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CONCEPTUAL DESIGN OF TRAIL WHEELCHAIR WITH EMPHASIS ON ERGONOMIC EVALUATION

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Abstract: This article describes the design of a wheelchair for trails, prioritizing ergonomic and affordable aspects. The inspiration arose from the need to integrate people with mobility disabilities to enjoy nature, recognizing the physical and mental benefits that this integration provides. The personal motivation came from the experience of family members of one of the authors, who face challenges due to a rare and degenerative disease (spinocerebellar ataxia type 3). After studying the development of the wheelchair, exploring existing solutions and carrying out questionnaires with the target audience, alternatives for the ergonomic design were identified. A detailed ergonomic analysis was performed for different percentiles (P5 and P95), ensuring consistent validations. The final project resulted in a wheelchair with a detachable structure, using rigid systems and a suspension set. It includes footrests, armrests, headrests, and front and back supports for caregivers, as well as static mechanisms for stabilization when at rest.

Keywords: Wheelchair; Trails; Ergonomics.

INTRODUCTION

More than a billion people around the world live with some type of disability, that is, 15% of the world's population, of which around 200 million experience considerable functional difficulties (ORGANIZATION et al., 2012). Among this group, one third of people who need a wheelchair in the world do not have access to one (of the 65 million people with mobility disabilities, 20 million do not have access). It is also projected that only a minority of people have access to an appropriate chair, that is, one that meets the needs of the user and the environment, provides adequate adjustment and postural support and is safe and durable (WHO, 2008).

Limited access to suitable wheelchairs is a worrying reality, with only a minority of the population having access to models that adequately meet their postural and environmental needs, as well as being safe and durable.

Assistive technologies, such as wheelchairs, play a crucial role in reducing social inequalities, but the high cost of these products remains a major obstacle for many individuals. This is the most relevant factor when it comes to the difficulty of accessing this good (CARRIEL, 2007).

Despite the health risks associated with the use of wheelchairs, these devices can facilitate social integration and improve the quality of life of people with disabilities, although their availability is limited and often inaccessible.

With the aim of improving the lives of wheelchair users and promoting inclusion in outdoor activities, this work aims to design a wheelchair for trails, with an ergonomic and low-cost focus. This includes ergonomic analysis to ensure correct posture and comfort for both users and chargers.

Most existing models are imported, which further increases costs and makes access to these products difficult. Considering the social nature of this product, it is crucial that a variety of users can access it, not just a small portion of the population.

The development of the project followed a methodology that included bibliographical research, benchmarking, study with the target audience, ergonomic analysis and detailed design. The process resulted in the creation of technical drawings and a list of materials for manufacturing the wheelchair, prioritizing accessibility and low cost.

Benchmarking was carried out, checking some options that exist in the Brazilian and foreign markets and the limitations linked to them, seeking to analyze and identify the best options among those addressed, continuing with the study with the target audience, through an online questionnaire, following the brainstorm. An ergonomic study was also carried out with a focus on biomechanics and anthropometry, as well as an analysis of the forces acting on the system, for subsequent sizing of the structure.

Next, the intermediate project is carried out, where the selection of percentiles was made, the static dimensioning of the structure based on the ABNT NBR ISSO 7176:8 standard (ABNT, 2009) and ergonomic analyzes carried out on the PCD and chargers, at this stage all the sets and components were dimensioned and designed via 3D modeling using Catia software. With all items validated, we proceeded to the executive project where the technical drawings of all components and assemblies were created, as well as the list of materials (Bill of Material - BOM) and the pricing of each component.

DEVELOPMENT

USER STUDY

A valuable source of data was the online questionnaire aimed at the target audience, with 25 participating volunteers. The majority (64%) reported discomfort when using a conventional wheelchair, with 80% of these volunteers suffering pain, mainly in the back (44%) and lower back (24%). Increasing comfort was the main modification requested by users, with 44% of them considering comfort to be the most important aspect of a wheelchair.

