Design of an Accessory to Protect Wheelchair Users from Rain and Sun

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***Abstract*—Nowadays, most people who use manual wheelchairs face difficulties moving outdoors, especially when there is unfavorable weather. Although different products are designed to protect them as umbrellas, raincoats, among others, these products have shortcomings that cannot meet the needs of wheelchair users, such as excess weight, lack of coverage, and adaptation of the product to the wheelchair. In this context, this research aims to propose an accessory that fulfills these needs through the design and feasibility study by simulation. This research was conducted in four phases, which comprised a search for information related to wheelchairs, their components, and accessories; likewise, it was determined a characterization of the right accessory's design, then the design was evaluated and analyzed through simulations using Solidworks. Finally, the advantages and disadvantages of the design are described, as well as the recommendations for future work. The results indicate that the accessory has a high resistance under normal conditions, according to the simulation studies conducted, for which it is concluded that the proposed design would be feasible if built. It would bring security to users, serving as a study base for future research, despite its shortcomings.**

***Index Terms*—accessory, adaptability, disability, weather, wheelchair**

I. Introduction

In the 1960s, people with disabilities were integrated and normalized as human beings. They were respected and accepted by society for their differential conditions. In this same decade, the organizations formed by people with this condition began to shape the definition of this concept, considering the limitations they experienced, and the design and structure of the environment they were in. [1]. This term has been evolving considering various factors and types of disability. According to the Colombian Ministry of Health, "It is a concept that evolves and results from the interaction between people with disabilities and the barriers due to the attitude and the environment that prevent their full and effective participation in society under equal conditions with others" [2]. According to the 2011 World Report on Disability of the World Health Organization (WHO), more than a billion people around the world have some type of disability, which is equivalent to 15\% of the population; of which approximately 3\%, which is equivalent to almost 200 million, have difficulties in their activities [3]. In Colombia, according to the 2018 National Population and Housing Census, 48,258,494 inhabitants were estimated, of which 3,134,036 people have difficulties in performing basic daily activities. This figure is equivalent to approximately 6.49% of the total population, which is divided into 4 levels according to the difficulty they have executing those activities through the Washington Group (WG) scale. Level 1 corresponds to people who cannot do any activity because they have total disability, while level 2 includes people who can perform daily activities with great difficulty and who, in general, need help or support from others. At these two levels, there are 1,784,372 people with disabilities (PwD), corresponding to 3.69% of the country's population. This work will focus on these levels. Level 3 includes those who present some difficulties (little-limited-slight) and, at level 4, those who have no difficulty in carrying out activities. At these two levels there are 1,349,664 people with disabilities (PwD), corresponding to 2.80% of the country's population. [4].

In addition, the WHO establishes different disabilities classified by the International Classification of Functioning, Disability and Health (ICF) into two types: the first based on Functioning and disability and the second type associated with contextual factors referring to environmental and personal factors. The first disability type is subdivided into two parts. The first one refers to body functions and structures associated with the anatomy of the body, such as the upper and lower limbs; and the second part refers to activities and participation in the performance of the individual and the act of becoming involved in a life situation [5]. Some people who are in the second component have difficulty performing certain activities, as they may have different physical, intellectual, or sensorial problems, including amputations, spinal cord involvement, degenerative diseases, cerebral palsy, among others. Displacement is an example of those activities where people must use wheelchairs. [6].

Wheelchairs are physical application devices that help or improve the execution of activities that cannot be performed because of deficiencies, disabilities, or partial or total handicaps. They facilitate the movement of people who have permanently, totally, or partially lost the ability to move around. [7]. The first graphic representation of a wheelchair dates back to 525 BC, but

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it was not until 1783 that the first conventional wheelchair was manufactured by John Dawson and its design has evolved over the years, due to the various needs of the people who use them. There are currently two types of wheelchairs: manual and electric. [6]. The basic components of a wheelchair are the chassis, chair, and wheels. The chassis is a structure on which the other components are supported, also known as “the frame.” A second component is the chair, which works as a support for the user and consists of two parts: the seat and the backrest. At last, the wheels allow movement in different terrains. In addition, most wheelchairs have armrests, footrests, and parking brakes. [8].

The structure of the wheelchair and each of its components have undergone a series of modifications to meet the needs of each user, generating a lighter, faster, more comfortable, and foldable structure, among other features specifically designed to provide greater benefits. Similarly, various accessories have been created for wheelchairs, such as brakes, motors, auxiliary tables, and cup holders.

