# COB-2019-1665
# COMPUTATIONAL ALGORITHM FOR RAPID PROTOTYPING SELECTION

**Marlon Leandro Henrique Cheiram**
Federal University of Santa Maria, Department of Production Engineering, Av. Roraima, 1000, CEP 97105-900, Santa Maria/RS.
e-mail: marlonhcheiram@hotmail.com

**Moacir Eckhardt**
**Marco Aurélio da Fontoura Gonçalves**
Federal University of Santa Maria, CTISM-UFSM, Av. Roraima, 1000, CEP 97105-900, Santa Maria/RS.
moacir@ctism.ufsm.br; marcoctism@gmail.com

*Abstract. This work presents the flowchart of a computational algorithm to aid the selection of rapid prototyping processes (RP) based on the decision-making method with multiple AHP (Analytic Hierarchy Process) criteria. There are several methods of rapid prototyping in the market which are differentiated by the method of deposition employed, in this way, the selection of the most feasible for a certain application requires a good understanding of the interactions of the various characteristics and potentialities. The AHP method is a tool of choice based on mathematical methods of judging criteria selected according to an established goal. As a result of the work, we had obtained the elaboration of a flowchart of a dedicated computational tool that follows the steps of the AHP method in the selection of rapid prototyping processes.*

*Keywords: rapid prototyping processes, AHP, flowchart, computational algorithmic*

## 1. INTRODUCTION

In accordance ISO/ASTM 52900:2015, Rapid Prototyping (RP) was the first commercially significant application for additive manufacturing, and have therefore used as a general term for this type of technology. Rapid Prototyping (RP) is an advanced digital manufacturing technology developed with the popularization of computers in the late 1980s. Under the control of computer, the three-dimensional digital model of the part is firstly layered and discrete, and then the materials are stacked or cut layer by layer according to the principle of digital integration, so that the three-dimensional CAD digital model can be rapidly transformed into a physical model (Bai and Hu, 2018).

This digital representation of the part is divided into virtual layers by computer software. Each layer, representing a cross-section of the desired part, is sent to the RP machine where it is constructed on the anterior layer. This process, constructing the piece layer by layer from scratch, is repeated until the piece is completed as shown in Figure 1 (Prakash et al., 2018).

The rapid prototyping process involves a number of steps, according to Figure 2, that move from the virtual CAD description to the physical model (Peko et al., 2018). Scientists and students can build and analyze models faster for theoretical understanding and studies. Among the main advances that this process presented for the development of products are the reduction of time and cost, human interaction and, consequently, the product development cycle, also the possibility to create almost any format that could be very difficult to machine (Wong and Hernandez, 2012).
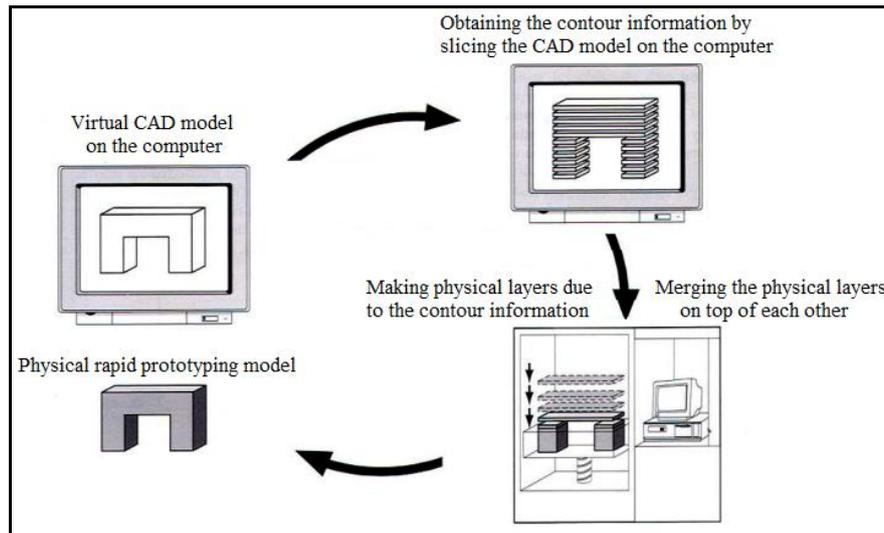
Figure 1. Rapid prototyping principle.
Available from: Prakash et al., 2018