All participants (100%) expressed an interest in being in contact with nature, believing that this brings benefits to their physical and mental health. However, more than half (56%) have never taken a nature walk due to the limitations of conventional wheelchairs. As for the preliminary model of the trail wheelchair, 80% of participants considered the idea excellent and 84% expressed interest in purchasing the product. An important question is about the appropriate value for this type of product, 28% believe that up to R$5,000.00 is valid for this type of product, 32% up to R$7,000.00, 36% up to R$10,000.00 and 4% up to R$ $15,000.00.

In relation to chargers, 36% of the participating individuals would have some difficulty finding 2 chargers, if they only needed 1, 80% would have an easier time finding it. When asked about chargers, 24% of participating individuals believe that they are very easy to help with and 56% believe that it is easy for them to help.

Regarding the aspects considered in the purchase, cost-benefit ratio and safety were the most voted (76%), followed by ease of transport (72%) and the amount of support and possibility of ergonomic adjustments (64%). Users emphasized the importance of strength and accessibility (32%), comfort and ease of disassembly (28%), and versatility and ergonomic adjustments (24%).

In summary, the questionnaire highlighted the need for improvements in the comfort of wheelchairs, especially for use on trails, highlighting the importance of cost-benefit, safety, transportation, support and ergonomic adjustments. Participants indicated an appropriate value of up to R$10,000.00 for a chair that meets these requirements.

CONCEPT OF PRODUCT

The product concept was realized following the results of benchmarking, brainstorming, by the Guidelines on the Provision of Manual Wheelchairs in Low-Resource Settings published by the WHO in 2008 and distributed by the State Secretariat for the Rights of Persons with Disabilities of São Paulo (WHO, 2008) and the standards ABNT NBR ISO 7176:5 - Determination of dimensions, mass and space for maneuver (ABNT, 2008a), ABNT NBR ISO 7176:7 - Measurement of dimensions of seats and wheels (ABNT, 2008b) and ABNT NBR ISO 7176:8 - Requirements and test methods for static, impact and fatigue strength (ABNT, 2009).

Using anthropometric measurements for the Brazilian population acquired from a survey carried out by ANAC in partnership with UERJ in 2009 where an anthropometric profile was obtained for the Brazilian population (ANAC, 2009), we can decide the percentile range, and with these estimate the maximum and minimum dimensions for the seat of our product, then define the other dimensions.

The main anthropometric measurements to be taken into consideration are: trunk-head height, popliteal height, glute-knee length and hip width. For the chosen percentile range (P5- P95), the dimensions are presented in Table 1.

Main anthropometric measurements		
Measurements	Percentile	
	P5	P95
Altura tronco-cefálica (mm)	843	975
Popliteal height (mm)	407	493
Gluteal-knee length (mm)	546	669
Hip width (mm)	329	446

Table 1 – Main anthropometric measurements

Source: Own preparation, 2023.

With the percentile range defined, it is possible to establish the maximum and minimum measurements that will guide the product design. The seat, being the main component, was prioritized as it supports the user's entire weight in the vertical direction. It must be sized to meet the percentile range and be ergonomically designed to prevent pain in the lower limbs, such as hips and thighs. Both the seat structure and the back are developed taking these aspects into account.

Next, the backrest was planned, being another crucial component, as it supports the weight force in the horizontal direction. It must be appropriately sized for the percentile range and feature depth adjustment to ensure comfort. It has been ergonomically designed to prevent torso pain, following the same approach as the seat design.

The headrest was then designed, being essential to support the weight of the head in the horizontal direction. It has height and depth adjustments to meet the percentile range and is ergonomically designed to avoid discomfort in the head area.

The next item planned was the foot support, which is extremely important, as it supports the weight of the lower limbs in a vertical direction. With height adjustments to meet the percentile range, it was designed to ensure comfort and stability.

The arm support was the next planned component, also crucial for supporting the weight of the upper limbs in the vertical direction. It has height adjustments to meet the percentile range and was ergonomically designed to ensure comfort and adequate support for users.

After planning the structure aimed at users with disabilities, the project moved on to the suspension assembly. We opted for an independent suspension model with articulated arms, one rigid and the other damped with an ATV Bike shock absorber. To meet the percentile range of the chargers, the suspension arms can be fixed in different locations by screws, guaranteeing a variation in the height of the chair. The arms were sized to accommodate a 14-inch wheel and 90/100 tire, with a load index higher than necessary and considering a safety factor.