There are also accessories that protect the user from the sun and rain. Some of them are the waterproof fabric, the support for umbrellas, canopy, and EQU. The waterproof fabric is a hooded layer, also known as a raincoat to protect the user and the chair from the rain [9]. It provides ample coverage, besides being lightweight, portable, and easy to use. However, it could present difficulties with strong winds and generate discomfort for the users to propel themselves, the umbrella holder is an accessory that can be adjusted to the push handles or armrests of the chair and can hold an umbrella covering the person from the rain with no companion [10]. It is light, adaptable, and adjustable; however, it does not provide complete coverage because it depends on the umbrella that is adjusted. In addition, it was created to adapt an umbrella without thinking about the needs of the users; hence, they may have problems with strong winds. The canopy is a modified umbrella with an electrical operation to protect a user in an electric wheelchair [11]. Although it is easy to operate and does not discomfort the user, it does not provide total coverage; it is not light and the product resistance cannot be determined. The EQU is an umbrella-type cover composed of two fixed hoods and two drop-down looms to cover the user and the chair [12]. It provides greater coverage and has a special design for wheelchairs; however, it lacks portability because it cannot be dismounted from the chair. Its resistance cannot be guaranteed and it can cause discomfort when propelled.

Based on the analysis of the advantages and disadvantages of the different products, it is concluded that the proposed accessory can offer broad coverage and portability. Its design does not generate difficulty for the users to propel themselves, but it is heavier compared to other accessories and it is not as easy to use.

II. Methodology

A. Characterization

Some parameters used to make the accessory are defined in Resolution 14861 of 1985 “whereby standards for the protection, safety, health and well-being of people in the environment and especially for people with disabilities are issued” [13], by the Ministry of Health of Colombia. Article 40 of this resolution stipulates the “accessibility to buildings”, which establishes that the minimum width of an entry must be 0.8 meters, and article 46 defined conditions for “indoor circulation”, establishing that no object will be projected at a height of fewer than 2.2 meters [13].

On the other hand, in the Colombian Technical Standard (NTC) 6047 about “Accessibility to the physical environment, spaces for citizen service in public administration, requirements”, according to subsection 7.4 “Internal corridors”, the minimum measurement of the width of the corridors is 1.2 meters. In addition, in subsection 8.2.3 “Width of ramps”, the unobstructed width of these must not be less than 1 meter between handrails [14]. Also, the NTC 4901-3 about “Vehicles for massive urban passenger transportation, part 3: conventional buses”, in subsection 5.4 Doors, the free width of double doors is 1.1 meters, and the free height is 1.9 meters, likewise in subsection 5.2 Passengers, the area for the disabled in wheelchairs must have a minimum space of 0.9 x 1.4 square meters [15].

Additionally, the Mexican Institute of Social Security (IMSS) [16] defined the standard measurements for a manual wheelchair, as shown in Table I.

TABLE I. Standard Manual Wheelchair Measurements. IMSS

Concept	Measurement
Chair width	0.60 m
Chair length	1.00 m
Chair height	0.93 m

Taking into consideration the regulations and measurements mentioned above, the width of the accessory installed in the wheelchair is 0.71 meters and its height is 1.55 meters. These measurements allow the user to move indoors, bathrooms, elevators, ramps, public transport, among other spaces without difficulty.

Considering the study completed by the University of Guadalajara “Anthropometric dimensions of the Latin American population: Mexico, Cuba, Colombia, Chile”; in which a measurement of 61 anthropometric variables was carried out for a population of 2,100 Colombian workers between 20 to 59 years of age, to characterize the measurements for this population [17]. The associated measurements were considered in this study for the 5th and 95th percentiles regarding the measurements related to the use of the accessory, for which additional calculations were made as shown in Table II.

TABLE II. 5TH AND 95TH PERCENTILE ANTHROPOMETRIC MEASUREMENTS. DATA EXTRACTED FROM THE ANTHROPOMETRIC STUDY.

Study measurements	Value P5	Value P95	Comparison measurement	Value
Seated height	1,18 m	1,35 m	Installed accessory height	1,55 m
Maximum vertical reach seated	1,56 m	1,81 m	Installed accessory width	1,55 m
Lateral wrist-to-wrist distance	1,37 m	1,58 m	Accessory width	0,71 m
Arm anterior reach	0,64 m	0,74 m	Accessory length	0,69 m
Knee-buttock length	0,52 m	0,60 m	Accessory length	0,69 m

When carrying out an analysis of the anthropometric measurements of the study and the measurements associated with the use of the accessory, it was demonstrated that the population of the 5th and 95th percentiles are completely covered by the covers. No extremities will interfere with the accessory system; likewise, they can be used comfortably in terms of adjusting the covers to the lower structure. Also, it was identified that the population in the 5th percentile could experience difficulties reaching the upper section of the accessory because the anthropometric measurement is close to the limit of the accessory's height.

Finally, the population in the 5th percentile will present difficulties, since they would not reach the total length of the accessory by 0.05m, thus making it difficult to use in terms of adjusting the upper cover to the lower structure.

B. Design and Simulation

Solidworks CAD Software was used during the design phase of the accessory. This design has two main parts. The first one refers to the structure and the second to the accessory's covering system.

1) Structure components

Fig. 1 shows the general design of the structure and Fig. 2 shows the upper part of the accessory in detail.

