25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0144
PROPOSAL OF A MORPHOLOGICAL CHART FILTERING METHOD THROUGH DESIGN FOR X TOOL

Jéssica Barbieri Gentile
Nathália Marcia Goulart Pinheiro
Franco Giuseppe Dedini
University of Campinas, School of Mechanical Engineering, Rua Mendeleyev, 200, Cidade Universitária "Zeferino Vaz", Barão Geraldo, Campinas, São Paulo, Zip Code 13.083-860
jbarbierigentile@gmail.com
nath.mgp@gmail.com
dedini@fem.unicamp.br

Abstract. *To meet product development demands, it is essential that companies use appropriate methodologies that allow adherence between customer requirements as well technical standards specifications. The product development process is the set of activities that, from the identification of a market need, lead to the design of a new product. Once started a new development project, ideas and alternatives are generated to meet end customers needs. DFX is an integrated optimization tool that allows to choose the best alternatives to continue the development process throughout the phases in an optimal way according to a specific attribute known as X. The objective of this work is to propose the use of DFS, DFSf, and DFMA to filter a morphological chart of a product in development, allowing to find optimizable solutions in relation to the chosen attributes through a case study. The filtering of the morphological framework allowed to reduce considerably the possible solutions and facilitated the choice from three to six principles of solutions for the product. It was possible to identify that two DFX can be competing, making it necessary to choose a prioritization method.*

Keywords: *Product development, Design for X, optimization, morphological chart.*

1. INTRODUCTION

Product development has been an important process to increase the competitiveness of organizations. To develop the design process properly, a series of events must be followed with a critical analysis of needs or motivations at each stage.

Back et al. (2008) affirm that a product development methodology aims to assist planning and design throughout activities that begin with the identification of the market needs through product design until the end-of -life.

There is an extensive literature about design process that establishes that when identifying a market need, a feasibility study is established that aims to expand product design, generating different alternatives behind creativity tools. At the outset, the goal is to generate as many alternatives as possible that meet customer needs defined in market research. Throughout design process, these alternatives must be systematically filtered until the best solution is defined and optimized in subsequent design steps.

Design for X is a tool used in the design methodology to assist in product development, so it allows the product to be competitive and meets the demands of the market throughout its life cycle. X is an attribute that represent the application of the tool in a development phase (as manufacturing or assembly) or some specific characteristic that the product must have (as design to low environmental impacts) (Holt and Barnes, 2009; Rozenfeld et al., 2006; Back et al., 2008).

The interest for sustainability issues has increased considerably over the past years, leading companies to adopt world-class sustainability policies to remain competitive. Therefore, Design for Sustainability (DFS) is used in the product development process to adapt product design to environmental, social and economic balance throughout the product life cycle, ensuring that market needs are met (Curtis and Walker, 2001; Kuçuksayraç, 2015).

DFMA (Design for Manufacturing and Assembly) aims to adapt the product design to the conditions of manufacture and assembly, optimizing the performance of the manufacturing system. DFSf attend the safety of the user and technical safety standards that the product must meet throughout its life cycle to ensure personal and environmental safety (Rozenfeld et al., 2006).

This work aims to present the application of DFS, DFSf and DFMA to refine the ideas proposed in the feasibility study phase, in which numerous solutions are generated to meet the need of the costumer through creativity, allowing to

find solutions that are optimizable in relation to the chosen attributes. It is possible that the DFS, DFSf and DFMA approaches have divergent results in the selection of alternatives, therefore, it is also expected to establish a comparison about the influence of different DFX as alternative, through a case study.

2. THEORETICAL FRAMEWORK

Asimow (1968) introduced in the literature first concepts about product development, determining all steps of product development. Pahl and Beitz (1977) separated the product development process into independent functional modules, giving systematization to the product development process.

Back (1983) published in his first work aspects of product design from the specification to the construction and testing of the prototype. He presented a structured methodology through product design phases at different levels of detail.

According to Rozenfeld et al. (2006), product development consists of a set of activities that aims to reach the design specifications of a product and its production process, based on the market needs.

Dedini (2018) presented a product development methodology in three stages:

a) First stage – Feasibility study: focuses on the use of creativity tools that will expand the solution options to solve market needs, considering the functions desired by the client.
b) Second stage – Preliminary design: aims to scale and optimize the functions based on the performance characteristics determined for the project.
c) Third stage – Detailed design: focuses in the definition of tolerance and product constructive adequacy in order to meet the technical needs and desired value conditions for the product.