The last components designed were the front, rear and static support arms. The front support arm was designed to facilitate the use of the chair by just one charger, with tilt and height adjustments to suit the percentile range. As for the rear support arm, two types of support were developed to allow different positions for the charger: one attached to the backrest structure, at the height of the charger's chest, and the other with horizontal rods and handles to facilitate grip at different heights. of the chair. The preliminary conceptual design can be seen in Figure 1, below.

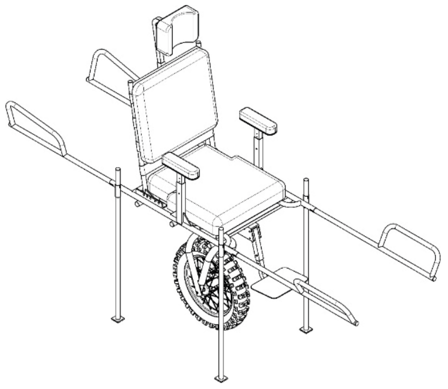


Figure 1 - Preliminary model of the trail wheelchair.

Source: Own preparation, 2023.

Based on the analysis of the questionnaire with users, it was found that 36% of participants would have difficulty finding two chargers if they only needed one, while 80% would have an easier time finding a single charger. In response to this need, the project was updated to develop a chair that allowed use with just one charger.

Other important conclusions were drawn from the questionnaire, including the lack of backrest comfort and the limitations of conventional wheelchairs when used on trails, such as difficulty with mobility and access. The need to increase comfort for users with disabilities and to implement relevant aspects, such as cost-benefit ratio, safety, ease of transporting the chair, amount of support and the possibility of ergonomic adjustments, was evident. These considerations have been incorporated into project updates. The final model can be seen in Figure 2, below.

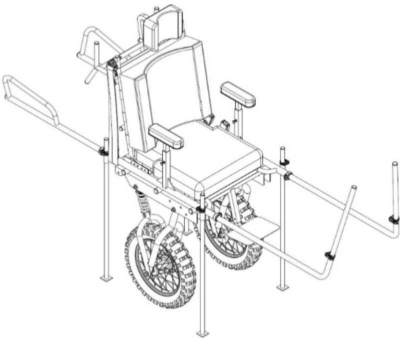


Figure 2 - Final model of the trail wheelchair.

Source: Own preparation, 2023.

Figure 3 shows the trail wheelchair configured for a PwD in the 95% percentile and for chargers also in the 95% percentile. All supports were adjusted according to the chosen percentile and the mannequin was inserted to carry out the ergonomic analyzes presented below.

Figure 3 – Chair configured for PwD and P95 chargers.

Source: Own preparation, 2023.

Figure 4 shows the trail wheelchair configured for a PwD in the 5% percentile and for chargers also in the 5% percentile. All supports were adjusted according to the chosen percentile and the mannequin was inserted to carry out the ergonomic analyzes presented in the next topic.

Figure 4 – Chair configured for PwD and P05 chargers.

Source: Own preparation, 2023.

ERGONOMIC VALIDATION USING CATIA V5R21

Deciding which ergonomic assessment instrument to employ depends on the context and objectives of the assessment carried out. Traditional and autonomous tools can be used when there are specific needs to be addressed or if there is doubt about posture, strengths and limits (DUFFY, 2008).

Catia has the Human Activity Analysis tool, which allows you to carry out various ergonomic analyzes and is a reference in this type of analysis. Among the various tools available, the most appropriate for the project are: RULA Analysis, Push/Pull Analysis and Biomechanics Single Action Analysis.

The analyzes were divided into two main parts: for PwDs, it is not necessary to use a complementary tool due to the position of the mannequin and the ergonomic supports of the chair; For chargers, it is necessary to simulate the loads that need to be compensated for when pushing and holding the chair. To do this, a tool is used that simulates a load with a defined direction and magnitude, known as Load.

For the loading function, the suspension assembly supports the entire load carried, as the center of gravity of the mannequin and chair has weight force applied directly to the wheel axle. The charger only works to control the chair, not carrying any weight. When tilting, there is a load that must be supported by the charger, to which a load of 4kg was added.