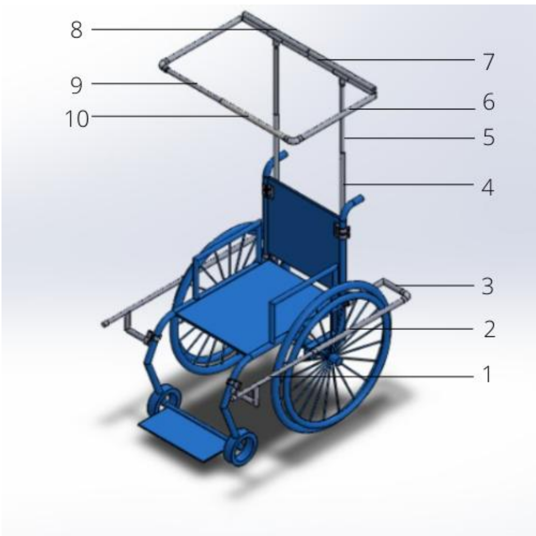

Figure 1. Structure of the accessory. Own authorship.

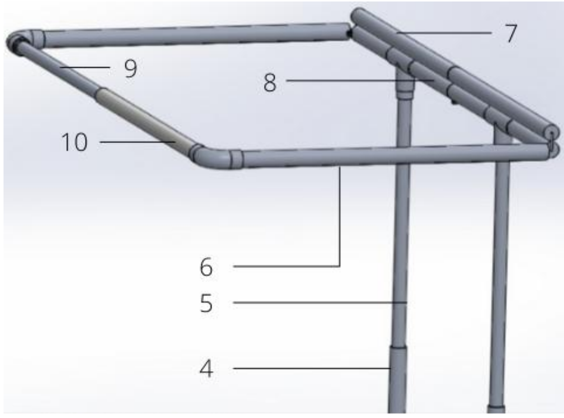

Figure 2. Detailed upper part of the accessory. Own authorship.

Most components of the structure are tubes to make the accessory lighter and easy to use, maximizing the user's comfort. These pieces are grouped as follows.

a) Fixed

This group is made up of the lower solid fixed tubes (3) and the rear fixed tubes (4) of Fig. 1. These are immobile and are attached to the wheelchair to provide support to the structure.

b) Support

This group consists of the lower fixed tubes (2), posterior tubes (8), and the anterior fixed tube (10) as shown in Fig. 1 and their purpose is to provide support to other pieces.

c) Telescopic

This group is composed of the lower telescopic tubes (1), rear telescopic tubes (5), and the front telescopic tube (9) Fig. 1. These are adjustable to expand the accessory fully when in use.

d) Cover

This group consists of the side tubes with cover (6) and rear tubes with cover (7) as shown in Fig. 1 and they are intended to store the cover when not in use.

e) Union

This group is a set of pieces made up of clamps, L-shaped double-pass connector tubes, and T-shaped connector tubes to join the different pieces and the attachment of the accessory to the wheelchair.

2) Cover system components

The cover system is divided into 3 groups as shown in Fig. 3, these are:

a) Rear

It is composed of 2 covers that are adjusted to the rear fixed and telescopic tubes.

b) Upper

It is composed of 2 covers that unfold from the rear tubes with cover towards the front, adjusting to the lower structure.

c) Side

It is composed of 2 covers that unfold from the side tubes with cover downwards, adjusting to the lower structure.

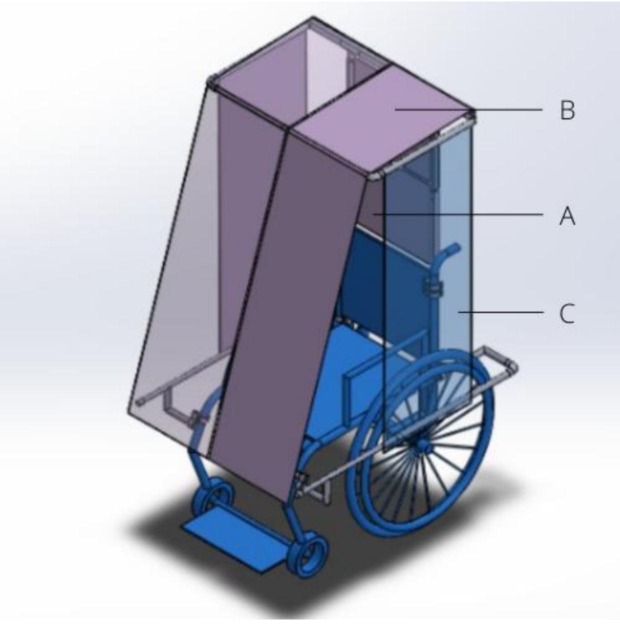

Figure 3. Accessory Cover. Own authorship.

3) Accessory assembly

Before assembly, it is necessary to adapt to clamps and/ or supports to the wheelchair. The first adaptation consists of 2 pairs of clamps located in the upper part of the sides of the backrest, which hold the fixed rear tubes. The second one consists of 1 pair of clamps that are located in the lower part of the sides of the backrest and give support to the lower solid fixed tubes. The third consists of 1 pair of clamps and 1 pair of L-shaped brackets, which are located on the front of the wheelchair on the footrest tubes, these elements will be present before and during the use of the accessory as shown in Fig. 4.

