

Product Development for Generation of Small-Scale Wind Power Using Design Methodology

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ABSTRACT

Use of electricity is largely responsible for human-technological development, however, there is a need to meet this energy demand using options that provide less environmental and social interventions. Use of wind energy provides a greater capacity of electric generation compared to photovoltaic energy, having less environmental impact among the so-called renewable energies. This proposal intends aesthetically and functionally to adapt a wind turbine for application in urban centers, in order to meet the residential energy demand. The method used consists of user-centered product design; similar analysis; survey of wind flows in the cities of Cruzeiro/SP and São Sebastião/SP; CAD virtualization processes; creation of mockups and finite elements for stress analysis. Bibliographical research was built in national periodicals in search of information about the market niche in Brazil and the use of product development and eco-design techniques. Final result showed that, using design techniques, it is possible to develop a wind turbine that meets the needs of users and is capable of withstanding winds of 40m/s. Thus, opening possibilities in the search for development of a small wind turbine, with relevance to national technological development.

Keywords: Design, Product design, Wind Energy, Eco-design.

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1. Introduction

The market of electricity generation distributed in Brazil has been gaining importance since 2012, especially after the publication of Normative Resolution No. 482 in April of the same year, which includes rules for decentralized generation market, guiding possible projects in the sector. The following definitions are adopted for the decentralized generation market:

- Microgeneration: units with installed power less than or equal to 100 kW, connected to the distribution network by means of a consumer unit.
- Mini-generation: units with installed power less than or equal to 1MW, connected to the distribution network by means of a consumer unit.
- As a generating source of electrical energy, the means: hydraulic, solar, wind, biomass or qualified cogeneration, according to ANEEL regulations.
- Electric energy compensation system: a system in which the active energy (generated) by the consumer unit by means of micro-generation or mini-generation is provided in the form of a free loan to the local distributor, which, in turn, makes the discount, offsetting it in the form of credits the consumer unit in which the electricity was generated. These credits can be used in the same generating unit or in another consumer unit, as long as they are duly registered in the same Individual Taxpayer Registry (CPF, in

Portuguese) or Legal Entity Registry (CNPJ, in Portuguese) of the same ownership as the generating unit.

According to a survey carried out by the Electric Energy Research Center (CEPEL, in Portuguese), by means of a request from the Ministry of Mines and Energy (MME), decentralized electricity generation using small-scale wind turbines (APP, in Portuguese) in Brazil is still very embryonic (PEREIRA et al, 2015). This brings great challenges with regard to the development of products for this market niche, due to the great incipience of national information in this regard.

On the other hand, a second survey carried out by CEPEL (PEREIRA et al, 2015) demonstrates a great acceptance by the general public for this type of product, with potential for growth in the electricity generation segment using APP in the medium term. Such a segment is strongly influenced by recent changes made in the distributed electricity generation sector after publication of Normative Resolution No. 482 (ANEEL, 2012), which, in turn, classifies electricity generation by wind power as an alternative to generation decentralized. The research also presents two important factors of acceptance by the final consumer for the purchase of this type of product, as shown in Figure 1, which shows the data obtained by research, pointing out the factors, Aesthetics/Design and Easy installation/Easy maintenance, as important factors for motivation to purchase the product. In this sense, Custódio (2009, p. 54) defines a wind turbine

as a machine which captures the kinetic energy existing in the wind and transforms it into mechanical, electrical or other energy. A wind turbine can also receive the name of weathervane or mill, being used, in this work, the nomenclature wind turbine or wind generator.



Figure 1. Top buying motivators. Source: Adapted from Pereira, 2015.

Two factors are important in the development of a product with the function of generating wind energy and can be directly influenced by designers, not only in aesthetic issue, that is, what is perceived as beautiful, but mainly in the application of rudiments and techniques for the user-centered product development process. Norman (2006, p.15) states that: “Appropriate and human-centered design requires all considerations are observed from the beginning”. In this way, designers can develop projects seeking improvements in mechanical strength, reduction in manufacturing and maintenance costs, among others. This segment of electricity production, in a decentralized manner using APP, is justifiable due to its low cost of production and transmission because, by producing electricity close to its consumption center, the need to build transmission lines is avoided, reducing, thus, the loss of potential generated during its transmission process.

The objective of this work is to develop a basic structure wind turbine concept for APP wind turbines, taking into account aesthetic, functionality and productivity requirements. Other goals can be included in this development:

- a) Use of CAD computational technology to create 3D prototypes.
- b) Use eco-design principles as a project requirement.

2. Literature Review

According to data and information presented by CEPEL, the APP wind turbine market in Brazil is still maturing, both

in terms of manufacturers of this equipment and in research and development. This factor is due to the lack of information and studies regarding the behavior of wind flow in urban and low altitude regions.