According to the author, in the feasibility study, initially the needs of the costumers are identified and translated into project language. Then the functional analysis is performed, which allows to establish the functional objectives of the product to be explored by the creativity tools. Once the functions of the product are understood by the design team, creativity tools are used to explore as many solutions as possible to each function of the product. According to Dedini and Cavalca (1993) all design process is essentially a procedure of employment of creativity.

The morphological chart is a systematic creativity tool, proposed by Zwicky (1969), that makes possible discoveries and inventions systematically in large quantity simultaneously. The systematization, according to the author, encourages creative thinking in the design team, allowing the construction of many solutions for each function of the product. The constructive steps of a morphological chart are (Zwicky, 1969):

a) Formulate the problem to be solved;
b) Identify and analyze the parameters and functions that may be important for solving the problem;
c) Construct the morphological chart that contains all the solution principles for each product function;
d) Examine and evaluate the solutions contained in the morphological chart, according to the product objectives;
e) Select the appropriate solutions for application.

Some product development methodologies, such as the proposed by Rozenfeld et al. (2006) and the one synthesized by Dedini (2018), suggest that a combination of all existing solution principles for each function must be made, so that the morphological chart is complete.

Design for X-bility (DFX) is an integrated optimization tool that allows to consider, simultaneously throughout the product design, factors that can lead to the choice of the best solution according to a specific attribute, known as X-bility (Rozenfeld et al., 2006; Back et al., 2008). In this work are considered DFS (Design for Sustainability), DFSf (Design for Safety), and DFMA (Design for Manufacturing and Assembly).

Crul and Diehl (2006) defined Design for Sustainability (DFS) as a method that considers environmental and social aspects in product design and in its production chain. According Holt and Barnes (2010), concern about environmental damage has increased interest in research and development of sustainable products. The environmental impact of a product must be determined during the decisions made in the project.

According to Simanovska et al. (2016) DFS is an expansion of eco design that considers the environmental, social and economic implications at all stages of the product life cycle. Küçüksayraç (2015) affirms that, in addition to environmental, social and economic impacts, DFS should also considers innovation strategies in daily development practices.

DFS objectives include waste reduction, material selection, energy use, minimizing the use and waste of materials that cause adverse health reactions and manufacturing products that benefit and improve economic conditions of the society (Rounds and Cooper, 2002; Arnette et al., 2014).

Design for Safety (DFSf) approaches user and product safety, highlighting four safety areas that the project must considers: constructive, functional, operational, and environmental. In order to conduce a safety project, it is necessary operate using some of these techniques: directly attending safe-life or fail-safe, indirectly using additional protection systems, indicatively that only warn of the risks, and/or through monitoring and diagnosis devices, according to the product (Dedini, 2018).

In any area or techniques of operation, DFSf must ensure a safety product for the entire environment in which it is inserted (Rozenfeld et al., 2006; Dedini, 2018).

Design for Manufacturing and Assembly (DFMA) proposes the reduction and/or modularization of product components, facilitating their manufacture and assembly, resulting in lower raw material cost and reduction of production times (Boothroyd et al., 2000; Rozenfeld et al., 2006; Back et al., 2008).

Boothroyd et al. (2000) affirm that DFMA emerged from the joint application of Design for Assembly (DFA), that proposes methods to simplify products, and Design for Manufacturing (DFM), that aiming to minimize production costs. According the authors, DFA provides guidelines for reducing the processing time in assembling parts of a product through its structural simplification. Dowtatshahi (1994) defines DFM as the guidelines for standardizing product design, aiming the reduction of the total cost of production while maintaining the quality required by customers.

Barbosa and Carvalho (2013) proposed the application of DFMA to the design of an aircraft, concluding that for the DFMA application be efficient, its concepts must be considered from the initial stages of the project, as any DFX. Favi et al. (2016) suggested that DFMA can be used for decision-making along with product development as a selection criterion. Pinheiro et al. (2018) proposed a DFMA application in the selection of alternatives for a product using computational simulation and obtained conflicting results between the choice of the best solution according to DFMA and DFS suggesting that in some cases the use of more than one DFX may not be convergent. Carretta et al. (2018) proposed the application of Design for Sustainability to filter possible solutions proposed in a morphological chart for a portable motorized wheelchair kit, resulting in three to six optimizable solutions for the next phase of the project.