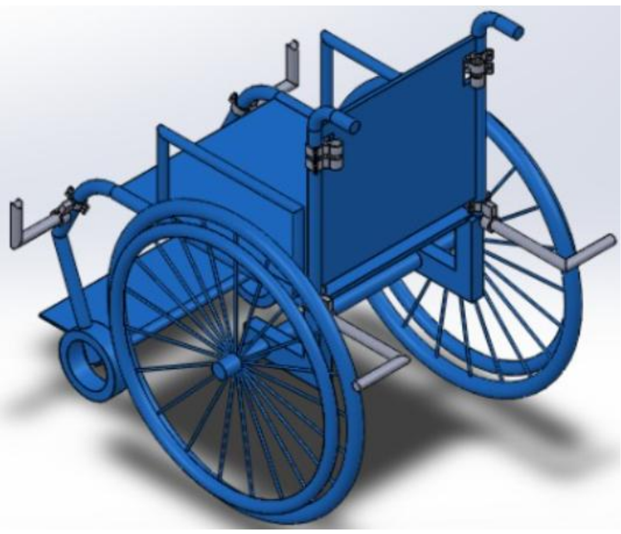

Figure 4. Adaptations of clamps to the wheelchair. Own authorship.

Fig. 5 shows the instructions for the correct assembly of the accessory on the wheelchair, from the initial adaptation to the covers' unfolding.

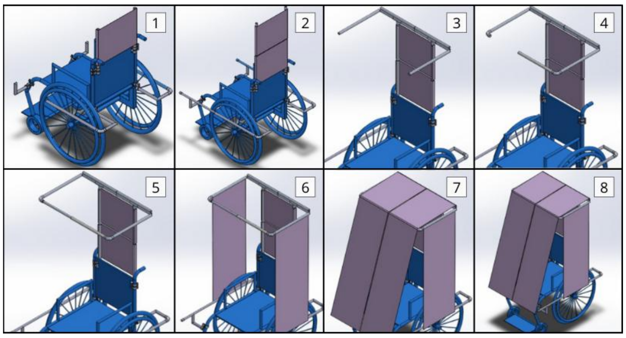

Figure 5. Assembly of the accessory on the wheelchair. Own authorship.

- Box 1 in Fig. 5 shows the adjustment of the lower fixed tubes to the lower solid fixed tubes utilizing L-shaped double-pass connector tubes. As for the upper part, the rear fixed tubes are adjusted, which have fitted a part of the rear cover, these elements will be up to the user's consideration if they want to install them before or after starting their tour.
- Box 2 in Fig. 5 shows the unfolding operation of the inferior telescopic tubes. These tubes are contained in the lower fixed tubes. Likewise, the rear telescopic tubes are unfolded, which are fitted inside the rear fixed tubes and have adjusted the other part of the rear cover.
- Box 3 in Fig. 5 shows the installation of the set of later tubes with covers, rear tubes with covers, and rear tubes attached to the rear telescopic tubes through T-shaped connectors.
- Box 4 in Fig. 5 represents the installation of the fixed rear tube to the lateral tubes with cover through a double-pass L-shaped connector.
- Box 5 in Fig. 5 shows the unfolding of the telescopic tube anterior to the fixed tube.
- Box 6 in Fig. 5 represents the unfolding of the lateral covers, which are adjusted to the lower structure.
- Box 7 in Fig. 5 shows the unfolding process of the upper covers, which are fitted to the lower structure in the front.
- Finally, box 8 in Fig. 5 shows the total assembly of the accessory on the wheelchair.

III. Simulation

A. Considerations

During the simulation phase, it was necessary to establish the most appropriate material for the accessory's structure. For this, a comparison was made between some materials that are available in the Solidworks database, which provides very detailed information about each material. Two factors were considered in the selection of the materials to compare. The first factor determined which families are best known in the market, and widely used in the manufacturing of structures, and the second factor defined the most representative material of each family. The selected materials are shown in Table III.

TABLE III. MATERIAL PROPERTIES, EXTRACTED FROM SOLIDWORKS.

Property	Stain steel	Titanium	Aluminum 1060	Malleable cast iron
Young's modulus	200.0 GPa	110,0 GPa	69,0 GPa	120,0 GPa
Poisson ratio	0,28	0,30	0,33	0,31
Shear modulus	77,0 GPa	430,0 GPa	270,0 GPa	770,0 GPa
Mass density	7800 Kg/m^3	4600 Kg/m^3	2700 Kg/m^3	7100 Kg/m^3
Traction limit	513,6 MPa	235,0 MPa	68,9 MPa	861,6 MPa
Elastic limit	172,3 MPa	140,0 MPa	27,6 MPa	551,4 MPa

