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Hierarchical Method for Prioritization of Sustainable Products' Characteristics

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The conception of the manufacturing process to be initially applied in the parts rapid production targeting a first embodiment of an idea (prototypes) and without many demands on strength and accuracy is called rapid prototyping. New rapid prototyping technologies are more accessible under the aspects of cost, accuracy, usability, environmental and prototypes started to be increasingly explored in the sustainable product development process. This paper proposes the application of hierarchical analysis method to support the decision-making in Rapid Prototyping processes based on the analysis of product and RP technology and prototype characteristics. The application of the developed method consists of assigning numeric values to the product characteristics and to the important characteristics for users in order to build the comparison matrix to perform the assessment and the prioritization steps of the relevant features. Performing the prioritization of features considered most important along with the characteristics of the chosen prototyping technology make possible the analysis of the effect of the characteristics prioritization. The concepts of product development, rapid prototyping and analytic hierarchy process for the sustainable product were used in a structure (lightweight dual) to evaluate the proposed strategy. The lightweight dual product from the 3D printing technology has been successful to show the product's purpose and functionality due to its lower cost, short execution time, good surface finishing and dimensional accuracy. The results show that the analysis of the sustainable product for rapid prototyping technology based on characteristics prioritization strategy improves the product design.

1. Introduction

The rapid prototyping use has been growing with the new technologies development resulting in faster production of improved prototypes. Rapid prototyping is used in several areas and can be of great importance to medical areas regarding the bone implants design (Sun et al., 2013), to electrical engineering with the full cells improvement (Jain, 2013) and to industrial engineering relating to sustainable products (Canciglieri et al., 2014). The efficient use of the rapid prototyping should observe aspects such as material to be used or the purpose of the prototype. The prototype conception must initiate with a study on the product concept, design, applications, users, processes and specifications and followed by the analysis of the sustainable aspects such as energy spent on the manufacturing, clean and renewable energy sources, raw material control, misuse and amount of the produced waste. The product concept is relevant due to the growing awareness on the economic and social aspects in the adoption of sustainable practices (Mattioda et al., 2013). The prototype of a product or part is essential in the development process since it enables the analysis of the product's geometrical form and functionality in an earlier phase to the production (Djamila et al., 2014).
A great advantage of rapid prototyping is the diversity of the material additive and subtractive technologies for the prototype production. The material addictive technology can accomplish more complex geometries, enhancing details and improving points which are hard to access to the more common manufacturing processes as milling and turning. According to Palm (1988), the rapid prototyping process must be sequential: (i) the construction of the component model in CAD format; (ii) the CAD model conversion into STL format that

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is adequate to stereolithography; (iii) slicing STL file into thin cross layers; (iv) physical construction of the model, stacking one layer at a time; and finally, (v) the constructed prototyping cleaning and finishing (Asiabanpour et al., 2004). For a thorough study, the analysis of the product's characteristics must not be performed only by reviews or empirical experiences, but through scientific methods to support the decision-making (Borille et al., 2008).

Rapid prototyping technologies have emerged to meet a growing demand to increase the speed of the new products development, and they allow the cooperative operation to improve the manufacturing of the prototype's parts in order to improve efficiency in terms of costs and time (Dvorak, 2004). For Vaidya and Kumar (2006), the methods of decision-making support permit the evaluation of the relevant criteria for the user, prioritize the opportunities for improvements and assist in decision-making. For Wang et al., (2007), the hierarchical analysis method, Analytic Hierarchy Process (AHP), is the most popular method of decision-making with multiple criteria that allow the measurement of the degree of decisions coherence. Moreno-Benito and Espuña (2011) suggest that the conception of new products must simultaneously consider structural and operational aspects of the product. Porzio et al., (2013) present a decision-making model to support the reduction of CO2 emissions and costs in the steel manufacturing process. Sant'Anna (2015) estates that decision support methods tend to be important in the data analysis because they provide a subsidy for decision-making.

The concept of developing products consists of market research activities, gathering information on technologies and identify the company's competitive strategies to define the product's specifications and its manufacturing process (Vinodh et al., 2014). Canciglieri et al. (2015) state that development of sustainable products can be defined as the application of sustainability concepts in organizational processes and other business activities integrated into the product development practices.

The integration and application of these concepts allow efficient implementation of sustainable (social, environmental, economic) and technological criteria in the analysis of the characteristics of processes and products for the design of new products. This article proposes the application of a hierarchical method to support the decision-making in Rapid Prototyping processes based on the analysis of product and RP technology and prototype characteristics. The method's aim is to foment companies to incorporate environmental sustainability in their product and processes and consolidate the development of effective sustainable products.

2. Conceptual Model

The hierarchical analysis method is a multi-criteria decision-making support which considers the product's characteristics acquired through meetings, trials and data surveys with the specialists as well as the characteristics of the rapid prototyping technology acquired according to the process technical. The concepts of rapid prototyping technologies, hierarchical analysis method and sustainable product development have been integrated to build the conceptual model to permit the execution of this experimental study. Initially, it was collected the relevant information for the user and identified the characteristics of rapid prototyping technology and product such as available time, desired quality, product usability, accuracy and cost of manufacture. This information is listed and analysed as criteria for structuring the construction of the hierarchical analysis method.

