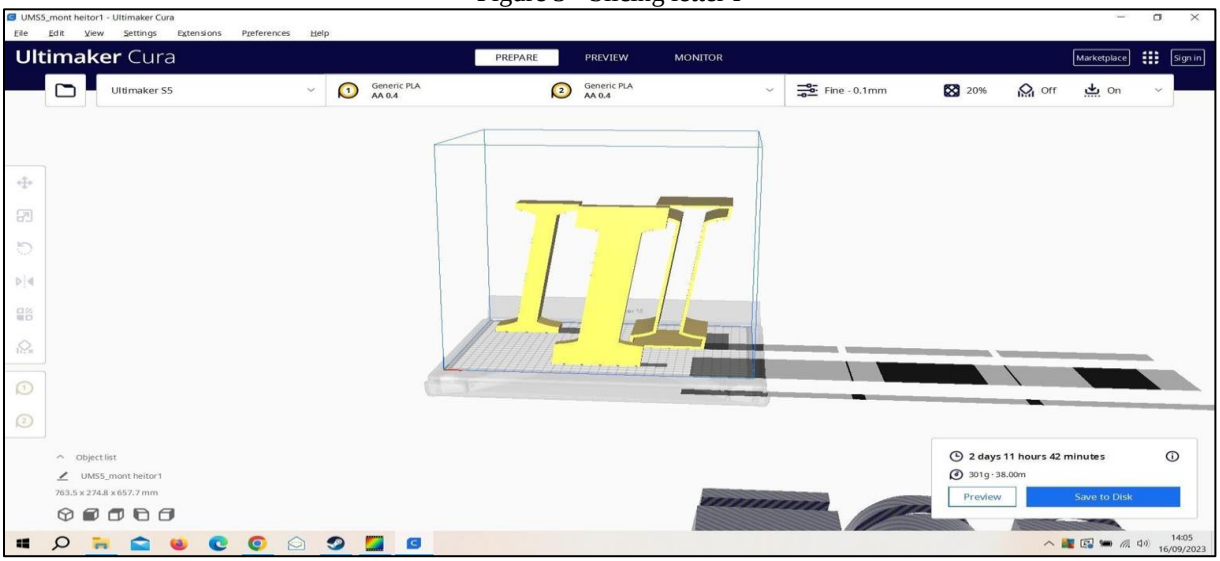
Therefore, it was necessary to estimate the cost of producing this pilot part to be able to continue studying the production of the molds. For this, contact was made with companies that work with MDF to create the piece using laser cutting. The best quote obtained from the contacts made was R$80.00 to produce the part, thus, this value will be added to the total cost for the production of both the alginate mold and the silicone mold.

To be able to produce the mold through 3D printing, it was necessary to design 3 parts in Solid Edge and perform the slicing in Ultimaker Cura, one piece being the base, one being the walls of the mold and the third piece being a lid for the mold. pressing and shaping the textile waste. After slicing the 3

pieces, the required production time was 2 days, 11 hours and 42 minutes and required 301 grams of PLA filament. Thus, the total cost for producing this mold on the 3D printer was quantified as R$ 37.59.

In figure 3 below, you can see the drawing of the parts that make up the mold designed for 3D printing, to provide a visualization of the mold and thus provide a better understanding of the information presented in this chapter. This figure is a screenshot of the Ultimaker Cura program where the pieces are sliced to transfer the information to the 3D printer.

Figure 3 - Slicing letter I



Source: research data

To produce the same mold using silicone and alginate, it was necessary to use the mass calculation formula again, where m = dv, to discover the amount of material needed for each, considering a wall of 1 cm for the mold, as previously described and considering the following measurements of the pilot piece produced in MDF: Total height: 18.4 cm; Width: 7.9 cm; Thickness: 8 cm.

In this way, by calculating the total volume of the mold and subtracting the volume filled by the pilot piece, the volume required to be filled to create the mold was obtained. Thus, by applying the mass formula, it was possible to discover the necessary quantity of each material, being 901 grams for alginate and 977 grams for silicone.