Today, rapid prototyping technology has become vital to the maintenance and enhancement of the competitiveness of the major manufacturing industries. Its application provides improvement in the research and development process (R & D) of products, promoting the reduction of its final cost (Bai and; Hu, 2018).
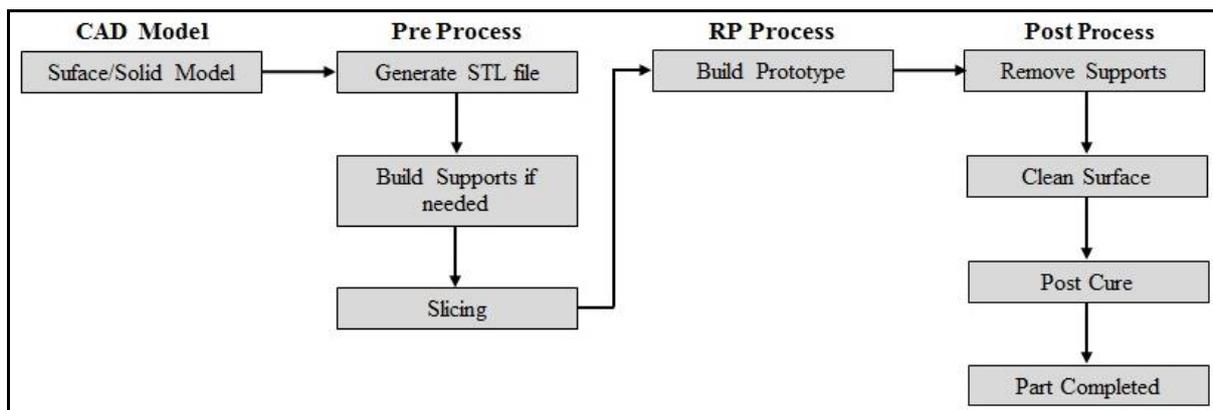


Figure 2. RP Process Work Flow.
Available from: Prakash et al., 2018

The selection of an appropriate process requires a sound understanding of the interactions among the part quality, part properties, part cost, build envelope, build time (speed) and other concerns (Rao and Padmanabhan, 2007 apud, Shende and Kulkarni, 2014). Each system has its own strengths, defects, applications, utilities and limitations (Lokesh and Jain, 2010). There are several RP systems on the market that employ different deposition methods, but are based on the same principle of adding flat and successive layers. These processes can be classified according to the initial physical state of the raw material in three groups: those based on liquids, those based on solids and those that use the raw material in the form of powder. Fig. 3 highlights some of these processes (Volpato et al., 2007).

Selecting rapid prototyping processes is a difficult and complex task. The focus is on which aspects will best meet product requirements by combining technical and economic factors (Booker and Swift, 2014). A tool that can identify the optimum process to meet specified requirements will therefore be immensely important to the designer as well as to the manufacturer of prototypes (Byun and Lee, 2005).

In accordance to the literature (Peko et al., 2018; Borille and Gomes, 2011), a tool of choice successfully used is the Analytical Hierarchy Process (AHP), which is a mathematical method of multi-criteria decision that possess as a characteristic the judgment of the criteria selected according to the purpose of the prototype. Can be found computerized systems on the worldwide network that apply the AHP method, but it is perceived that they are constructed for generic applications, different from the problem in question on this paper.