3. METHODS

Motivated by the growing search for means of obtaining energy through renewable and efficient sources that contribute to sustainability, this work proposes a feasibility study for a domestic wind generator which was developed by students of the course of mechanical engineering at Unicamp.

Initially, the needs of the customer in relation to the product are determined through questionnaires, which must be translated into a design language that allows them to carry out their functional analysis. In this way, dismembering the product in its functions, it is intended to create a morphological chart presenting the principles of existing and/or possible solutions for each function, generating the maximum possible combinations of product characteristics.

Once a morphological chart of the product embracing all options for each function is generated, many combinations will be possible to generate alternatives solution. It is intended to filter this morphological chart to obtain three to six solutions, according to DFX, following the steps:

a) Choice of DFX according to customer needs. In this work, through a preliminary analysis, have been chosen: DFS, because it is a product that aims to reduce environmental impacts; DFSf, to guarantee the safe use and; DFMA, since this product must present a low manufacturing and assembly cost in order to be feasible, allowing a low investment by the costumer. Therefore, the application of the method will be performed three times, once for each DFX.
b) Classify each solution principle of each function of the morphological chart between easily optimizable, intermediate and non-optimizable, assigning colors green, yellow and red, respectively, for each classification and according to one of the DFX.
c) Discard all solutions that are not optimizable and prioritize the use of easily usable solutions. In this step, it is possible that cannot be combined only easily optimized solutions, due to constructive product constraints, so it may be necessary to use an intermediate solution.
d) Choose combinations, among the viable solutions, that is, those that are easily optimizable or intermediate, for that three to six constructive alternatives for the product are created.
e) Analyze if occurs convergence or divergence between the solutions chosen according to each DFX, in order to illustrate whether they can be conflicting for the proposed product.

4. PRODUCT CHARACTERIZATION

During the research to identify the target audience of the wind turbine studied in this paper, some important characteristics were determined for the product, which allowed the choice of DFX to filter the morphological chart. These are:

a) Ease of assembly, installation and operation;
b) Fast investment result and investment of up to 3.600 dollars;
c) Reduction of environmental impacts;
d) Low noise;
e) Main use in residential water heating and lighting systems;
f) Safety for the user during installation and operation.

Based on the researches with potential consumers, it was determined that the wind generator of this paper should be used to urban residential installations in cases where it is desired to complement the main energy source, that is, the electricity grid from an energy concessionaire, aiming reducing costs with energy consumption and environmental impacts, as it is a renewable source of energy. It is expected that the product is suitable for urban installations as well as

rural areas. As regards the place of installation, it is expected that it can be installed in any place of the residence in an efficient way.

To facilitate the conception of the morphological chart, a diagram with its functional analysis was created, as shown in Fig. 1.

