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APPLICATION OF TURBINE PROTOTYPING FOR TEACHING HYDRAULIC WORKS

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Abstract. *The Pelton Turbine is an essential machine to produce energy in hydroelectric power plants and distributed generation micro plants, as well as in works of Water Supply Systems, in addition to models of Pumps Functioning as Turbine (BFT) in hydraulic systems, where BFT's are used as pressure controllers while generating energy. 3D Printing is a tool that can be used on a universal scale, fundamental to industrial, commercial, academic, and domestic environments, as it manufactures three-dimensional parameterized models that are low cost and lower in value than alternative methods. It allows the free production of objects, applied to biology, chemistry, medicine, and engineering. The manufacture of Pelton Turbine in an academic environment, dimensioned to measure, for the generation of energy in a specific system and for teaching subjects in hydraulic works, is an effective and innovative teaching methodology, as it leads to immersion in content and practical development, fostering the scale up of the model. With the objective of producing a parameterized model of a Pelton turbine, to be applied in a pilot-scale channel and subsequent teaching of the discipline of hydraulic works. The Turbine was modeled in BIM and manufactured with ABS material. This material was chosen because it is the lowest cost on the market. The good rotational behavior of the turbine on the hydraulic bench stands out, the low cost of the amount of ABS used at R$ 3.51 and the abbreviated time of 2h26 to manufacture the turbine, which demonstrates the economic viability of the system.*

Keywords: Pelton turbine, 3D printing, energy, hydraulic, teaching.

1. INTRODUCTION

3D printing is a technology that can be applied on a large scale, usable in industrial, academic, and domestic environments and has a great recurrence of use in teaching, as a methodological innovation. In this scenario, Oertel and Shen (2022) deal with how three-dimensional printing enables the manufacture of reduced hydraulic structures for conducting complex studies that fit into low-cost production standards.

According to Nicoletti et al. (2022), although there is still a large research and development gap on the exchange of information between the BIM concept software and those that perform structural analysis, the interoperability of the concept presents advantages of use, such as agility in the flow of information regarding the elaborated project and the valuation of BIM in the industry.

The importance of this work is justified, the discussion about the flexibility and scope of 3D printing for the manufacture of parts, with the objective of elaborating studies, solving problems and the meaning of theoretical teaching, through the application of real problems and case studies, to refine the professional profile of the student.

2. LITERATURE REVIEW

As the use of turbines for generation and electricity is a technology used on a large scale and the advancement of technology has recurrently assisted teaching, in this scenario, analyzing the state of the art on the use of prototyping with 3D printing in teaching, contributed to the identification of research gaps and trends in the subject. Like this Lopes and Marques (2023) used bibliometrics to know the state of the art on the use of Pressure Reducing Valves, the present study was conducted through bibliometric, qualitative, and quantitative analysis.

According to the data collected in the "Scopus" database, belonging to the company Elsevier, using the keywords: turbine, 3D Printing, and teaching and without temporary delimitation, eight works were obtained located between 2013 and 2022. The other countries of origin of the works presented one publication each, including Brazil.

The research identified eight works in a recent and short space of time. This value already indicates the presence of technological innovation in the academies since it correlates with the prototyping of models for teaching. However, there is an apparent lack of works that deal with the prototyping of turbines, used to enhance the teaching of flow machines and

hydraulic works. It should be noted that the area with the highest number of publications was Engineering, totaling eight documents. The areas of publications found are shown in the figure below.
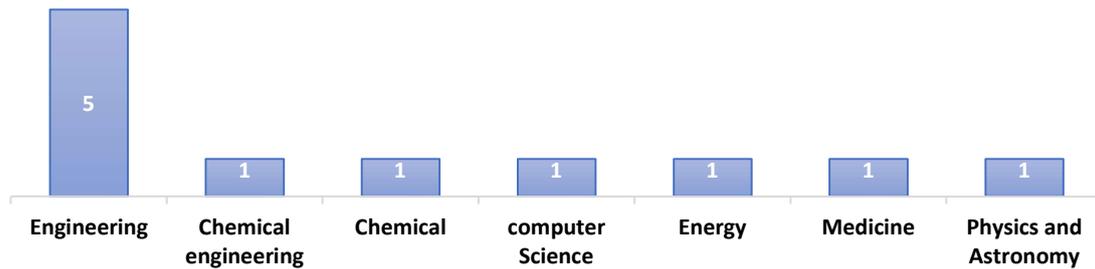

Figure 1. Publications by discipline.