The objective of the present paper is to develop the flowchart of a computational algorithm to aid the selection of rapid prototyping processes using the multi-criteria AHP decision method.
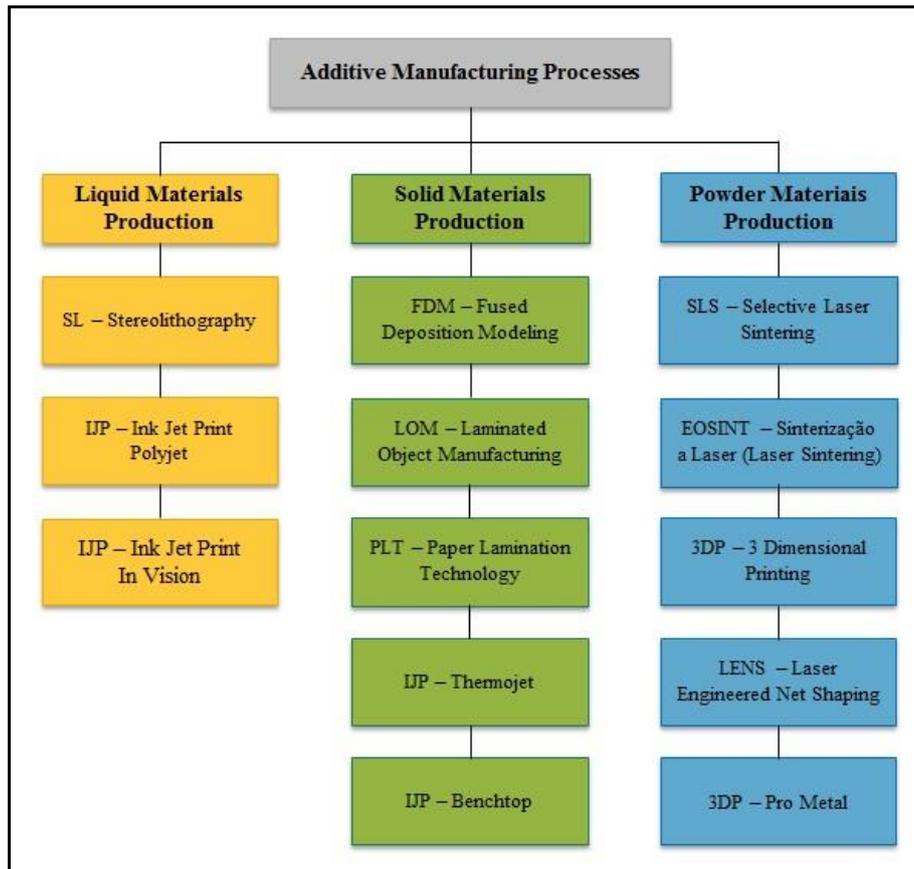
Figure 3. Classification of RP processes according to the material production.
Available from: Volpato et al., 2007 (adapted)

## 2. METODOLOGY

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making approach. Introduced by Saaty (Borille and Gomes, 2011), the AHP finds its application in solving complex problems and can be describe in three steps (Peko et al., 2018):

a) A hierarchy model of decision making problem by be developed. That model should have its objective, defined criteria and available alternatives (Fig. 4).

b) On each level of the hierarchy structure elements should be compared in pairs one with each other. Preferences of the decision maker are expressed by Saaty's scale of relative importances (Tab. 1).

c) From the estimations of relative importances of elements from appropriate level of hierarchy structure using a mathematical model, weights of criteria and local priorities of alternatives can be obtained, which can be later synthesized in overall priorities of alternatives. Overall priority of each alternative can be calculated by summing its local priorities multiplied by weights of criteria.
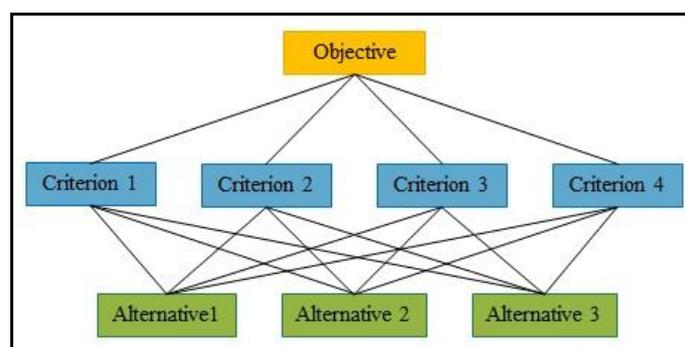


Figure 4. The hierarchical structure of AHP.
Available from: Marins et al., 2010 (adapted)

An important feature in the application of the AHP method is consistency checking of decision maker's estimations. During comparisons of pairs of hierarchy structure elements, consistency of decision maker's estimations and determined correctness of obtained weights of criteria and priorities of alternatives should be checked (Peko et al., 2018).