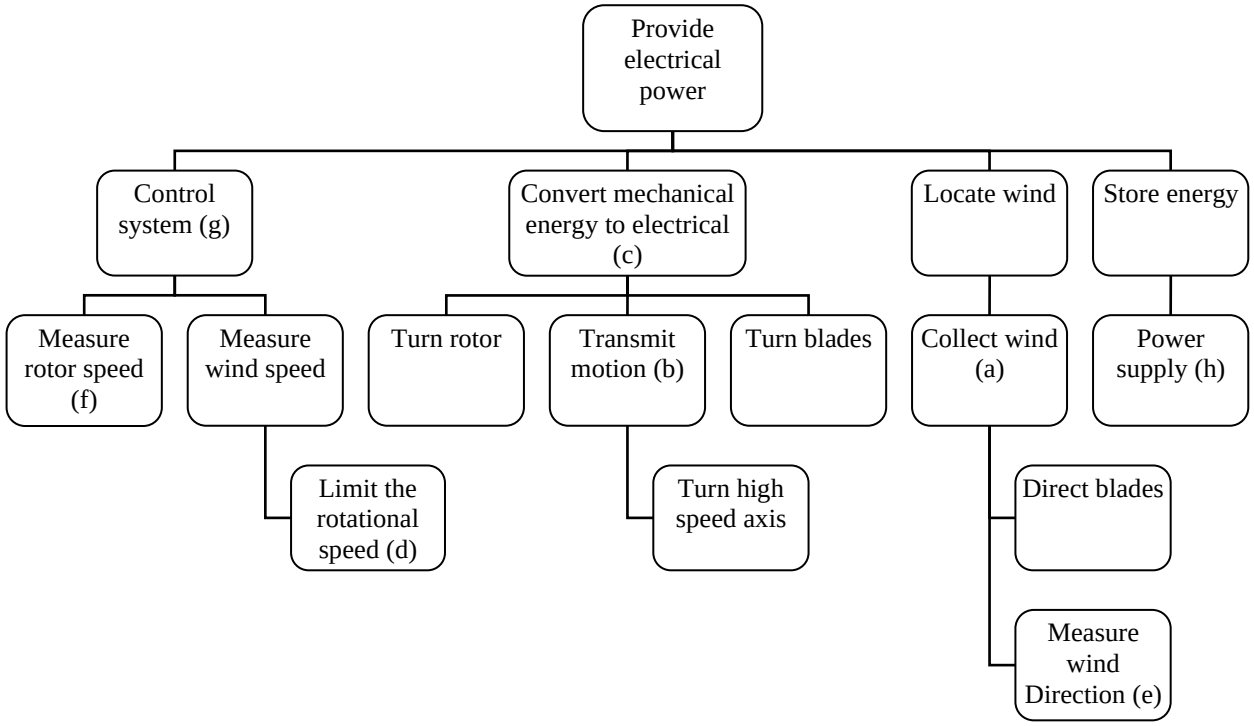

Figure 1. Functional diagram of the wind turbine for domestic use. Source: authors.

Once the product functions were identified, a morphological chart was created containing the main functions and solutions available to meet them, as shown in Tab. 1. The functions can be detailed as follows:

a) Collect wind: system that allows the capture of the wind to move the electric generator generating mechanical energy. It must be exposed to the wind and allow its capture efficiently.
b) Transmit motion: system that allows to transmit the motion captured from the wind to a transformer of mechanical energy in electric energy.
c) Convert energy: system that allows to convert mechanical energy in electric energy.
d) Limit the rotational speed: system that allows to reduce the rotational axis of the wind turbine aiming to stop system operation or only reduce the generation in case of excessive wind speed.
e) Measure wind direction: system that allows to measure wind direction aiming to direct the wind collect in order to make it more efficient.
f) Measure rotor speed: system that allows to measure rotor speed, feeding possible control systems implemented in the wind turbine.
g) Control system: general control system of the wind turbine. It allows to control speed, to direct the collection system, to feed loads and stops for safety. It also may be responsible for man-machine interface control and automatic security systems.
h) Power supply: system that allows to charge loads with electric power. Mechanisms may be used to store electrical energy for use when demand is present or the energy generated can be applied directly to the home network or to the external network, providing power to the system.

The solutions to meet each product function were determined by the project team by researching existing solutions on some patents for similar products and according to technical knowledge of the project team about the principles of product solution.

The morphological chart allows, through the selection of a solution for each function, to generate numerous combinations of possible solutions to compose the projected product. In this specific case, 19.921.440 solutions for the product are possible combining all the elements of the morphological chart with each other, maintaining the relation of only one element per function. In practice, it would be impracticable to analyze all these solutions to verify which of them meet the objectives of the product being eligible to continue the design process and can be optimized in the later stages. For this reason, it is suggested a filtering of the morphological framework allowing the reduction of possible solutions.

Table 1. Morphological chart of the wind turbine for domestic use

Functions	Solution options									
Collect wind	Horizontal axis wind turbine	Vertical axis wind turbine savounius	Vertical axis turbine darrieus	Static electricity wind plates	Piezo plates	Linear translating magnet	Darrieus rotor (egg bater)	Dutch windmill	Americam farm windmill	Cup
Transmit motion	Direct transmission	Sequential manual transmission	CVT	Planetary gear box	Timing belt	Chain drive	Belts and pulleys			
Convert mechanical energy in electrical	Homopolar generator	Asynchronous induction generator	Dual powered induction generator	Synchronous generator	Solenoid	Linear alternator	Stepper motor			
Limit the rotational speed	Drum brake	Magnetic brake	Hydraulic brake	Aerodynamic brake	Eletromechanic brake	Mechanical brake	Progressive clutch	Feather blades	Driving rotating base	Air fin - hawt
Measure wind direction	Wind Direction indicator (analogic)	Wind direction indicator (digital)	Wind vane	Anemometer	Barometer	Directional piezoeletric plates	None			
Measure rotor speed	Encoder	Anemometer	Eletromagnetic tachometer	Traction tachometer	Tachometer via pulse processing	Inductive tachometer	Hall effect current sensor	Hall effect linear proximity sensor	Gyroscope	Load cells
Control system	PLC	Micro controller	Analog controller	HPC	Passive mechanic	Active mechanic				
Power supply	Nickel/ cádmium battery	Metal/ Nitride battery	Capacitor bank	Direct on the equipment	Direct on the internal network	Direct on the external network	Direct on the internal and external network	Inertia Flywheel		