From the data collected in the Scopus collection, it was possible to create a density chart correlating in clusters, the keywords, and the authors, according to recurrence in the publications. The four clusters are divided into students, aerodynamics, 3d printers and education. In general, the groupings indicated lines of research around teaching and experiments, aerodynamics and compressors and machine design.
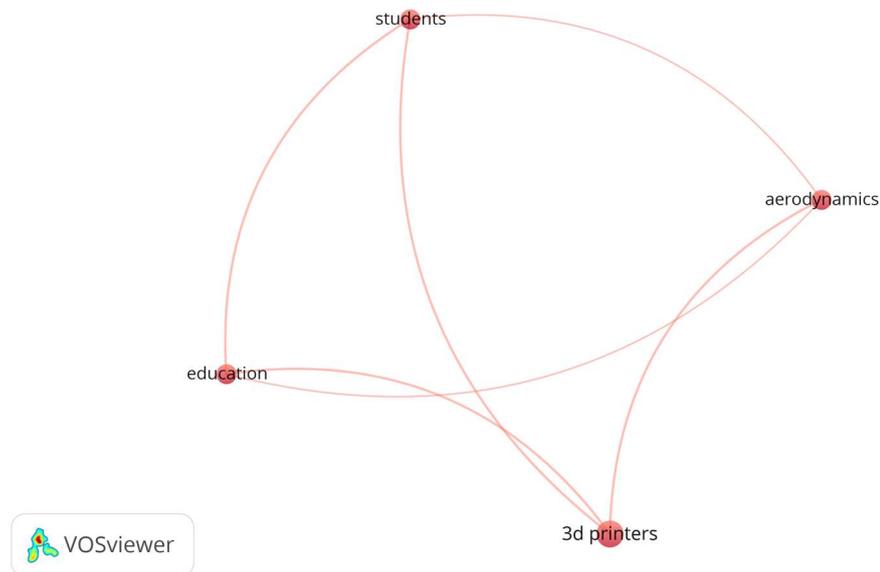

Figure 2. keyword groupings.

Analyzing the keywords according to the years of publication, it was possible to notice two lines of research, from 2018 to 2022, addressing the themes of 3D printers in education and from 2014 to 2017, on projects of flow machines. In this scenario, it is observed that currently the greatest focus is directed to the technological advance applied to teaching.

From the research it was also possible to analyze the most recurrent authors and the respective line of research. In this context, it was understood that the line of research addresses the application of 3D printing in high school subjects, to prototype blades for compressors of jet engines and gas turbines, as a way of giving meaning to teaching.
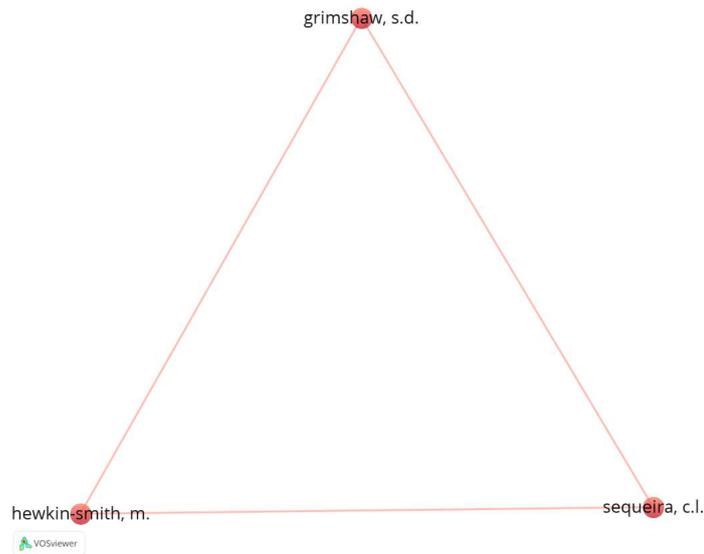
Figure 3. Grouping by authors.