Considering the properties of the materials summarized in Table III, in the first place the elastic modulus (Young's modulus) was compared, which refers to the stiffness of a material that is subjected to a load [18], from the table it can be inferred that stainless steel (ferritic) has greater rigidity. Second, the Poisson's ratio, which is a specific parameter that each material possesses and which represents the relationship between the perpendicular deformation to the force and the deformations in the direction of the force experienced by the component [18], the material aluminum 1060 has the best coefficient. Third, the shear modulus refers to the stress-strain relationship of any small material [19], malleable cast iron is the one with the best relationship. Fourth, density is an intensive property that expresses the mass concentration and depends on the composition and structure of the material [20]. Comparing the materials, it is clear that aluminum 1060 is the least dense material. Fifthly, the traction limit is compared, which consists of the application of two forces in the opposite direction up to the yield point or plasticity of the material [21] and it is observed that the material that would support a greater load is malleable cast iron. Finally, the elastic limit was taken into consideration, which corresponds to the stress for which a solid stops being elastic and starts to deform plastically [22], the material that would support a greater load is malleable cast iron.

Based on the results of the comparison for each property identified in Table III, it is evident that although malleable cast iron has high resistance to efforts, it has a very high density, which is why it was discarded. Following this, the second material with the best properties was analyzed, which corresponds to 1060 aluminum, which was chosen to a greater extent for its low density since one of the factors of this accessory is that it must be light.

Considering the density of the material, the mass of the structure is:

0.41 Kg (lower structure)

1.55 Kg (upper structure).

Two simulations were carried out to observe the accessory's behavior in a specific scenario. One simulation was a static test and the other one a frequency test for each part of the structure, both, the upper and lower sections. In the simulation phase, the material that was established for all parts of the accessory structure was a 1060 aluminum alloy. For both tests, a force of 49N was applied. This was determined based on the mass of the accessory structure, which corresponds to approximately 2 Kg and a safety factor of 2.5 was established to calculate the force to be applied on the front tubes of the upper structure and the telescopic tubes of the lower structure as seen in Fig. 6 and Fig. 7.

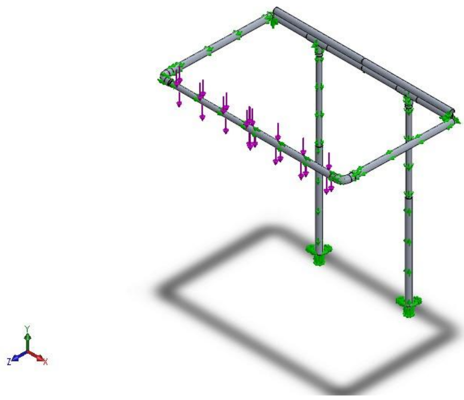

Figure 6. Upper structure. Own authorship.

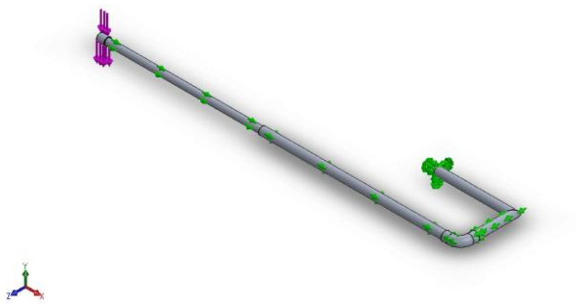

Figure 7. Lower structure. Own authorship.

It can be seen in each figure the clamping forces (green arrows) that exist in the structure, which serve to keep the load in a rest position in such a way that it prevents its movement [23], in the same way, it can be observed the direction and area where the force was applied (purple arrows). For the development of the simulation, it was carried out in the first place a static study to determine the reaction of the structure to external elements, this depends mainly on the material of which the accessory is composed and as a result, deformations, cracks, vibrations, stresses, and reactions among others can be obtained [24]. And in second place a frequency study to determine the natural frequencies that are specific to each structure [25] and to observe those forced frequencies that can cause a break by resonance.

B. Results and Analysis

1) Static study

The static results of this study are divided into 3 sections.

The first section corresponds to the structure's stresses after applying force. The results of the stresses in the upper section do not exceed 4.83 MPa as shown in the color scale in Fig. 8; the structure's stresses in the lower part do not exceed 8.88 MPa as shown in the color scale of Fig. 9. When comparing these results to Young's modulus of the material, it is evident that the elastic limit is not exceeded, therefore the accessory will not deform permanently.

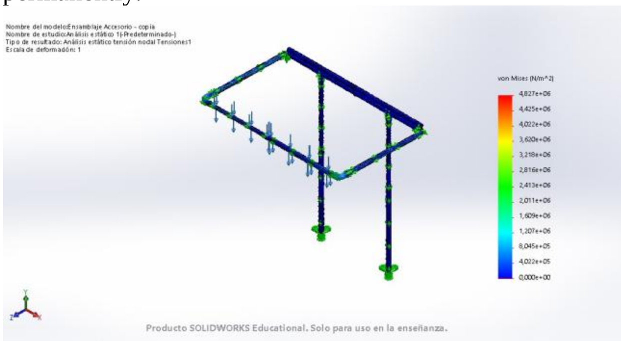

Figure 8. Result of the stress study of the upper structure. Own authorship.