The application of AHP method consists of assigning numeric values to the listed criteria in order to build the comparison matrix in pairs between the criteria and to perform the necessary steps for the development of the method. The method provides a prioritization for the involved criteria and allows the identification of the hierarchical level of importance. Performing the prioritization of features considered most important along with the characteristics of the chosen prototyping technology make possible the analysis of the effect of the characteristics prioritization. Canciglieri Jr et al. (2014) suggest that industrial processes problems solution can be easily and robustly achieved when the experiment is planned and the answers analysed with methods that support the decision-making. Figure 1 illustrates the conceptual model of the decision-making method proposed.

The case study examined a toothbrush as it presents aspects of the sustainability concepts (economic, social and environmental) and features of solid and lightweight composite product. The selection of this product took into consideration the possibility of the prototyping process main features comparison as it shows features such as different degrees of complexity; different geometries and mass functions; and are produced in different polymeric materials. Firstly, the selected product has passed through the process of creation, analysis and three-dimensional modelling in the CAD system.

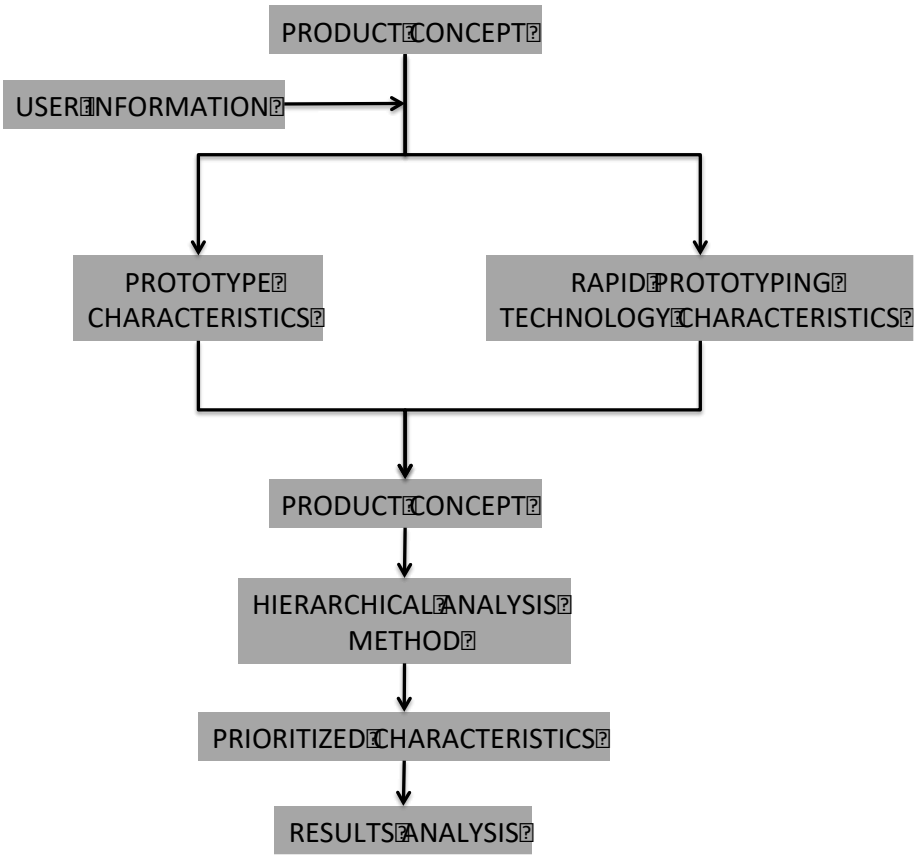
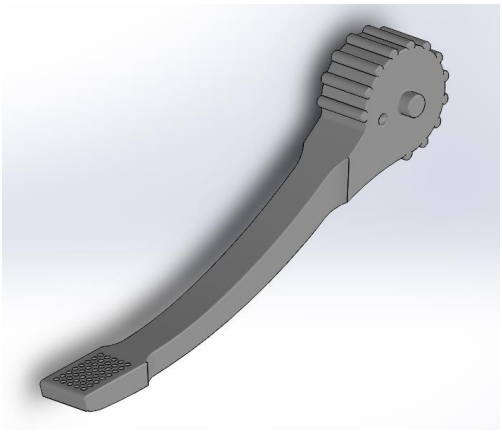


Figure 1: Proposed Conceptual Model

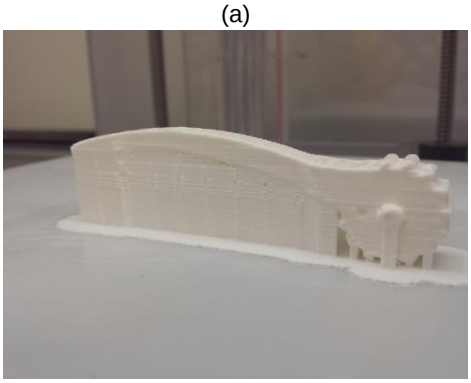
Case Study Phase 2 of the prototyping process allowed the conversion of the CAD model into STL format, and the product was prototyped in printer technology 3D Cubex Duo, from 3D Systems manufacturer. The printer setup for product specifications was an average density, using 0.25 mm thickness for each layer and orientation of 0°, with ABS material (acrylonitrile-butadiene-styrene) for production, as it presents excellent toughness and good dimensional stability (Sanchez et al., 1999). The time to perform the prototyping was 2 h and 36 min, showing a real weight of 14 g. Figures 2 (a) and (b) illustrate the prototype model in CAD system and the prototyped product.