In this scenario, Grimshaw, Sequeira and Hewkin-Smith (2017) we discuss the design of parts for Turbocompressor's and subsequent manufacture through 3D printing, as a strategy to attract and signify the role of engineering in industries. The authors address the issue with the aim of bringing young high school students closer to higher education courses in engineering, since research has pointed to young people's lack of interest in engineering as an obstacle to the development and growth of the industrial sector.

Grimshaw, Sequeira and Hewkin-Smith (2017) held workshops with students, with activities to introduce the theme, so that young people could understand the theory and practice of science and engineering. The activities ranged from immersion to the theme, design using 3D CAD, three-dimensional printing of the parts, conducting tests and presenting students with the works produced. The authors point out that the project reached the objective of integrating students to research and that the practical activities were efficient in the meaning of research for career formation.

As well as identifying the line of research that addresses projects and prototyping applied to teaching, Alber et al. (2022) designed and printed a turbine model, using PLA material, with the objective of studying the structural and functional behavior of the turbine and later comparing it to simulation data.

Alber et al. (2022) points out some 3D printing parameters specific to the development of the study, in this scenario, the layer height at 0.5 mm, the wall thickness at 2 mm, the gyroid filling pattern and the filling at 10% are fundamental for manufacturing and present efficiency in relation to weight, stability and duration. The authors conclude that the work is effective for research and teaching purposes, which points to the importance of technological innovation in the field.

Singhal et al. (2022) approaches additive manufacturing and 3d printing as a key element for the evolution of teaching, since competition in the manufacturing industry is based on process automation, which requires more agility from students entering the market. In this way, the authors defend the improvement of practical classes with applications of problems foreseen in case studies and solving them through the elaboration and manufacture of models. In this way, students can hone their ability to identify the problem and develop specific solutions.

Aiming to analyze the interaction of the BIM concept with structural analysis software, Nicoletti et al. (2022) researched the State of the Art in the SCOPUS and WEB OF SCIENCE databases with the keywords BIM and ABAQUS, ANSYS, ROBOT STRUCTURAL and SAP2000, which represent the research software. In this context, the authors pointed out the existing interoperability of BIM with the mentioned software, indicating the necessary exports and formats until the final simulation software and considered the growth in the area, although there are research gaps.

3. OBJECTIVE

This work aims at the application and meaning of modeling with BIM tool and prototyping with 3D printing of Pelton Turbine, in the teaching of Hydraulic Works.

4. METHODOLOGY

The materials and methods applied in the present work are divided into two phases, the first being responsible for the detailed description of the Pelton Turbine modeling using the REVIT Software and the second phase contemplating the manufacture of the model using the 3D Printer GTMax H4 Core and consequent application in a hydraulic bench for engineering teaching.