In 2013, the Ministry of Mines and Energy asked CEPEL to carry out a survey in order to identify the market potential for small wind turbines in Brazil. The research aimed to identify determining factors which influence the purchase decision of the final consumer to purchase an APP.

According to information published by CEPEL, 74% of respondents are interested in acquiring the equipment, indicating a positive horizon for the promotion of this technology in the medium term.

Table I. Motivation for Purchasing Wind Turbines

Motivation	%
Reduction in electricity bill	54
Reduction of greenhouse gas emissions	18
Price	8
Easy installation and maintenance	4
Energy independence	4
Search	4
Distributed generation	2
Basic network backup	2
Strategic	2
Personal interest	2

It is possible to observe that the main motivation for the acquisition of equipment is directly associated with reduction of electric energy bill, with 54% of the total. Another important factor to be observed is the price motivation, which, in turn, is inversely proportional when we refer to the investment value by the final consumer, that is, the lower the importance of the price item (Table I: Purchase motivation wind turbines), the greater its value (Table II: Investment disposition).

Table II. Investment Disposition

Investment	%
Until USD 1822,12	61,2
USD 1822,12 until 2733,19	8,2
USD 2733,19 until 5466,37	8,2
USD 5466,37 until 10.932,74	2,0
USD 10.932,74 until 18.221,24	0,0
USD 18.221,24 until 182.212,40	2,0
I don't know/ I don't want to answer	18,4

Source: Adapted from Pereira, 2015
 (Converted from reais to dollars. Quotation for 10/06/2021).

Table II shows the possibility of investments in acquisition of an APP by potential consumers (also based on answers to questionnaires by Pereira et al (2015), noting the most consumers face a purchase of an APP as an investment, with 61.2% declaring they would agree to invest up to US\$2000.00.

2.1. Climate changes

According to Wessie D. (2007) and Palmer T. (2014), there is a gradual increase in the average temperature of the Earth's surface due to greenhouse gases (GHG) leading the planet to increasingly extreme weather events with impacts on the sustainable development of countries, including Brazil. TF Stocker et al., (2013), explains that this phenomenon is occurring mainly due to constant human activity on the planet. Palmer T. (2014), comments that the reduction of GHG emissions can be achieved through the implementation of various local and global actions, which involve changes in people's consumption patterns. Faced with this urgency, the concept of sustainable development emerged, with the global objective of guiding policies aimed at balancing economic and social systems and ecological conditions

2.2. 2030 National Energy Plan

According to the National Energy Plan (PNE, in Portuguese) 2030, "Energy efficiency is one of the most important instruments of Brazilian strategy to reduce energy consumption [...]" (EPE, 2017). The national objective is to achieve a more balanced energy matrix in relation to renewables, as shown in Figure 2.

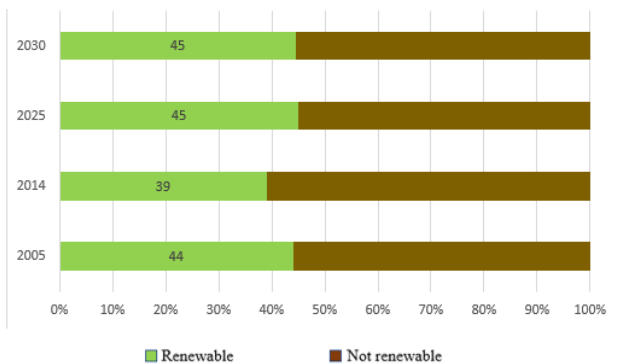


Figure 2. Source: Adapted from EPE (2021).

Brazil's main challenge is not to increase its share of renewable energy from its energy matrix, but to increase the levels of solar and wind energy, as hydraulic energy (considered sustainable) represents more than 65% of the matrix (EPE, 2016).

Although hydraulic energy is considered a sustainable matrix with regard to its main element of electricity generation, it has major challenges in managing impacts of its installation, such as modifying the flow of rivers, expropriation of land for creation of lake. dam and its high cost of construction and maintenance (EPE, 2017). One of the great disadvantages of a hydroelectric power plant is directly linked to its high distance between consumption center and electric power generating plant, causing other

costs such as, for example, transmission lines and distribution substations.

It is possible to see in Figure 3, in 2014, 39% of energy sources were renewable, and it is expected that from 2025 onwards, 45% of the share of renewable sources will have already been reached, maintaining this proportion until 2030. It is assumed that wind, solar and other sources have an increase equivalent to 20 million tons of oil equivalent (toe) between 2014 and 2025 and 29 million toe between 2014 and 2030. Between 2025 and 2030, its growth will surpass the expansion of water source in national matrix. Table 3 presents projections for this growth.