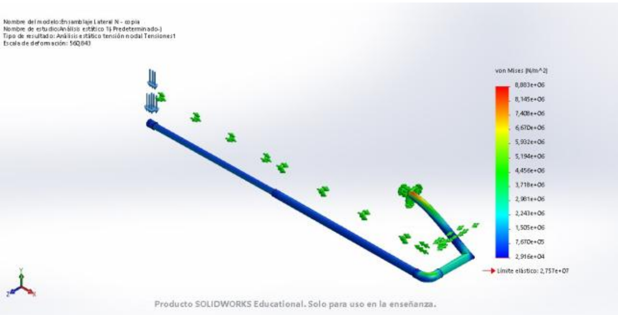

Figure 9. Result of the stress study of the lower structure. Own authorship.

The second section corresponds to the displacements in the structure after applying force. The maximum displacement in the upper structure corresponds to 1.16 mm as seen in the color scale of Fig. 10, and in the lower structure, it corresponds to 1.72 mm as seen in the color scale of Fig. 11. These results indicate that this structure will not have a relevant displacement that could affect its operation.

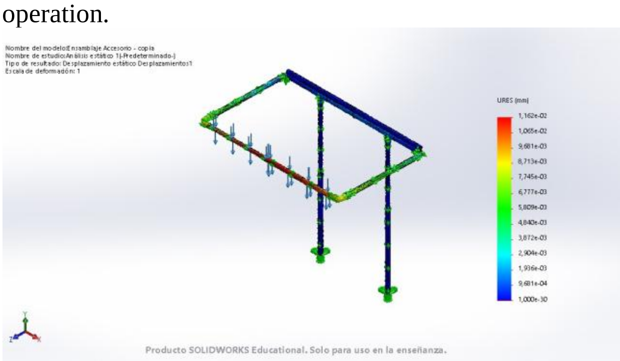

Figure 10. Result of the study of the displacement of the upper structure. Own authorship.

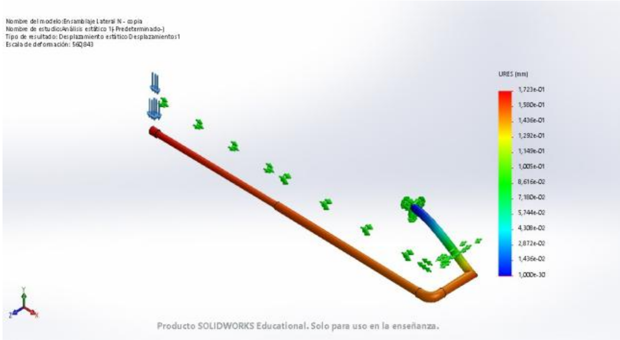

Figure 11. Result of the study of the displacement of the lower structure. Own authorship.

The third section of the static study corresponds to the safety factor of each part of the structure, for the upper structure this value is 4.0 as shown in Fig. 12 and for the lower structure this value is 3.1 as shown in Fig. 13. Thus, the safety factor is 3.1 for the total structure, which corresponds to the minimum value.

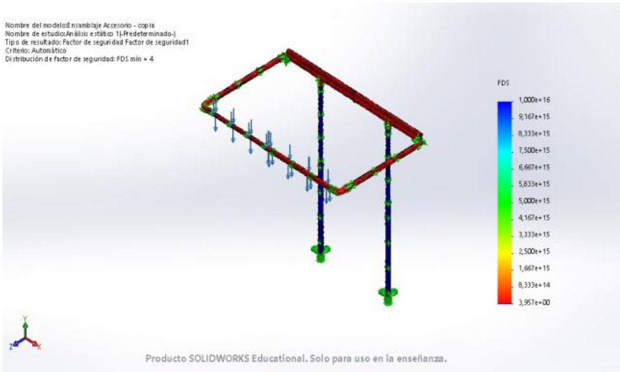

Figure 12. Superior structure safety factor. Own authorship.

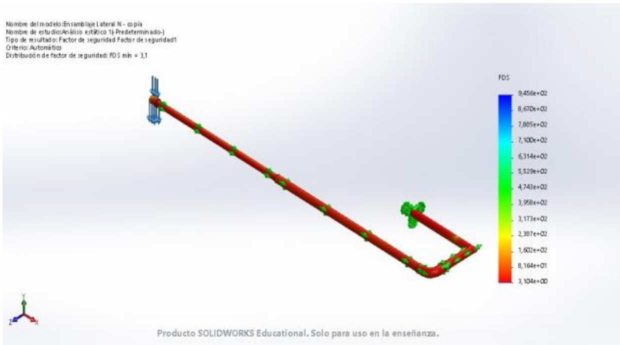

Figure 13. Lower structure safety factor. Own authorship.

2) Frequency study

For the frequency study, the Solidworks design software shows different frequencies at which if the accessory resonates, the structure would deform, then two simulation scenarios are observed for each part of the structure.

Fig. 14 and Fig. 15 show the frequency scenarios for the upper and lower structure of the accessory, respectively.