As predicted in the literature by Macintyre (1983) and Pfleiderer and Petermann (1979) the Pelton turbine blades are essential for the operation of the machine. In this scenario, the blade design is described in real scale 1:1 and measurement unit in millimeters. Modeling is conducted using the REVOLVER command, because with this function, a revolution with the desired cross section and degree of rotation is projected – Initial and final angle – and for the blade section, the radius and arc lengths of the formed ellipse can be dimensioned, as shown in the following figure:
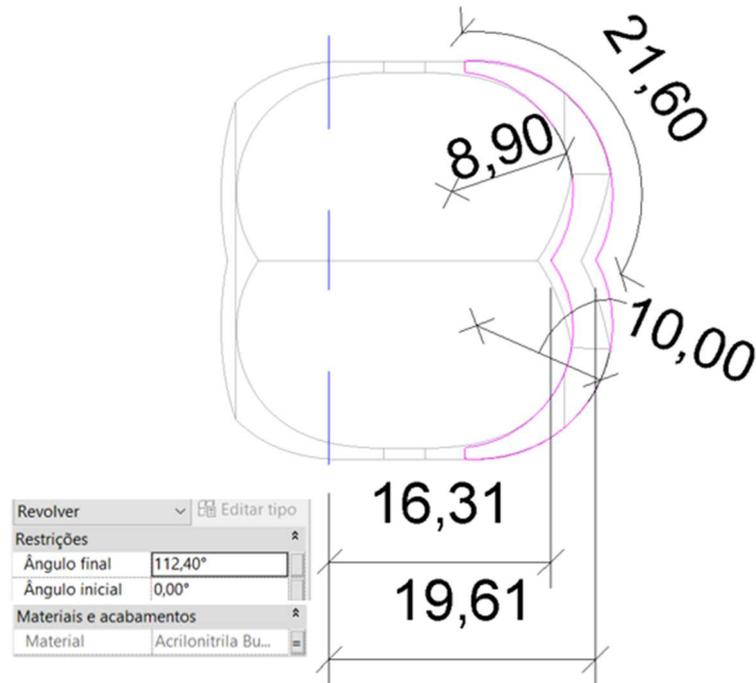
Figure 4. Elaboration of the Shovel.

To make the slot at the end of the blade, an empty extrusion is created, with the required circular section, diameter, and perpendicular positioning of the blade.
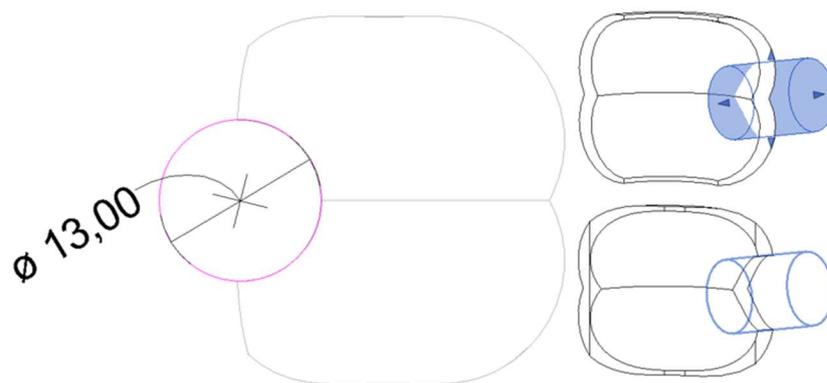
Figure 5. Opening projection on the Shovel.

As a result, the number of blades desired is replicated with the location equidistant and connected to the rotor. This, in turn, is designed using the extrusion command where the cross section is detailed. You can visualize the Pelton turbine in the image below.
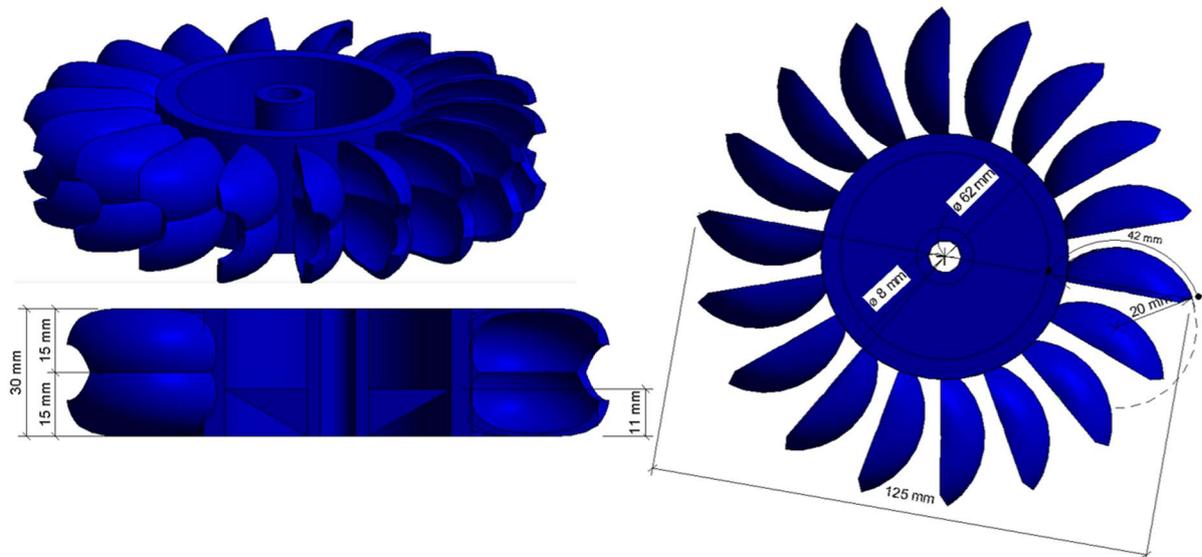
Figure 6. Pelton turbine project.