In the next section, after determining the morphological chart, the filtration will be done according to the DFX chosen in this paper.

5. FILTERING THE MORPHOLOGICAL CHART

The filtration of the morphological chart, presented in Tab 2, follows steps b, c and d presented in the methods section of this work.

Table 2. Filtered morphological chart of the wind turbine for domestic use

Power supply	Control system	Measure rotor speed	Measure wind direction	Limit the rotational speed	Convert mechanical energy in electrical	Transmit motion	Collect wind
Nickel/ cádmium battery	PLC	Encoder	Wind Direction indicator (analogic)	Drum brake	Homopolar generator	Direct transmission	Horizontal axis wind turbine
Metal/ Nitride battery	Micro controller	Anemometer	Wind direction indicator (digital)	Magnetic brake	Asynchronous induction generator	Sequential manual transmission	Vertical axis wind turbine savounius
Capacitor bank	Analog controller	Eletromagnetic tachometer	Wind vane	Hydraulic brake	Dual powered induction generator	CVT	Vertical axis turbine darrieus
Direct on the equipment	HPC	Traction tachometer	Anemometer	Aerodynamic brake	Synchronous generator	Planetary gear box	Static electricity wind plates
Direct on the internal network	Passive mechanic	Tachometer via pulse processing	Barometer	Eletromechanic brake	Solenoid	Timing belt	Piezo plates
Direct on the external network	Active mechanic	Inductive tachometer	Directional piezoeletric plates	Mechanical brake	Linear alternator	Chain drive	Linear translating magnet
Direct on the internal and external network		Hall effect current sensor	None	Progressive clutch	Stepper motor	Belts and pulleys	Darrieus rotor (egg bater)
Inertia Flywheel		Hall effect linear proximity sensor		Feather blades			Dutch windmill
		Gyroscope		Driving rotating base			Americam farm windmill
		Load cells		Air fin - hawt			Cup
		Extensometer		None			

Table 2 presents the eight functions of the product and the solutions generated exhaustively using creativity tools to meet each one. Each function had its possible solutions filtered according to the three DFX proposed in this work: DFS, DFMA, and DFSf. To classify the solutions are used a mnemonic parameter assigning the green color for easily optimizable solutions, red color for those that cannot be optimized and yellow color for the intermediaries that can be optimized, although less easily.

By combining all possible solutions for each function before filtering the morphological chart, it is possible to obtain 19.921.440 different sets for the product. However, most of these solutions may not meet the project objectives, in this work represented by the three DFX chosen. After filtering, all red fields are discarded, since they cannot be optimized in the subsequent steps of the project, thus they do not meet the project objectives. In this way it is possible to obtain the amounts of combinations for the product according to each DFX, shown in Tab. 3.

Table 3. Number of possible combinations before and after filtering of the morphological chart

DFX	DFS	DFMA	DFSf	Before filtering
Number of possible combinations	1024	1296	810	19.921.440

The number of possible combinations for the product is still large for the three DFX used in the filtration, however, it significantly reduces the time of analysis of combinations by the designers in relation to the number presented before the filtration.

After filtering the morphological chart, in the next section three solutions are determined for the product, respecting the filtration result, which must be used to proceed to the next stage of the product design.

6. RESULTS AND FINAL CONSIDERATIONS

After filtering the morphological chart, three possible solutions were selected to be optimized in the preliminary project phase to exemplify the tool proposed in this work, presented in Tab. 4.

To select a solution to the product compatible with DFS or DFSf, all non-optimizable (red) and intermediate (yellow) solutions were excluded, combining only the easily optimized (green) solutions.