Table 1. Saaty's fundamental scale.
Available from: Marins et al., 2010; Borille and Gomes, 2011 (adapted)

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance of one over another | Experience and judgment slightly favour one activity over another. |
| 5 | Essential or strong importance | Experience and judgment strongly favour one activity over another. |
| 7 | Very strong importance | An activity is strongly favoured and its dominance demonstrated in practice. |
| 9 | Extreme importance | The evidence favouring one activity over another is of the highest possible order of affirmation. |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgments | When compromise is needed |
| Reciprocals of above nonzero | If activity $i$ has one of the above numbers assigned to it when compared to $j$, then $j$ has the reciprocal value when compared with $i$ | |
| Rationals | Rations arising from the scale | If consistency were to be forced by obtaining n numerical values to span the matrix |

The Consistency Ratio is an indicator of the consistency of comparisons (Marins et al., 2010). Higher value of the Consistency Ratio ($CR$) means that the decision maker is less consistent in his answers whereas lower value means the opposite. Generally, the Consistency Ratio has value 0,10 or less when the decision maker's answers are relatively consistent. If the Consistency Ratio is higher than 0,10, the decision maker should again estimate the importances of criteria. In this case, the calculated Consistency Ratio fulfills the condition $CR \le 0,10$ (Marins et al., 2010; Peko et al., 2018).

The calculated priorities are plausible only if the comparison matrices are consistent or near consistent. The approximate ratio of consistency can be obtained using Eq. (1) (Saaty, 2004):

$$CR = CI/RI \tag{1}$$

Where:
CR = Consistency ratio,
CI = Consistency index, and
RI = Random index for the matrix size, n. The value of RI depends on the number of attributes under comparison. This can be taken from Tab. 2 given by Saaty (2004).

Table 2. Average Random Index values.
Available from: Saaty 2004

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Random Index | 0 | 0 | .52 | .89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

The consistency index, CI, is calculated from the following Eq. (2):

$$CR = (\lambda max - n)/(n-1) \tag{2}$$

Where λmax is the principal eigenvalue of a n × n comparison matrix A.

From the study of the AHP methodology and similar applications in the literature, a flowchart of its hierarchical structure was made to support the elaboration of a computational algorithm that will help to select rapid prototyping processes.

In the flowchart all the steps of the AHP methodology are contemplated presenting, as a result, the capacity of the process to execute the objective according to the criteria and the established weights.

The validation of the flowchart will be performed through the implementation of a computational application, where all steps of the AHP method will be considered. The system should use as initial information the constants in bibliographies that use this method in the selection of rapid prototyping processes. In this way, it will be possible to compare the results obtained and, if necessary, make adjustments. The computational application will be the object of another paper.

Figure 5 illustrates a flowchart containing the steps of the method adopted for the selection of fast prototyping processes.