To compose the Pelton turbine system, a bearing was designed to support the hydraulic turbine in the channel and provide the turbine rotation with correct positioning. For the channel that has a rectangular section with a width of thirty-nine centimeters, the projected bearing is composed of assemble able parts and includes a thread for pressure fastening. The part can be seen in the figure below:
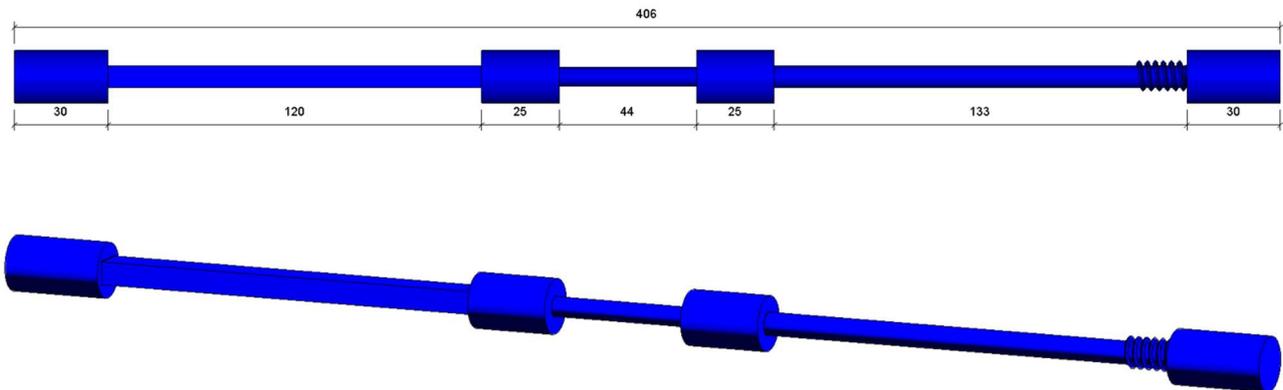

Figure 7. Bearing project.

The model has a height of 30 mm, as well as the eighteen blades, which have a semicircle shell shape. The overall diameter is 125mm, the impeller 62.5mm and the shaft 8mm in diameter.

With the project completed, the model is exported from the REVIT software to the ULTIMAKER CURA software in STL format. This allows for the adjustment of parameters according to the printer, material, and the desired quality and strength of the piece. Since the part needs to have good mechanical efficiency, heights and thicknesses of the filament walls are configured in smaller quantities and larger dimensions, as this way, there are fewer points of interaction between layers and less susceptible to collapse.

For perfect interchange between digital slicing and the printer, the software needs to be configured according to the dimensional and performance settings and the printer programming. In this way, the maximum plotting dimensions on the three axes, the maximum speeds and temperatures reached by the extruder and plotting table, number of extruders and coolers, extrusion nozzle diameter and Start and End Code programming are applied to the software.

In this context, the part is configured with 99% filling, deposition thickness of 0.8 mm and wall height of 0.4 mm. The temperature used at extruder is 240 ºC and on a table heated is 100 ºC, using ABS, the deposition pattern used is in lines, adopting a speed of 50 mm/s and filament flow at 105%.