To select a solution to the product compatible with DFMA, it was not possible to choose only easily optimized solutions, as the "Restrict rotation" function that does not provide easily optimized solutions that can be combined with solutions defined for the other functions. Therefore, it was necessary to choose the “dynamic brake”, which was considered an intermediate function in terms of optimization, but which is the best option for this solution.

When selecting a yellow option for a determined function it is understood that, in addition to filtering the solution possibilities for each function about a specific DFX, it is also important to consider constructive constraints between the proposed combinations.

Table 4. Example of possible combinations to compose the product according to each DFX

Functions	**Collect wind**	**Transmit motion**	**Convert mechanical energy in electrical**	**Limit the rotational speed**	**Measure wind direction**	**Measure rotor speed**	**Control system**	**Power supply**
Soluction 1 (DFS)	Vertical axis wind turbine savounius	Belts and pulleys	Synchronous generator	Driving rotating base	Wind vane	Hall effect current sensor	Passive mechanic	Direct on the internal network
Soluction 2 (DFMA)	Darrieus rotor (egg bater)	Direct transmission	Synchronous generator	Aerodynamic brake	Barometer	Gyroscope	Micro controller	Direct on the internal network
Soluction 3 (DFSf)	Vertical axis turbine darrieus	CVT	Synchronous generator	Mechanical brake	Wind Direction indicator (analogic)	Load cells	PLC	Direct on the internal and external network

Thus, all cells in red should be excluded immediately because they are incompatible with the DFX chosen for filtering the morphological chart and are not solutions that can be easily optimized in the preliminary project phase. The green cells are optimized for the defined DFX and should be combined to result in a set of three to six solutions that

meet customer and engineering voice requirements, both parameters defined at the beginning of the viability study. The cells in yellow, considered intermediate, are maintained and can be selected if the green options are not viable or considered inconsistent for the project. It is therefore returned to the table by selecting a yellow cell for best combinations and ending with three to six solutions that will be optimized in the preliminary design phase.

Three solutions combinations for the product were generated in this work so that each of them meets a single DFX. When filtering it was evident that it is not always possible to find solutions compatible with all DFX for a certain function in the filtering of the morphological chart. As an example of this occurrence it is possible to quote the function "Measure rotor speed" that does not have a solution that is green or yellow for the three DFX. In this case, selecting a green option for one DFX will necessarily be red for at least one of the other DFX. To perform a joint analysis of DFX it is necessary to add some attributions to the filtering method. Some possibilities to perform the joint filtering, which can be discussed in future works are:

a) Use a mathematical method to equalize the function in relation to the set of DFX, such as assign a numerical value to each color and perform a simple or weighted arithmetic mean to determine the final color of each function in relation to the set of DFX.
b) Use a statistical method such as the mode of colors in each field, assigning to the function the color that appears most in each DFX. In this case, it is also important to define a tie-breaking criterion.
c) Establish a DFX prioritization criterion according to the project objectives so that filtering priorities are met in cases where there is no green or yellow option for each function.

The tool used is an efficient method to filtering possible solutions, since the morphological chart generates an excessively high amount of possible solutions, being unfeasible for the project team to think of all the best solutions and can therefore ignore good solutions. The design team must be rigorous and properly experienced to censor non-feasible partial solutions to optimization in the preliminary project phase, finalizing the feasibility study with three to six possible solutions to be optimized and that are more likely to succeed.

It is important to ensure that the design team does not disregard important options leading the proposal tool to exclude technical important creative solutions, i.e, censor the creative process in the feasibility study phase. So, it is relevant that the design team has a lot of experience.

It is also very important that the design team has the appropriate qualification to judge each function, which can be facilitated by a multidisciplinary team since a product can carry out functions of different applications areas.

As proposals for further works it is suggested the implementation and use of the tool through computational methods, so that it is more likely to generate an optimal solution. Another proposal of further work would be the application of the filtering method of the morphological chart in joint analysis between different DFX comparing results obtained between the use of mathematical methods of means, statistical methods or hierarchization. Finally, a final proposal of further work would be the application of a second filtration in the morphological chart, after DFX filtering, considering only the constructive constraints of the product when combining its different functions.

7. ACKNOWLEDGEMENTS

This work was developed with financial support from the Coordination for Improvement of Higher Education Personnel (CAPES), the National Council for Scientific and Technological Development (CNPq) and the State University of Campinas (UNICAMP).