To apply the AHP method, initially it is necessary to insert pre-selected criteria according to the prototype specificities. These criteria, determined by the designer in the planning and construction of the model, will be analyzed in pairs and judged according to their importance. Following the flowchart shown in Fig. 5, the step 1 indicates the nominal entry of these criteria that will be stored in a database.
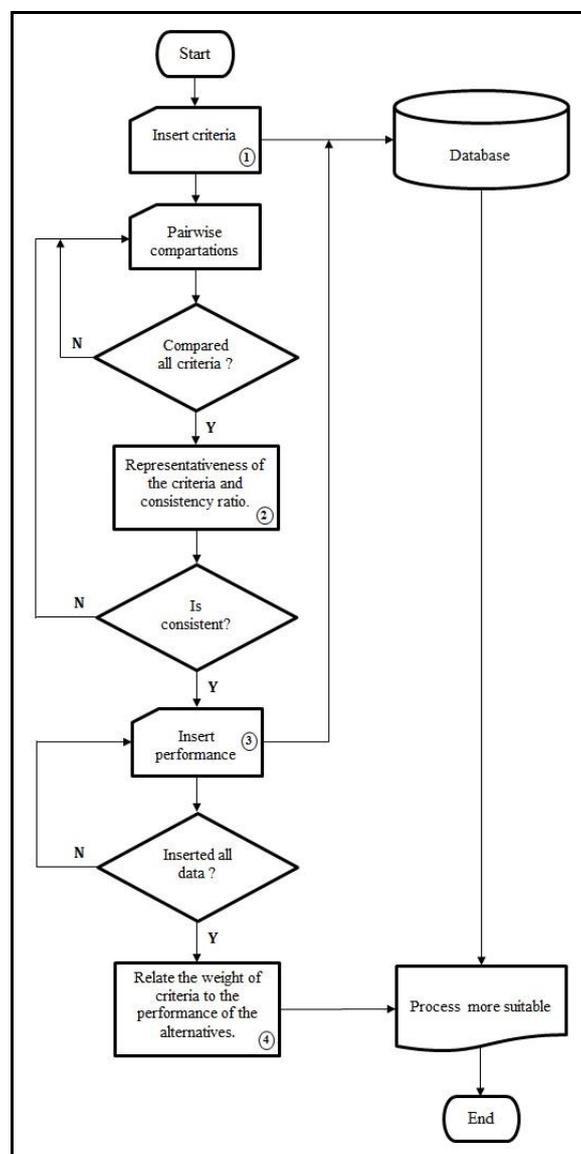


Figure 5. The hierarchical structure of AHP.

After analyzing the relevance between the criteria, a matrix of comparisons is produced that will provide the weight of each criterion in the prototype design. This weight represents the relevance of each criterion to the purpose of the prototype. According to these judgments a matrix model suggestion is presented in Tab. 2.

Table 2. Pairwise comparison matrix.

|  | Criterion 1 | Criterion 2 | Criterion 3 | Criterion 4 | Criterion 5 | Criterion 6 |
|---|---|---|---|---|---|---|
| **Criterion 1** | 1 | 1 | 3 | 5 | 9 | 9 |
| **Criterion 2** | 1 | 1 | 3 | 5 | 9 | 7 |
| **Criterion 3** | 0,333333333 | 0,3333333 | 1 | 5 | 7 | 7 |
| **Criterion 4** | 0,2 | 0,2 | 0,2 | 1 | 3 | 3 |
| **Criterion 5** | 0,111111111 | 0,1111111 | 0,14285714 | 0,33333333 | 1 | 3 |
| **Criterion 6** | 0,111111111 | 0,1428571 | 0,14285714 | 0,33333333 | 0,33333333 | 1 |
| **Σ** | **2,75555556** | **2,787302** | **7,4857143** | **16,66667** | **29,333333** | **30** |

The process performed the normalization of the matrix, Table 3, thus obtaining the weight relative to each of the methods in the model construction. The number 2 in the flowchart (Fig. 5) represents this step. The process also shows the result of the eigenvalue, the Consistency Index and the Consistency Ratio.

Table 3. Calculated weights of criteria.

|  | Criterion 1 | Criterion 2 | Criterion 3 | Criterion 4 | Criterion 5 | Criterion 6 | Weight |
|---|---|---|---|---|---|---|---|
| **Criterion 1** | 0,362903226 | 0,3587699 | 0,40076336 | 0,3 | 0,30681818 | 0,3 | 0,338 |
| **Criterion 2** | 0,362903226 | 0,3587699 | 0,40076336 | 0,3 | 0,30681818 | 0,23333333 | 0,327 |
| **Criterion 3** | 0,120967742 | 0,11959 | 0,13358779 | 0,3 | 0,23863636 | 0,23333333 | 0,191 |
| **Criterion 4** | 0,072580645 | 0,071754 | 0,02671756 | 0,06 | 0,10227273 | 0,1 | 0,072 |
| **Criterion 5** | 0,040322581 | 0,0398633 | 0,01908397 | 0,02 | 0,03409091 | 0,1 | 0,042 |
| **Criterion 6** | 0,040322581 | 0,0512528 | 0,01908397 | 0,02 | 0,01136364 | 0,03333333 | 0,029 |
| **Σ** | **1** | **1** | **1** | **1** | **1** | **1** | **1** |

After these operations, the step 3 of the flowchart (Fig. 5) indicates the input of the data regarding the performance of the available rapid prototyping processes against the criteria analyzed for the construction of the model.