Table III. Domestic Supply of Types of Electricity Generation in Brazil

Source	2005	2014	2025	2030	Addition
Millions of tep					
Renewable energy	96.117	120.489	184.097	216.820	63.608
Hydraulics	32.379	35.019	53.209	59.949	18.190
Other Renewables	63.738	85.470	130.888	156.871	45.418
Sustainable Bioenergy	30.150	50.321	73.545	88.421	23.224
Cane derivatives	30.150	48.128	69.087	80.940	20.959
Vegetable Oil (Biodiesel)	0	2.193	4.458	7.481	2.265
Wind	8	1.050	7.898	8.989	6.848
Solar	0	0	1.075	3.056	1.075
Others	5.112	9.370	21.037	27.383	11.667
Non-renewable energy	121.819	185.100	226.153	265.152	41.053
Total	217.936	305.589	410.240	481.972	176.383

Source: adapted from EPE (2021).

In Table 3, it is possible to observe the growth of renewable sources in the national matrix, as well as their impact on the environmental issue, since the data presented refer to the amount of oil needed to meet the demand for electricity generation. Based on these projections, Brazil assumes two major specific commitments regarding the use of renewable sources, excluding hydraulic sources, and were established as follows: i) Increase the share of sustainable bioenergy in the energy matrix to approximately 18% by 2030; ii) Expand the use of renewable sources, besides hydropower, in the total energy matrix to a share of 28% to 33% by 2030 (EPE, 2016).

With changes in behavior of the final consumer, such as energy efficiency actions, load management and decentralized energy generation, small generating units emerged which resulted in a reduction in the need for expansion of centralized generation in the country (EPE, 2016). Without this contribution of energy efficiency and distributed generation, the demand to be met for centralized generation of electricity would be much greater, causing greater investments.

3. Methodology

3.1 Product Development and Design Methodology

Human perception is strongly influenced by the sense of vision, which, in turn, has a great impact on some decisions, including purchasing.

This decision is based on cognitive information of each individual, comparing the visualized object with his memory bank acquired throughout his life and attributing beauty and aesthetic values to the product. Based on these information, it is understood that products which are easier to understand, that is, those which allow less effort to be understood and have a more concise uniformity among their components, tend to receive greater attention from their observer. According to Baxter (2011, p.47), “Visual style of a product is what causes its visual attractiveness”. Products consisting of simple lines, in which there is greater uniformity among their related components and a symmetrical alignment, have greater market chances. The purpose of this simplicity is to reduce the user's cognitive effort as much as possible, making it easier for him to identify the product's functionalities without the need for any technical knowledge of the subject. Baxter (2011, p.47) also tells us that: “Complexity tends to increase people's security, the same way complexity or the unknown cause insecurity”. Based on this concept, the development of the small wind turbine (APP, in Portuguese) model is premised on the simplicity of its shape, in order to facilitate the understanding of the entire set of subsystems necessary for assembly of equipment. This concept of simplicity has been guiding all product research and development.

The design methodology applied to product design was used as a basis for development of this project, divided into three stages:

- a) Problematization;
- b) Survey of user data, similar products, ecology;
- c) Idealization;
- d) Prototypes;
- e) Evaluation.

4. Result and Discussion

4.1 Problem Definition - Durability and Eco-design

Durability allows extending a product life. Strategy of this extension has been widely used by the green economy and consists not only in application of quality raw materials, but also in creating a certain affinity between user and product (COLTRO, 2007). Another characteristic of durability is the possibility of improvements and/or replacement of parts and components of product, thus extending its useful life.

According to the Technology and Packaging Center of the Institute of Food Technology (COLTRO, 2007), development methodologies aimed at economic, environmental and social goals are outlined by the following actions:

- a) Greater efficiency of materials (renewables, recoverable, etc.);
- b) Greater energy efficiency (including during use, renewable sources, etc.);
- c) Land use;

- d) Cleaner production and use (avoiding hazardous products, etc.);
- e) Durability (longevity, maintenance, repair, etc.);
- f) Optimized functionality (modular, multiple functions, optimized controls, etc.);
- g) Reuse, recovery and recycling (dismountable, non-complex, recyclable, etc.);
- h) Avoiding hazardous substances (health, safety, lower environmental impact, etc.)

When talking about ecologically correct or ecological products, often only the product itself is taken into account, not analyzing its context as a whole. With this vision in mind, it is possible to exemplify the APP in a simple way: as a product aiming to generate clean and cheap energy in a decentralized way for an urban residence.

Custódio (2009, p.240) states "Installation of wind farms close to small load centers in the interior reduces electrical losses in transmission and sub-transmission, increases region's reliability and encourages the use of local resources". Applying Eco-design methodology, one can globally analyze all issues pertaining to the creation of a product which is less aggressive to environment, and this is only possible by applying this methodology from its inception. Its basic idea should already be thought of ecologically. A product considered ecologically correct is one that consists of a greater reduction in impacts, whether environmental or social (Figure 5). Maintaining the technical characteristics of original product, with no change in its functionality and performance.