Thus, the safety factor 3.1 of the total structure corresponds to the minimum value.

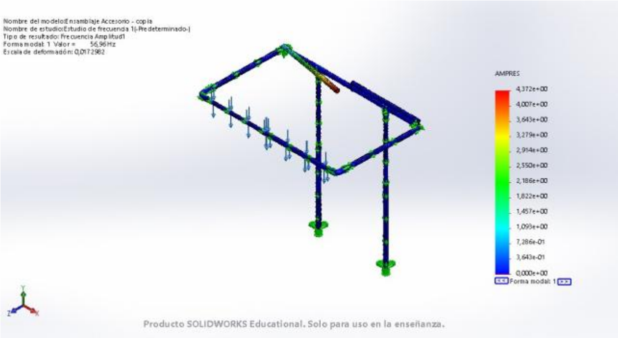

Figure 14. Frequency for the upper structure. Own authorship.

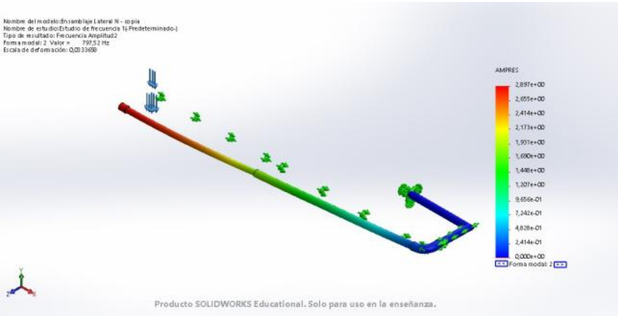

Figure 15. Frequency for the lower structure. Own authorship.

Fig. 14 shows the behavior of the upper structure when it is subjected to a frequency with a value of 56.96 Hz. This value represents the lowest frequency at which the structure can experience a break or damage. The maximum deformation occurs in one of the rear tubes with a cover with a displacement of 4.37mm, it should be noted that these frequencies are very atypical; however, it is important not to reach this value since abnormal behavior may occur in the structure.

Fig. 15 shows the behavior of the lower structure when it is subjected to a frequency of 797.52 Hz, resulting in two pieces of the structure moving away from the main axis (Green arrows). The first part corresponds to the lower fixed tube, which has a maximum downward displacement of 1.93mm, the second part is the lower telescopic tube, which undergoes a downward displacement of 2.89mm. Under normal conditions, it is very difficult to reach the value of this frequency.

IV. Conclusions and Discussion

According to the results of the research of accessories intended to protect users of manual wheelchairs from sun and rain, it is possible to notice that the current products do not meet all users' needs, since most of them do not offer full coverage and could create inconveniences for the user to propel themselves. Considering the problems of the existing products, the proposed accessory seeks to meet these characteristics, creating an adequate design.

Based on the Colombian regulations, the permissible measures were analyzed so that the circulation of people in wheelchairs is not obstructed when using this accessory, obtaining a design that helps the user to move without difficulties and ensuring that the area it occupies complies with national regulations.

In relation to the analysis of the anthropometric measurements associated with the use of the accessory, it is observed that most people can use it without difficulty since the adjustment points of the cover are within its range.

Considering the information obtained, the accessory could provide high resistance under normal conditions according to the results of the simulations; therefore, it would be feasible to build it, providing safety for the user.

Finally, for future studies, a modification could be made to the design of the accessory to obtain greater coverage so that the user has greater protection from the weather. In addition, new material could be implemented for the structure and cover, for example, a hydrophobic fabric, to increase the resistance of the structure and its useful life, and to reduce the total weight of the accessory. On the other hand, an automatic mechanism could be added for the activation and deactivation of the accessory cover, in such a way that the user must only press a button to activate it.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

Author Contributions

Carlos A. Toledo contributed to monitoring this design work; Andrés F. Ortiz contributed to the mechanical design and simulation; Diana K. Luis contributed to the mechanical design and writing of this paper. In general, all authors approved the final version.

References

[1] M. I. Hernández Ríos, "The concept of disability: From illness to the rights approach," *Rev. CES Derecho*, pp. 46–59, 2015, Accessed: Dec. 28, 2020. [Online]. Available: http://www.scielo.org.co/pdf/cesd/v6n2/v6n2a04.pdf.

[2] Ministerio de Salud, "ABC OF DISABILITY What is disability?" Accessed: Dec. 28, 2020. [Online]. Available: https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/DE/PS/abece-de-la-discapacidad.pdf.

[3] Organización Mundial de la Salud and Banco Mundial, "SUMMARY WORLD REPORT ON DISABILITY," 2011. Accessed: Dec. 28, 2020. [Online]. Available: https://www.who.int/disabilities/world_report/2011/summary_es.pdf.

[4] Departamento Administrativo Nacional de Estadística, "PEOPLE WITH DISABILITIES, differential challenges in the framework of COVID-19," 2018. https://www.dane.gov.co/files/investigaciones/discapacidad/2020-Boletin-personas-con-discapacidad-marco-COVID-19.pdf (accessed Dec. 28, 2020).