For the push/pull function, there are two possible scenarios: when the ride is carried out with only one charger and when it is carried out with two. For the first scenario, all the force is exerted by a single charger, and for the second scenario, there is a division of the force, therefore, analyzes for the first scenario (a single charger) are necessary, as they encompass the second scenario.

Based on calculations of rolling resistance and traction force, it is possible to determine an estimate of the force required to push any object with wheels, starting from a static state and to keep it moving. The calculations consider the mass of the PcD/chair set and the mass of the P95 man, as well as the geometric properties of the chair and the static and dynamic friction coefficients.

For the calculations we use the mass of the PwD/chair set, for the PwD we use the mass of the P95 man, as it is the heaviest weight (115.9kg), for the chair we use the mass when it has all the components, even those that are the possibility of being removed (at the discretion of the PCD and chargers), so that we can find the forces necessary to move the chair when it is heavier. We used the acceleration of gravity of 9.78 m/s2, the static and dynamic friction coefficients (μ), as these vary according to the material of the object and surface, there are different configurations, therefore different values.

In order to find the most difficult configuration for this set, the largest coefficients (μ) were used, for rubber on cement, respectively 1 and 0.85 (CTB, 2023), and geometric properties of the chair (CG height, distance between the drive axle and the CG and wheelbase of the vehicle). The respective values were found:

- Force to break static friction (start movement) = 113.98N
- Force to break dynamic friction (continue movement) = 48.45N

Calculating the resultant between the weight force that the PwD supports at some moments and the force necessary to push the chair, we find:

Resulting load to break static friction (start movement) = 12.5kg with force vector at 21°.

Resulting load to break dynamic friction (continue movement) = 6.4kg with force vector at 43°.

With these values, it is possible to configure the Load tool, according to the directions and magnitudes of the loads found. In Figure 5 you can see the tool configured with the load necessary to break static friction and dynamic friction respectively.

PULL/PUSH

The Push/Pull Analysis tool is capable of analyzing and determining the safe force for pushing/pulling, comparing the results with real data obtained by Snook and Ciriello (1991). In the Human Activity Analysis option, there are different parameters to be configured:

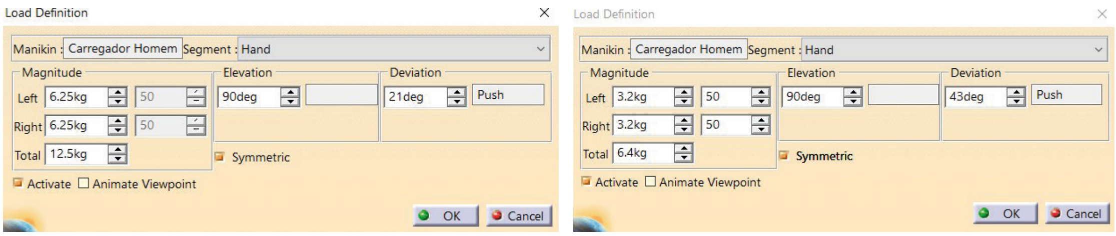
- "Guideline" refers to the guideline used to carry out the analysis, with only one option available, based on Snook and Ciriello (1991).
- "1 push every" is related to the frequency with which the body performs the movement.
- "Distance of push" refers to the pushing distance accomplished within the given period of time.
- "Distance of pull" refers to the pulling distance accomplished within the given period of time.
- "Population sample" refers to the population percentiles provided (90%, 75% and 50%), which represent the percentage of the population capable of carrying out the task safely. The selected percentile takes into consideration, the gender of the mannequin.

After filling in the specification fields, the tool generates a diagram indicating the results divided into "Maximum acceptable initial force", which expresses the maximum force required from the charger to put the object in motion, and "Maximum acceptable sustained force" to maintain the moving object. Initial forces are needed to initiate the object's motion, and as the object begins to move, these forces decrease to a relatively constant level (sustained forces), as illustrated in Figure 6.

In addition to analyzing the force required to push/pull, this ergonomic analysis tool can also quantify the comfort level of the working posture while workers perform their tasks, using the Rapid Upper Limb Assessment (RULA) (Hashim et al., 2014).