These costs can be seen more clearly and summarized in table 4:

Table 4 - Comparison of letter mold x material

MATERIAL	COST/KG	NECESSARY AMOUNT	PILOT PART COST	COST OF THE MOLD IN REAL
ALGINATE	R$ 127.10	901 g	R$ 80.00	R$ 194.64
SILICONE	BRL 76.71	977g	R$ 80.00	R$ 154.96
PLA FILAMENT / 3D PRINTING	R$ 124.90	301 g	R$ 0.00	R$ 37.59

Source: research data

It was possible to determine the production cost of each mold based on the values for each product previously reported. The cost of producing the mold using silicone as material was calculated at R$74.96, while the cost of this same mold produced with alginate was calculated at R$114.64. Adding also the production cost of the pilot piece of R$ 80.00, the final cost for the production of the silicone mold and the alginate mold was obtained, as being R$ 194.64 for the alginate and R$ 154, 96 for silicone.

Table 4 provides a summary of the elements covered in this chapter, where emphasis is placed on the impact that the need to have a pilot part for mold production has on the mold production cost, which can represent approximately 50% of the total cost of production. production, as in the case of silicone. As with the mold for the mochinho, 3D printing proved to be the best option in terms of cost, however, in this case, its benefit is even more significant as it does not suffer from the need for a pilot piece, considering that this This means there is no dependence on the availability of an external supplier or the risk of delays in delivery. It can be seen that there is an advantage to the production time of the 3D printer.

MOLD ANALYSIS 1 AND 2

Analyzing the two molds, it was possible to see that the production of both molds had the lowest cost through the 3D printer using PLA filament. It is worth noting that the difference in costs between the silicone and the 3D printer were very close in the production of the mochinho, with a difference of R$ 8.42. The difference between alginate and 3D printing was R$29.50.

As for the production of the letter I, the difference in costs between 3D printing of other materials became very significant, mainly due to the fact that both alginate and silicone require the production of a pilot piece to create the mold, while In 3D printing, it was possible to directly design the parts that make up the mold, without the need for a pilot part. Thus, for this mold, the difference in cost of 3D printing for silicone was R$ 117.37 while for alginate it was R$ 157.05, showing that producing the mold through 3D printing is a better alternative than alginate and silicone.

It is important to comment that in both molds, alginate proved to be the most expensive material for producing the molds, with a significant difference in relation to the other options. Furthermore,

combined with the fact that it is a material that only allows for a single reproduction, that is, providing a single-use mold, alginate does not become a viable option for the production of molds within the scenario of waste reuse companies. textile waste, which is closely linked to the ideas of the 5 Rs rule (rethink, refuse, reduce, reuse and recycle), a methodology created by environmental activist Bea Johnson. According to Johson (2013), the 5 Rs philosophy focuses on rethinking consumption habits, instead of focusing exclusively on recycling, that is, keeping in mind the impact of actions from the first step. This concept has an impact on the entire consumption chain, where each stage is intrinsically connected to the next.

It is worth highlighting other studies carried out on the topic of costs and 3D production where, Abreu (2015), cites as advantages of 3D Printing the lack of need for supports, the reduced printing time and its suitability for parts with complex geometries (which allows for a larger customization portfolio). Zier et al. (2019) found in their study a significant reduction of 82% in costs and 96% in deadlines, using 3D printing methods and compared to traditional production with external suppliers.

FINAL CONSIDERATIONS

The objective of this research was to quantify the cost of producing two molds using 3D printing technology and verify whether their use is financially viable compared to the production of the same mold made with alginate or silicone.

To achieve this objective, this work sought to identify the production costs of 2 molds, with different characteristics, for each of the materials considered in this study. It is important to highlight that one of the molds studied aims to produce a textile covering to be placed in a backpack, while the other mold studied aims to produce a solid piece of textile waste, without the need for any other part. These pieces were selected because they deal with projects of interest to the company and ways to be produced were being studied.

It was possible to conclude from the results of this work that using 3D printing to produce new molds, in addition to avoiding possible waste by allowing visualization and detailing of the part before its production, is the most financially viable option than alginate and silicone, being enhanced by the fact that it does not require a pilot piece to produce certain molds. Furthermore, the use of 3D printing becomes more favorable by facilitating the production of unique pieces for participation in competitions, as well as a greater degree of personalization of the pieces.

A limiting factor is the degree of knowledge about 3D modeling and the materials used, as the use of the material is an essential item to know the resistance of the structure.

It is suggested as future research to carry out a cost survey considering the outsourcing of the design stage of the 3D project to be produced in 3D printing as well as verify the possibility of mixing the

materials used, for example, the production of a pilot part through 3D printing and the mold with silicone. In this way, it is possible to expand the analysis of the efficiency of using 3D printing.

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