In step 4 of the flowchart information about the weight of the criteria in relation to the rapid prototyping processes performance according to the AHP method is processed. This step indicate which process is the most efficient to fulfill the purpose of the prototype.

## 3. RESULTS AND DISCUSSION

As a result of the work, the flowchart (Fig. 5) was elaborated, which graphically presents the steps and logical relationships between the various stages of the AHP methodology to carry out the selection of rapid prototyping processes.

Also, were elaborated, according to this flowchart, some proposals for graphical interfaces that will be part of the computational application to be developed were elaborated.

Figure 6 illustrate the graphical interface proposal that allows to insert the criteria (according to step 1 of the flowchart) in the database.

Figure 6. Graphical interface for data input.

The interface presented above (Fig. 6) also allows the judgment of the criteria evaluated in pairs according to the AHP method. At each evaluation, the comparison matrix will receive the determined values so that at the end of the trials the matrix will be complete.

Once this step is completed, the ANALYSE button will activate the processing of this data through a computational algorithm, which will complete the comparison matrix according to the interface suggested in Fig. 7.
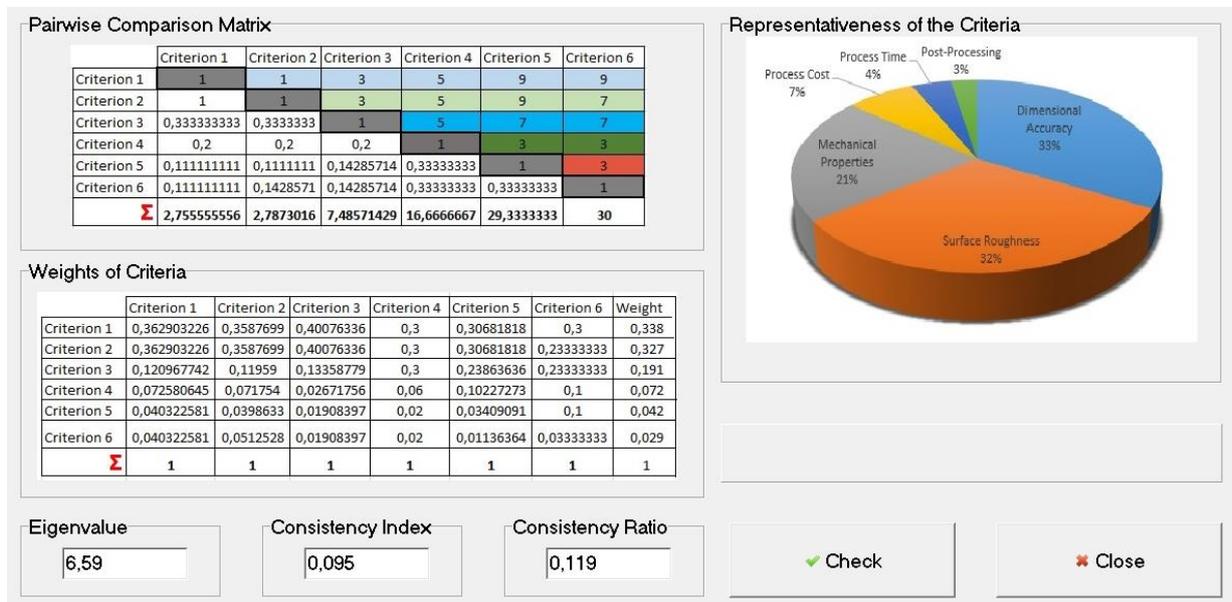


Figure 7. Interface to present the consistency judgment.

In this way it will be known the eigenvalue, the weight relative to each criterion analyzed, consistency index and the Consistency Ratio of the judgments made. The CHECK button will confirm if the judgments were actually consistent, Consistency ratios greater than 0,10 invalidate the process, necessitating a retrial.