Aldabó (2002, p. 105) mentions that conserving environment is a way of valuing man in all aspects, developing conditions for life quality. Also, according to the same author, sustainable development has as its goal the nature conservation, aiming to maintain the planet's capacity to support development [...] (ALDABÓ, 2002, p. 107), this must meet the needs for human and technological development, with no prejudice to future generations, and also presents the main questions between the need to develop new technologies and environmental aspects (Table IV).

Table IV. Social and Environmental Questions for Product Development.

Engineering	Socioenvironmental
Deterministics	Probabilistic
Task-oriented	Purpose oriented
Deductive	Intuitive
Objective	Subjective
Quantitative	Qualitative
Operational analysis	Analysis of system dynamics
Cost benefit analysis	Analysis by multiple attributes
Technological decisions	Alternative systems
Optimized use of resources	Conservation of social and environmental integrity
We can do it	Should we do?

Source: Adapted from Aldabó (2002).

It is possible to note inherent differences of two points of view presented in Table 1, for instance, while engineering view turns to issues such as quantitative product analysis,

focusing on the cost-benefit involved, optimization of the use of involved resources and prioritizing the technology used, the socio-environmental focus permeates issues such as product purpose, performing qualitative analysis, permeating multiple involved attributes, prioritizing socio-environmental integrity and seeking alternative systems.

A product considered ecologically correct is one which provides a reduction in impacts, whether environmental or social (Figure 3), maintaining the same technical characteristics of the original product, striving not to alter its functioning and performance qualities (KAZAZIAN, 2005).

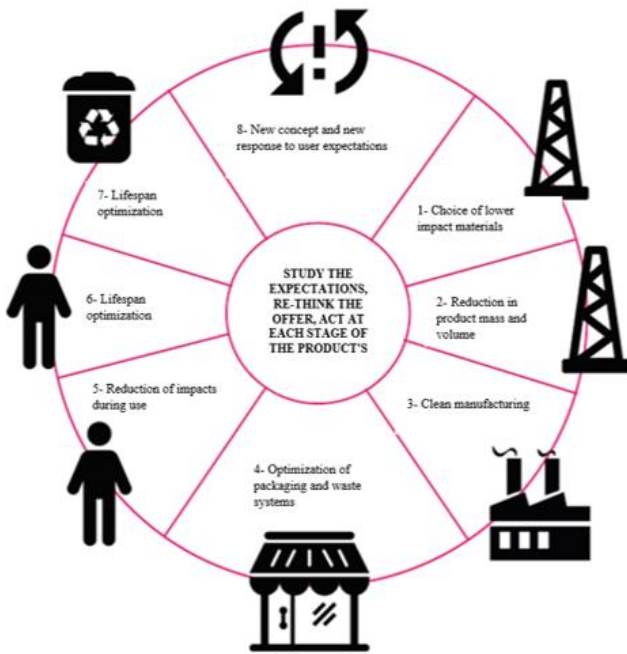


Figure 3. Eco-design Wheel – for ecologically correct products. Adapted from Kazazian, 2005.

In Figure 3, it is possible to observe the so-called Eco-Concept Wheel (Kazazian, 2005), which starts with the materials choice with less impact (social and environmental); reduction in product mass and volume; clean manufacture of it; optimization of possible problems related to packaging and waste; impacts reduction during the use of product; optimization of product life and end of that life; and, finally, a new concept centered on users' expectations and needs. Thus, this cyclical process allows the development of an ecologically correct product since its inception, even opening up room for continuous improvement for future development teams.

4.2 Similar Analysis

Bearing in mind the process for similar analysis using Prioritization Matrix, four similar products were analyzed. Data are shown below.

Similar 1 – Vertical axis wind turbine Gale of Tangerine Alternative Power LLC.



Manufacturer	Tangarie Alternative
Source	USA.
Rotor diameter	Not provided
Min speed of wind:	3 m/s.
Max speed of wind	40m/s.
Generator:	10 kw.
Weight	200 kg.
Turbine height	1 m.

Figure 4. Gale vertical axis wind turbine. Source: The authors from data provided by the company (2021).

Positive parameters:

The minimum wind speed to drive the turbine is within the design parameters in relation to the total height of the turbine suitable for the type of application proposed, thus avoiding a visual intervention in the environment.

Negative parameters:

- a) Excessive weight makes it difficult to install on some types of roofs;
- b) It does not have a safety lock with manual activation, which can cause accidents during maintenance;
- c) Due to the lack of information on noise emission in other similar products, it will be disregarded in this evaluation.