It should be noted that delaying the cooling of the ABS part is a way to guarantee the effectiveness of the printing, therefore, exposing the material to a high extrusion temperature and keeping the extruder coolers turned off provides better conditions for printing, as the material undergoes rapid heat loss that results in early shrinkage of the part and

impairs the printing and the final quality. In this way, adjusting the filament flow at 105% and at low speed helps to avoid under-extrusion and provides better printing conditions.

It is important to emphasize that the precise adjustment of the Z offset is crucial for efficient 3D printing. This adjustment ensures that the molten filament adheres correctly to the build surface, promoting effective layer adhesion in subsequent layers. It also helps prevent print failures and material wastage, reducing prototyping costs. Inadequate nozzle-to-print bed distance can lead to damage to both the printer and the prototype, resulting in undesired outcomes. Therefore, this configuration is considered one of the most critical aspects of 3D printing.

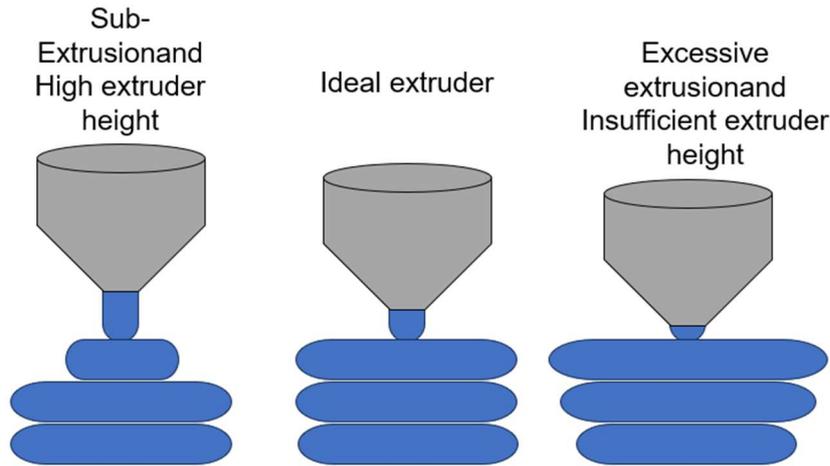The next figure shows an example of ideal extrusion, with the Z offset and filament flow being perfect.

Figure 8. Ideal extrusion.

5. RESULTS AND DISCUSSIONS

According to the Turbine modeling, which was developed in a BIM concept tool, the precision of the creation of the part is pointed out, both in the shape of the part and in the millimeter precision. In this context, the following advantages of modeling with the REVIT software are indicated: summary of project quantities, detailing the quantities of material per component; the technical specifications of the material used in the project; the flow of technical and project information that can be replicated in other projects and the interoperability with CAD software, which elaborate simulations and structural analysis.

The material volume of the Turbine is 91.32 cm³, made of ABS and can be seen in the figure below, which represents the project quantities, separated by part.

MATERIAL QUANTITATIVES		
OBJECT	MATERIAL	VOLUME
LOW ROTOR	Acrylonitrile Butadiene Styrene - ABS	28867,51 mm³
TOP ROTOR	Acrylonitrile Butadiene Styrene - ABS	8777,50 mm³
SHOVELS	Acrylonitrile Butadiene Styrene - ABS	53678,24 mm³
Total		91323,24 mm³

Figure 9. Project quantities.

As for the technical specifications of the applied material, it is possible to disseminate the data in other projects and replicate the parameters, which allows the exchange and flow of information. The following image indicates the mechanical data specification of the material, the chemical composition, commercial and manufacturer reference.

Figure 10. ABS – BIM parameters.