The criteria inserted in Fig. 6 are exported into a process performance interface. The values referring to the performance of each criterion, according to the rapid prototyping process used, will be filled in this interface.

A suggestion of graphical process performance interface can be seen in Figure 8. This information will be stored in a database.



Figure 8. Rapid prototyping process performance interface.

The solution presented by the computational algorithm will be the most suitable process for the construction of the prototype, considering all the processes involved, as well as the analyzed criteria. A more detailed report will be available at the end of the program.

## 4. CONCLUSION

Rapid prototyping allows ideas or concepts to be materialized and subjected to assessments and corrections in the design phase, ensuring that all specificities are met before the product is released for series production. This feature reduces time-to-market and enables companies to become more competitive. The market for additive manufacturing equipment has been growing steadily and its results allow for optimism and promise of a significant place in the future of manufacturing. However, given the existence of several different processes that have distinct characteristics and results, the selection of a rapid prototyping process has become a difficult task.

In this way, the design of a computational algorithm dedicated to assist the selection of additive manufacturing processes becomes relevant. For that, a flowchart was elaborated following the multicriteria AHP decision method, according to the purpose of the prototype. The AHP method, based on user-defined criteria, results in the performance of each process. The objective is to make the selection of these rapid prototyping processes easier, revealing among the selected processes the one that best meets the criteria and the purpose of the prototype.

## 5. REFERENCES

Bai, S. and Hu, F., 2018. "The Role of Rapid Manufacturing Technology in Industrial Design". In: *IOP Conference Series: Materials Science and Engineering*. IOP Publishing,. pp. 032011.

Booker, P.D. and Swift, K.G., 2014. *Seleção de processos de manufatura*. Elsevier Brasil, São Paulo.

Borille, A.V. and Gomes, J.O., 2011. "Selection of additive manufacturing technologies using decision methods". *In Rapid Prototyping Technology - Principles and Functional Requirements*. 04 Jan. 2019 <http://www.intechopen.com>.

Byun, H.S. and Lee, K.H., 2005. "A decision support system for the selection of a rapid prototyping process using the modified TOPSIS method". *The International Journal of Advanced Manufacturing Technology*, Vol. 26, No. 11-12, pp. 1338-1347.

ISO/ASTM 52900. Additive Manufacturing – General Principles – Terminology; 2015.

Lokesh, K. and Jain, P.K., 2010. "Selection of rapid prototyping technology". *Advances in Production Engineering & Management*, Vol. 5, No. 2, pp. 75-84.

Marins, F.A.S., Pereira, M.S., Belderrain, M.C.N. and Urbina, L.M.S., 2010. *Métodos de tomada de decisão com múltiplos critérios: aplicações na indústria aeroespacial*. Blucher Acadêmico, São Paulo.

Peko, I., Gjeldum, N. and Bilić, B. "Application of AHP, fuzzy AHP and PROMETHEE method in solving additive manufacturing process selection problem". *Tehnički vjesnik*, Vol. 25, No. 2, pp. 453-461, 2018.

Prakash, K.S., Nancharaih, T., Rao, V.V.S. "Additive Manufacturing Techniques in Manufacturing-An Overview". *Materials Today: Proceedings*, Vol. 5, No. 2, p. 3873-3882, 2018.

Saaty, T.L. "Decision making—the analytic hierarchy and network processes (AHP/ANP)". *Journal of systems science and systems engineering*, v. 13, n. 1, p. 1-35, 2004.

Shende, V. and Kulkarni, P., 2014. "Decision support system for rapid prototyping process selection". *International Journal of Scientific and Research Publications*, Vol. 4, I. 1.

Volpato, N., Ahrens, C.H., Ferreira, C.V., Petrush, G., Carvalho, J., Santos, J.R.L. and Silva, J.V.L., 2007. *Prototipagem rápida - tecnologias e aplicações*. Edgar Blücher, São Paulo.

Wong, K.V. and Hernandez, A. "A review of additive manufacturing". *ISRN Mechanical Engineering*, Vol. 2012, 2012.

## 6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.