Similar 2 – Vertical Axis Wind Turbine (VAWT) wind turbine from Clearfield Energy.



Manufacturer	Cleanfield
Source	USA.
Rotor diameter	2,75
Min speed of wind:	3 m/s.
Max speed of wind	10 m/s.
Generator:	4.5 kw.
Weight	245 kg.
Turbine height	3 m.

Figure 5. Vertical Axis Wind Turbine (VAWT). Source: The authors, based on data provided by the company (2021).

Positive parameters:

Minimum wind speed to drive the turbine is within the design parameters, as well as the rotor diameter, avoiding the need for a larger area for installation.

Negative parameters:

- a) It has excessive weight, making it difficult to install on some types of roofs;

- b) It does not have a safety lock with manual activation, which can cause accidents during maintenance;
- c) Low wind speed for automatic safety lock activation.

Similar 3 – Wind spire Technology (Wind spire 200) from Wind spire Technology.



Manufacturer	Cleanfield Energy
Source	USA.
Rotor diameter	
Min speed of wind	3.8 m/s.
Max speed of wind	47 m/s.
Generator:	1.2 kw.
Weight	283 kg.
Turbine height	9.1 m.

Figure 6. Wind spire Technology (Wind spire 200). Source: The authors from data provided by the company (2021).

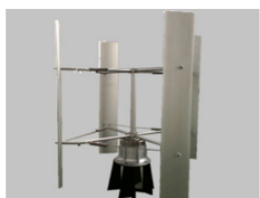
Positive parameters:

The minimum wind speed to drive the turbine is within the design parameters. Its maximum operating wind speed is considered adequate due to the large variation in wind direction and speed found in urban environment.

Negative parameters:

Its height and weight allow its installation only on the ground or in large buildings, limiting its application.

Similar 4 – Shanghai Aeolus Wind power Technology (SAWT P-10) from SAWT.



Manufacturer	Windspire Technology
Source	China.
Rotor diameter	30 cm
Min speed of wind:	4-20 m/s.
Max speed of wind	40 m/s.
Generator:	DC 12v.
Weight	2 kg.

Figure 7. Shanghai Aeolus Wind power Technology (SAWT P-10). Source: The authors, based on data provided by the company (2021).

Positive parameters:

- a) The minimum wind speed to drive the turbine is within the design parameters. It has a full diameter suitable for the type of application, enabling a wide variety of installation locations.
- b) Negative parameters:
- c) Lack of manual activation of safety lock can cause accidents during its maintenance.

According to data obtained by means of the use of the Prioritization Matrix, the minimum wind speed to activate a turbine is in the range of 3 to 3.8 m/s; 100% of similar evaluated; they need specialized labor for their assembly and installation; the maximum wind speed for operation is between 40 and 47 m/s.

4.3 Sketches

Sketches development process aims at a better understanding of the creative process, making its execution a step of great importance to product designers, having several purposes. In this step, project characteristics are created and analyzed in a simplified way. A highlight referring to this stage is linked to creation freedom. At this moment, there is no concern with measurements, weights and manufacturing mode, but rather with understanding the problem encountered and providing the best possible solution within a short period of time (Figure 8). For that, quick drawings are made in order to solve the intended problem. Figure 8 illustrates the basic characteristics of an APP project, as determined by the global analysis carried out in the similar search using the GUT12 matrix (Prioritization Matrix).

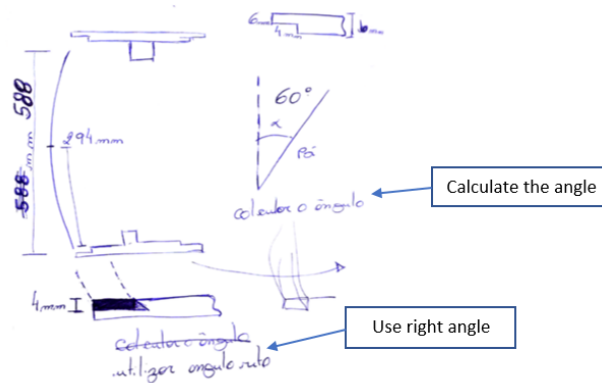


Figure 8. Creative process (support and attachment system of APP). Source: The authors (2021).

Figures 9 and 10 bring the sketches depicting the creative process to think, respectively, of the shaft cavity system; the blade/holder slot system; angle of attack of the blade and the cross section.

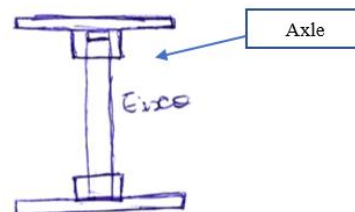


Figure 9. Shaft cavity system. Source: The authors (2021).