The application of hierarchical analysis method began with the analysis of the product, rapid prototyping technology characteristics and the user's information that are important for the process of new product development. The important characteristics for users were an endurance test, exact size, high precision, low cost, less waste of material and the speed of production. In this way, it was analysed product characteristics such as size, precision, surface finish and functionality as well as the rapid prototyping technology characteristics of mechanical strength, material diversity, surface finish, accuracy, the prototype size, the speed of construction, the need for support, the loss of material, the need for post processing and the construction time. It is worth noting that all these characteristics must be analysed to avoid waste of raw materials and the possibility of using renewable energy, such as solar or hydraulic, for the printer operation.

To carry out the calculations for the hierarchical analysis method application, 09 (nine) characteristics were selected for the comparison matrix in pairs building: surface finish, mechanical strength, material cost, accuracy, prototype size, the speed of construction, need for support, loss of material and time. Following, it was assigned for each one a numerical value of importance and the calculations performed, resulting in values of relative priorities, which prove the initially assigned values and the importance of the relative priorities. It is pointed out that the characteristics that present the highest values of importance were mechanical resistance, prototype size and time for product manufacturing. Figure 3 illustrates the prioritization of analysed technology and product characteristics.



(a)



(b)

Figure 2: (a) Prototype Model in CAD format and (b) the prototyped product.

The sensitivity analysis of the hierarchical analysis method showed the reason value of consistency equals 0.0209 ($\varphi < 0.10$), considering consistent and coherent the numeric values assigned to the examined characteristics (Saaty, 2001). In this way, the use of hierarchical analysis method has allowed the determination of the prioritization of RP technology and product characteristics of great relevance on the prototyping execution.

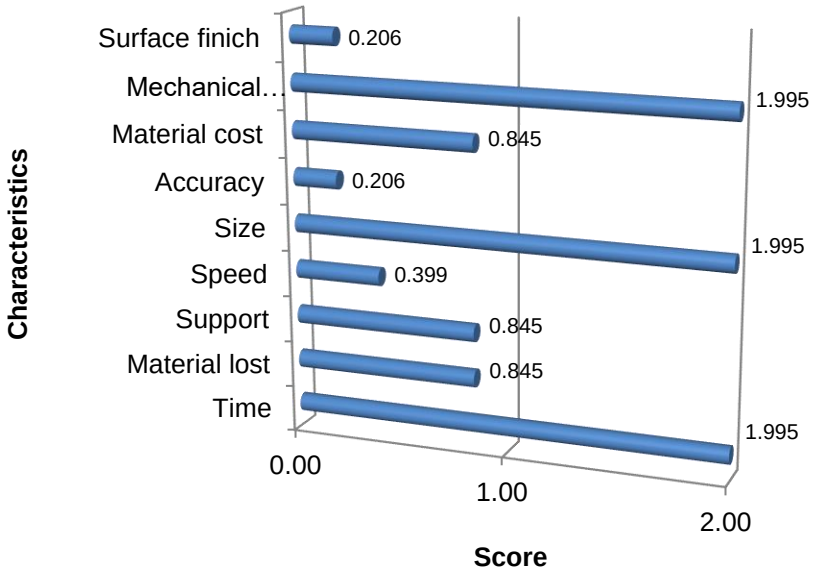


Figure 3: RP Technology and product characteristics prioritization

3. Conclusion

This article proposed a hierarchical method for decision-making support of Rapid Prototyping processes based on the analysis of product, RP technology and prototype characteristics. The method was developed and implemented from the relationship among these characteristics, generating the prioritization of the selected characteristics, their relevance level and their importance to the product design.

The performed experimental study with the toothbrush showed the prioritization of the analysed characteristics, highlighting the mechanical resistance, prototype size and prototype manufacturing time. The selection of the ABS material for the prototype development took into consideration the specificity of the chosen RP technology and works found in the literature that indicate relevant results in the analysis of its use and degradation through the thermal or photochemical ageing. The sustainable product development concepts must be applied, concerning the use of materials that are less harmful to the environment, not only in the prototype construction but also to the product mass production.

The importance of the developed hierarchical analysis method in the determination of the product and technologies characteristics prioritization to support the Rapid Prototyping process is highlighted by this study. The developed method involves the organization's strategic and operational areas orienting the development of sustainable products. For this research continuity, the authors suggest its application on other products types to investigate also aspects such as energetic efficiency and cost analysis.

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