The importance of BIM is also verified because it contains the CAD base in its composition, that is, it is possible to export parameterized three-dimensional BIM models to CAD software, simulations, and structural analysis. In this respect, this attribution enables the structural analysis of 3D models with complex surfaces that would be difficult to elaborate in CAD software. However, some matches can also be complex. The following figure illustrates the Pelton Turbine model in the ABAQUS Software, for structural analysis. It is noteworthy that the REVIT tool exports the model in SAT format, suitable for the analysis software, representing the interoperability between the software.
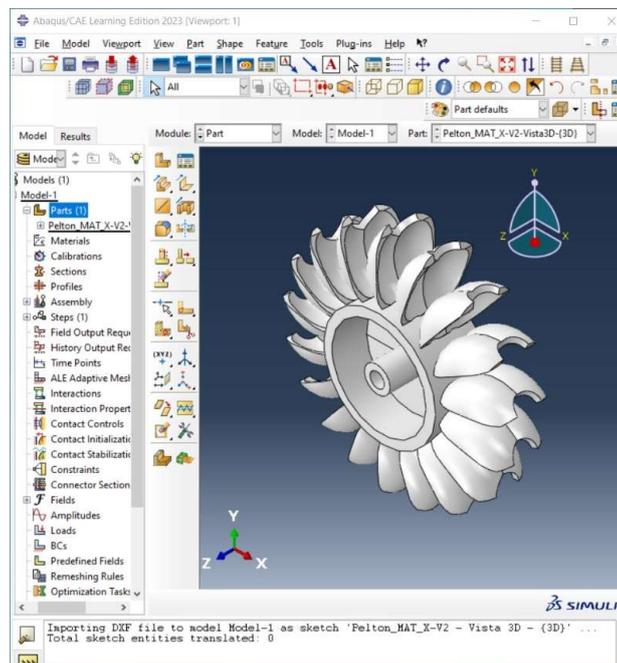

Figure 11. Model in ABAQUS software.

The Turbine was manufactured in 2 hours and 27 minutes and used 12.49 m of ABS filament, which represents an input cost of R$3.51, which is low when compared to different technologies and methodologies for prototyping. The following figure indicates the cost of the printer, filament and software used.

Tools, Machines and Supplies Cost	
Material	**Valor**
3D Printer	R$ 8.520,00
Revit License Student	R$ 0,00
Ultimaker Cura License Student	R$ 0,00
Simulia Abaqus License Student	R$ 0,00
Filament ABS 39 g	R$ 3,51

Figure 12. Project costs.

The following figure illustrates the turbine on the manufacturing plate and allows you to understand the printing efficiency in relation to the concave details of the blades.

Figure 13. Pelton turbine prototype.

To signify the importance of modeling mechanical machines in BIM concept, a search was carried out on the network for similar models of flow machines, using the keywords "Pelton" and "Turbine", in consonance and separately, on the following sites: BIMOBJECT, REVITCITY, BIMSTORE, BIMBR, NATIONALBIMLIBRARY, SYNCRONIA, BIMCONTENT, ARCAT, CONCORA, BIMCATALOGS, CADDETAILS, PRODLIB, CADFOR UM, MARKET.BIMSMITH, MODLAR, 3DLIBRARY, BIMETICA, POLANTIS and SPECIFIEDBY.

The returns from the searches pointed to models of blowers and generators that included Francis and wind turbines and general models of water pumps and exhaust fans but did not return any example of Pelton Turbine. In this scenario, the scarcity of Pelton turbine modeling is pointed out, although it verifies the existence of the application of the BIM concept with other flow machines.

6. CONCLUSIONS

There is a knowledge gap regarding the modeling of mechanical machines using BIM concept software. This was evidenced in the quantity and variety of models found on websites and open forums and no example was found for the Pelton Turbine.

The use of the BIM concept for modeling flow machines can be interesting in distinct aspects, among them the possibility of replicating parameterized models in various projects, generation of quantitative reports by part and material, interoperability with structural analysis software and the flow and exchange of project information.

Parameterized three-dimensional printing is an excellent technology that allows the free fabrication of complex and reduced-scale models for analysis. In this way, theoretical teaching on engineering, flow machines and hydraulic works can be understood through practical application, when elaborating and manufacturing prototypes, with the objective of presenting innovations, carrying out tests and comparing with data obtained in simulations.

After checking the quality of the turbine print, the efficiency of the project can be credited to the BIM concept tool, as in addition to providing precision for the modeled part, the tool dialogues with digital slicers through the STL format. It should be noted that the BIM concept allows the model to be exported and the project disseminated over the network, both using CAD and IFC bases, which makes it possible for several users to easily use the model and provide greater flexibility in the desired adaptations for printing.

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