Figure 10. Paddle/bracket slot system. Source: The authors (2021).

Figure 11 displays the sketch of the fastening system between the blade unit and the APP support. This system aims to make the equipment assembly process easy to understand. The use of sketches makes a visual and simplified approach feasible for a better understanding and solution of the problem found.

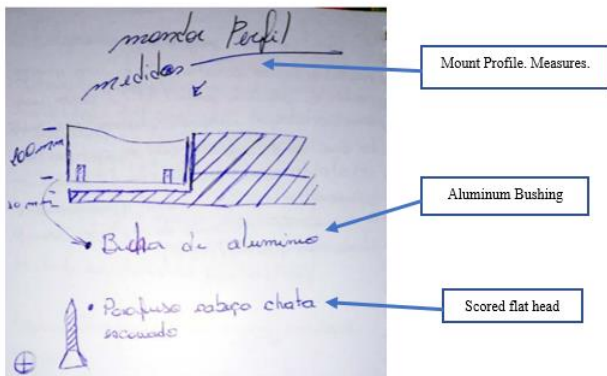


Figure 11. Attachment system shovel/support of APP. Source: The authors (2021).

Figure 12 illustrates the basic characteristics of an APP project, as determined by the global analysis, carried out in the similar search, using the Prioritization Matrix

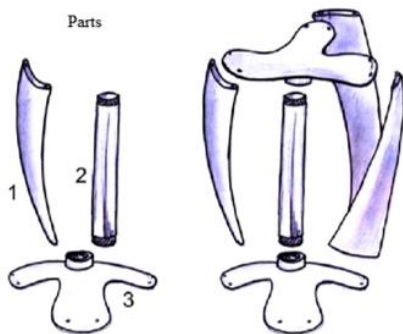


Figure 12. Basic characteristics of APP project. The authors (2021).

4.4 Physical restrictions

Physical limitations have ability to restrict possible

operations of an object or product. In this way, we avoid incorrect handling or assembly. These are characteristics which rely on the physical world to carry out their operations and their main application will be aimed at avoiding errors in the equipment assembly process. Norman (2016, p.114) states physical restrictions become more efficient and useful if they are easy to see and interpret. Only the right processes must be visualized to identify which part must be operated, physical restriction process is shown in Figure 13. In this step, the assembly process between the base and the aerodynamic profile of the APP is carried out.

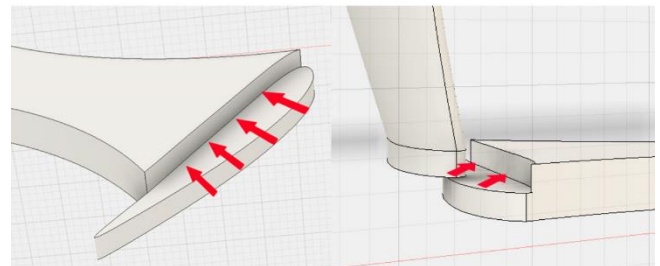


Figure 13. Physical restriction process. Source: The authors, 2021.

In this way, we guarantee the correct execution of the assembly and maintenance processes, avoiding the user's excessive cognitive load and enabling a clean and efficient process.

4.5 Semantic Constraints

Semantic constraints (Figure 14) aim to work out the meaning of the situation at the time of performing the task, controlling the number of possible actions by the user. According to Norman (2006, p.115), semantic constraints rely on our knowledge of the world situation. This knowledge has been worked on in order to create a simplified assembly process for the APP product, and it can be easily observed in the fitting system between the support and the wind turbine blade.

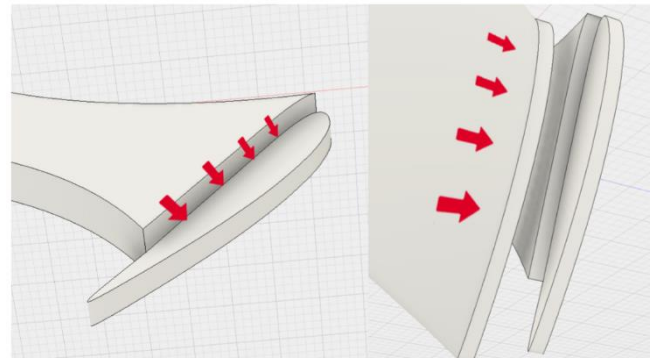


Figure 14. Semantic constraint. Source: The authors, 2021.

4.6 Design

Based on research, similar analysis, sketches and questions related to semantic and physical constraints, the APP was developed according to the apparent technical drawings which demonstrate details of the APP assembly, and describe the process of product development, parts which involve it, base design and subsystems. The simplified form (Figure 15) has other characteristics beyond aesthetics, such as ease in production process, reduction in production cost, ease in assembly process and replacement of parts. There is no need for specialized labor.