[5] C. Egea García and A. Sarabia Sánchez, "WHO classifications of disability," 2001. Accessed: Dec. 28, 2020. [Online]. Available: https://sid.usal.es/idocs/F8/ART6594/clasificacion_oms.pdf.

[6] D. M. Castanier Muñoz and E. V. Mendía Idrovo, "Design, construction and implementation of a folding electric wheelchair for a person with mobility problems," Universidad Politécnica de Cuenca, Cuenca, 2018.

[7] J. Gorgues, "Selection and adaptation of conventional wheelchairs," *OFFARM*, vol. 24, pp. 149–152, Sep. 2005, Accessed: Jan. 06, 2021. [Online]. Available: https://www.elsevier.es/es-revista-offarm-4-pdf-13078588.

[8] Álvar Palencia Diéguez, “Ecodesign of a custom wheelchair,” Sep. 2016. [Online]. Available: https://core.ac.uk/download/pdf/288499481.pdf (accessed Dec. 28, 2020).

[9] A. E. Dávila, “Design of an accessory system for protection against solar and rainy weather conditions (Case: central sector of the city of Quito).,” Jan. 2018.

[10] M. Puig and A. Bolta, “The 'emotion research lab' methodology in object design to protect wheelchair users from the rain,” pp. 16–18, 2014.

[11] M. Battah, J. Brown, D. McClendon, and G. Francisco, “Power wheelchair canopy,” 2019. [Online]. Available: https://ideaexchange.uakron.edu/cgi/viewcontent.cgi?article=2000&context=honors_research_projects (accessed Jan. 15, 2022).

[12] B. Lienas, “Study of the feasibility for the introduction to the market and design of a system adaptable to the wheelchair to protect the user from the rain.” Cataluña, Jan. 10, 2018, Accessed: Jan. 15, 2022. [Online]. Available: https://upcommons.upc.edu/bitstream/handle/2117/189965/bruna.marin_fitxer de consulta.pdf?sequence=5&isAllowed=y.

[13] Ministerio de Salud, *Resolution No. 14 861 of October 4, 1985. Colombia, 1985*.

[14] ICONTEC, *Colombian Technical Standard NTC 6047*, Bogotá, 2013.

[15] ICONTEC, *Colombian Technical Standard NTC 4901-3*, Bogotá, 2007.

[16] Instituto Mexicano del Seguro Social (IMSS), “Standards for accessibility for people with disabilities,” México D.F, 2000. Accessed: Feb. 22, 2021. [Online]. Available: https://www.academia.edu/11620719/NORMAS_PARA_LA_ACCESIBILIDAD_DE_LAS_PERSONAS_CON_DISCAPACIDAD.

[17] R. Ávila, L. Prado, and E. González, “Anthropometric dimensions of the Latin American population: Mexico, Cuba, Colombia, Chile,” Universidad de Guadalajara, Guadalajara, 2007.

[18] C. Herrera, J. Gómez, M. Bolaño, and H. Rodríguez, “Modulus of elasticity compressive strength of concrete,” 2018.

[19] M. Ortiz, J. Gaitán, and J. Camacho, “Unified model of degradation curves of the shear modulus in sands of the Guayuriba River,” Sep. 2013, Accessed: May 18, 2021. [Online]. Available: https://www.researchgate.net/publication/265413437_Modelo_unificado_de_curvas_de_degradacion_del_modulo_cortante_en_arenas_del_rio_Guayuriba.

[20] M. N. Fraile, J. E. Morrás, A. Z. González, L. S. Cervera, and J. I. Murillo, “Strategies of secondary school students to estimate density,” *Ensen. las Ciencias*, vol. 36, no. 1, pp. 61–76, Mar. 2018.

[21] A. Cabrera and M. Koller, “Tensile behavior of structural steel, according to NTC 2289 Standard, from different manufacturers of reinforcing steel on the market,” Bogotá, 2017.

[22] A. Gallardo, D. Gómez, J. Martínez, and A. Domínguez, “Yield stress in fully stabilized zirconia single crystals with high yttrium oxide content,” 2001. [Online]. Available: https://idus.us.es/bitstream/handle/11441/17593/file_1.pdf?sequence=1&isAllowed=y (accessed May 13, 2021).

[23] Instituto Nacional de Seguridad e Higiene en el Trabajo (INSHT), “Devices for securing work equipment and various loads on transport vehicles: safety,” España, 2015. Accessed: Feb. 22, 2021. [Online]. Available: https://www.insst.es/documents/94886/330477/NTP+1038.pdf/37da0e81-6054-4ce7-8131-c8844c277343.

[24] M. A. Nuñez Guerra, “Static analysis of the base plate to improve the alignment of the pumping system in the company Roval S.A.,” Huancayo, 2016.

[25] L. Miguel, B. Rivera, D. Esteban, and L. Muñoz, “Static analysis of natural frequencies of the crankshaft and flywheel of the Hyundai Accent vehicle,” Cuenca, Feb. 2015.

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