8. REFERENCES

Arnette, A. N.; Brewer, B. L.; Choal, T., 2014. Design for sustainability (DFS): The intersection of supply chain and environment. Journal of Cleaner Production, v. 83, p. 374–390.

Asimow, M., 1968. Introdução ao Projeto de Engenharia. São Paulo: Mestre Jou.

Back, N., Ogliari, A., Dias, A., Silva, J.D. 2008. Projeto Integrado de Produtos: planejamento, concepção e modelagem. Barueri: Malone.

Barbosa, G. F.; Carvalho, J., 2013. “Design for Manufacturing and Assembly methodology applied to aircrafts design and manufacturing”, IFAC Proceedings Volumes, Vol. 46, No. 7, pp. 116-121.

Back, N., 1983. Metodologia de Projeto de Produtos Industriais. Rio de Janeiro: Guanabara Dois.

Boothroyd, G.; Dewhurst, P.; Knight, W. A., 2000. Product Design for Manufacture and Assembly, Marcel Dekker, NY.

Carretta, F.; Gentile, J. B., Pinheiro, N. M. G., Pinto, D. D. M., Dedini, F. G., 2018. "Proposta de utilização de DFX na filtragem do quadro morfológico para seleção de alternativa para um produto sustentável". Em anais do XV Simpósio de Engenharia de Produção- XXV SIMPEP. Bauru, Brasil.

Crul, M., Diehl, J.C., 2006. Design for Sustainability: a Practical Approach for Developing Economies. UNEP, Paris.

Curtis H., Walker J., 2001. Design Council European Survey of Manufacturing Companies' Attitudes Towards Design for Sustainability. London: Design Council.

Dedini, F. G., 2018. Metodologia de Projetos. Notas de Aula. Campinas: Faculdade de Engenharia Mecânica da Universidade Estadual de Campinas.

Dedini, F. G.; Cavalca, K. L., 1993. Aplicação De Metodologia E Sistemática De Projeto Em Disciplina Do Curso De Engenharia Mecânica. Congresso Brasileiro De Educação Em Engenharia - COBENGE.

Dowlatshahi, S. (1994), "A comparison of approaches to concurrent engineering", The International Journal of Advanced Manufacturing Technology, Vol. 9, No. 2, pp. 106-113.

Favi, C.; Germani, M.; Mandolini, M.,2016. "Design for manufacturing and assembly vs. design to cost: toward a multi-objective approach for decision-making strategies during conceptual design of complex products", Procedia CIRP, Vol. 50, pp. 275-280.

Holt, R.; Barnes, C., 2010. Towards An Integrated Approach To "Design For X": An Agenda For Decision-Based Dfx Research. Research in Engineering Design, v. 21, n. 2, p. 123–136.

Küçüksayraç, E., 2015. Design for sustainability in companies: strategies, drivers and needs of Turkey's best performing businesses. Journal of Cleaner Production, v. 106, p. 455-465.

Pahl, G., Beitz, W., 1977. Konstruktionslehre: Methoden Und Anwendung Erfolgreicher Produktentwicklung. Berlim: Springer-Verlag.

Pinheiro, N. M. G., Ordoñez, R. E. C., Barbosa, G. L. L., & Dedini, F. G., 2018. Computational simulation applied in choosing the best solution in a product development using design for manufacturing and assembly approach. Brazilian Journal of Operations & Production Management, 15(4), 618-628.

Rounds, K. S.; Cooper, J. S., 2002. Development of product design requirements using taxonomies of environmental issues. Research in Engineering Design, v. 13, n. 2, p. 94–108.

Rozenfeld, H.; Forcellini, F.A.; Amaral, D.C.; Toledo, J.C.; Silva, S.L.; Alliprandini, D.H.; Scalice, R.K., 2006. Gestão De Desenvolvimento De Produtos: Uma Referência Para A Melhoria Do Processo. São Paulo: Saraiva.

Simanovska, J.; Grigale-Sorocina, Z., 2016. Design for sustainability approach in product development – a case study using innovative nail polishes developed by a small enterprise. Proceedings of the Estonian Academy of Sciences, v. 65, n. 3, p. 297.

Zwicky, F., 1969. Discovery, invention, research: through the morphological approach. Toronto: Macmillan.

9. RESPONSIBILITY NOTICE

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