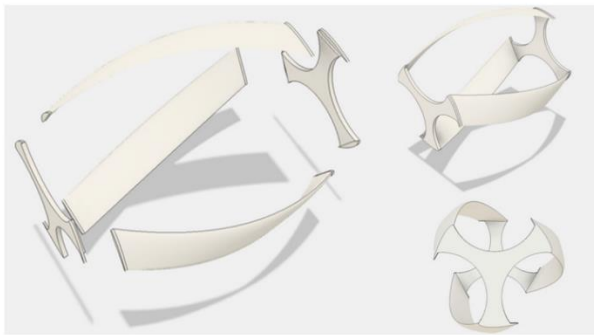


Figure 15. Mounting System. Source: The authors, 2021.

To arrive at this concept, an analysis of similar was carried out, taking into account the number of simultaneous factors to be analyzed, ranking the problems by means of application of the Prioritization Matrix.

4.7 Durability

Durability makes it possible to extend the product life. This market strategy has been widely used by the green economy and consists not only in application of quality raw materials, but also in creating a certain affinity between user and product. Another characteristic of durability is the possibility of improvements and/or replacement of parts and components of the product, thus extending its useful life. Environmental objectives related to product strategy are: lower environmental impact; maintaining or increasing product functionality; resource conservation; recycling; energy recovery and pollution prevention; reduction of waste and other impacts on environment (ACV - CETEA / ITAL, 2007). According to the Center for Technology and Packaging of the Institute of Food Technology (CETEA/ITAL, 2007), methodologies aim at economic, environmental and social goals and are outlined by the following actions:

- Greater efficiency of materials (renewable, recoverable, etc.);
- Greater energy efficiency (including during use, renewable sources, etc.);

- Land use;
- Cleaner production and use (avoiding hazardous products, etc.);
- Durability (longevity, maintenance, repair, etc.);
- Optimized functionality (modular, multiple functions, optimized controls, etc.);
- Reuse, recovery and recycling (dismountable, non-complex, recyclable, etc.);
- Avoiding hazardous substances (health, safety, lower environmental impact, etc.).

This feature will be attributed to the small wind turbine (APP, in Portuguese) model and can be easily observed in its assembly subsystems, which consist of three unique parts and form the entire wind turbine assembly, causing a reduction in production cost and especially easy replacement, providing an increase in the life cycle of equipment.

4.8 Material Selection

For the material choice of small wind turbine (APP, in Portuguese) production, all stages of development of an ecological product were taken into account, opting for the thermoplastic polymer of Polyethylene Terephthalate (PET), found in large quantities today, due to its low lifetime. At this stage, the premise of ecological product development (Eco-design) is taken into account. The objective is to transform a product, in this case the PET bottle, to generate electricity.

4.9 3D Modeling

After preparing geometry, it was defined material properties, load types and constraints. The type of desired analysis was also defined. In Figures 16 and 17, it is demonstrated the modeling of complete geometry of the developed APP and an emphasis on fixation points, respectively.



Figure 16. Full Geometry of APP. Source: The authors (2021).



Figure 17. Attachment points of the APP parts. Source: The authors (2021).

The complete geometry (Figure 18) and the fixation points (Figure 19) can be visualized in the form of a technical drawing. After defining these parameters, the APP blade mesh was created (Figure 18), thus completing the creation of mathematical model to perform the FEM tests (Finite Element Methods).

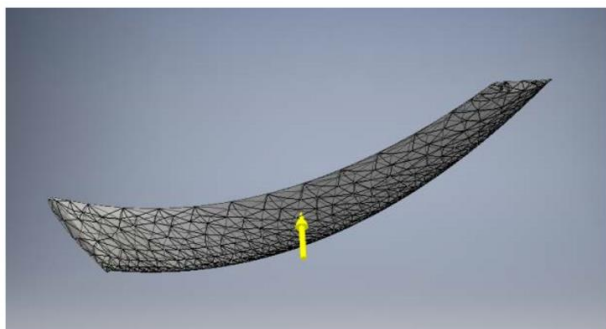


Figure 18. APP Shovel Mesh. Source: The authors (2021).

To obtain data for the FEM analysis, Autodesk Inventor software was used. Great care must be taken in preparing the geometry as it can result in errors which result in flawed results. Discretization in FEM is the process of creating mesh in which the object is subdivided into elements and each element has a determined size, a finite size, and from the understanding of each element, the set behavior is understood.

In Results Analysis, it is discussed about the results of 3D modeling made under the MEF and based on Von Mises Stress theory. In Figures 19 and 20, the result of the stress test carried out by means of the MEF is shown. As it is an aerodynamic element, tests were carried out on the blades, it is being the region which will receive the greatest load of kinetic energy from the wind.

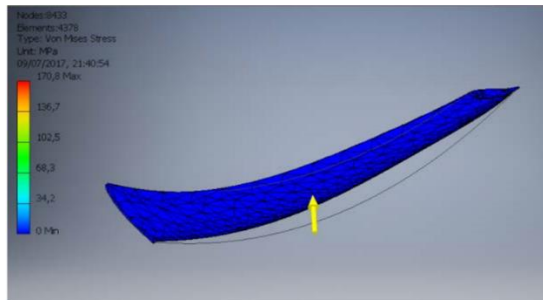


Figure 19. Von Mises tension in the APP blade mesh. Source: The authors (2021).

Figure 20 shows that the highest stress points are located in the fastening system between the blade and the wind turbine support, however, the stress rate was low, not causing any kind of damage to the structure.

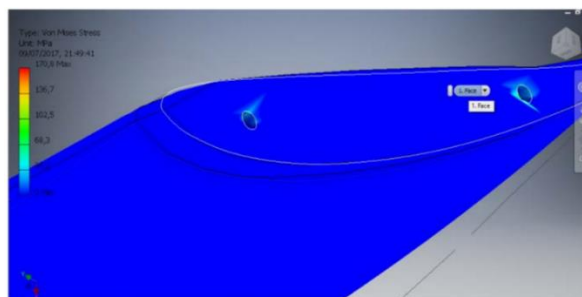


Figure 20. Expansion of the greatest stress place. Source: The authors (2021).

The major stress points can be seen in Figure 20, indicated in light blue. Comparing with the scale indicated on left side of image, it is possible to see the voltage is low. The blade system analysis was carried out based on data relating to the wind regime of cities such as Cruzeiro and São Sebastião, SP, Brazil, between 2014 and 2016, provided by the atmospheric electricity research group of the National Institute for Space Research (INPE, in Portuguese). Figure 21 displays the Von Mises stress distribution analysis along the wind turbine blade structure after applying a force related to the wind flow displacement at 40 m/s or 144 km/h. And Figure 22 displays the resulting displacement of 11 mm.

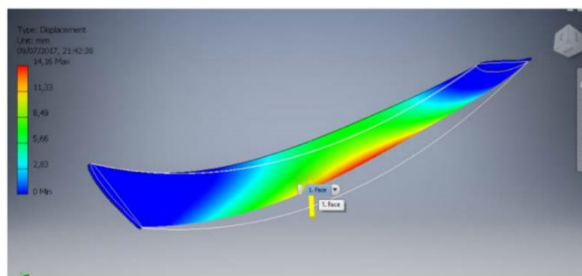


Figure 21. Von Mises stress distribution analysis. Source: The authors (2021).

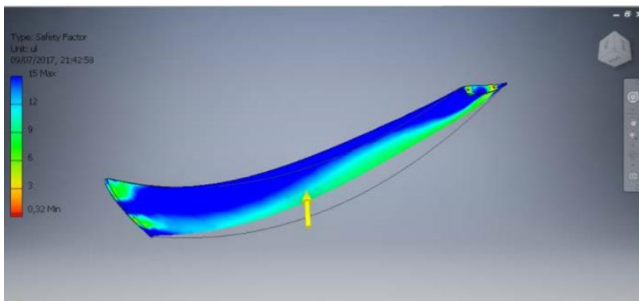


Figure 22. Demonstration of displacement of just over 11 mm.
Source: The authors (2021).

At lower speeds, there was no breakage or damage to the blades. In parallel with the Beaufort wind speed scale (MET OFFICE, 2017), winds of 40 m/s are considered hurricane winds, which indicates that the developed APP would only break if it encountered very high-speed winds, framed in the highest category of Beaufort scale.

5. Conclusion and Implication

The proposed product is within parameters required in analysis of results. According to the performed tests, it can be stated that the assembly process was easy to achieve (Application of user-centered design techniques guarantees an agile and safe system, thus preventing the user from making mistakes during the assembly step and maintenance of equipment and thus providing a greater durability of the same).

In addition, ease in the production process was also achieved (design as a product development tool enabled creation of a simplified structure, meeting the initial requirements of project, thus ensuring a lean production process and reducing costs of product manufacturing).

Safety factor was also satisfactory due to the type of application for which the product is intended, issues related to safety are of great importance in the project development. It must be guaranteed the product operating quality and total user safety and, using product design techniques, a flexible structure was created, capable of withstanding winds of up to 40 m/s (144 km/h), winds which are rarely recorded in urban environments.

Thus, as a proposal for future work, it is considered there is a need to manufacture some units of the proposed APP model to carry out tests in real environments, in order to

ascertain its electrical generation and noise emission capacity.

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