In Figure 7 it is possible to observe the results Maximum acceptable initial force which expresses the maximum force required from the charger to put the object in motion and Maximum acceptable sustained force to keep the object in movement, for a P95 male charger with a chair set to its percentile with different configurations of the front charger (neutral grip) and the rear (supinate grip and neutral grip on the support arm (optional)) respectively Figures 4(A), 4(B) and 4(C). All forces presented in the analysis are greater than the calculated forces (force to break static friction (start movement) = 113.98N and force to break dynamic friction (continue movement) = 48.45N) by 90%, meaning the P95 charger can easily use the chair.

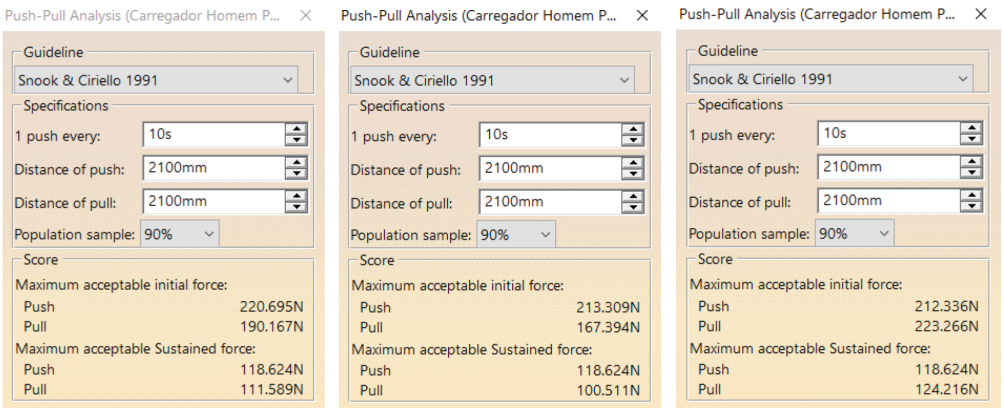
In Figure 7 it is possible to observe the same results for a female P5 loader with a chair



A B

Figure 5 – Load configured with load to break static (A) and dynamic (B) friction.

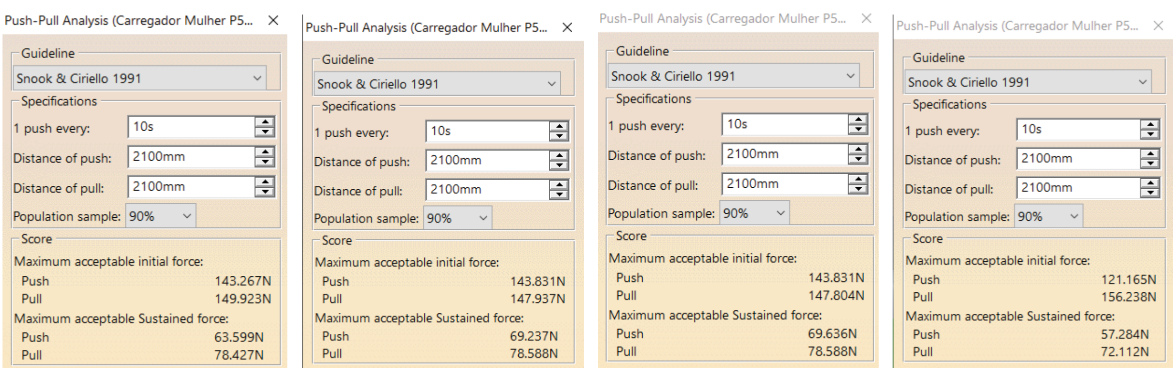
Source: Own preparation, 2023.



(A) (B) (C)

Figure 6 - Push/Pull analysis of the P95 male charger for a chair configured to its percentile, different configurations. (A) - Front charger (neutral grip), (B) - Rear charger (supine grip) and (C) - Rear charger (support arm).

Source: Own preparation, 2023



A B C D

Figure 7 - Push/Pull analysis of the P95 male charger for a chair configured to its percentile, different configurations. (A) - Front charger (neutral grip), (B) - Rear charger (supinated grip), (C) - Rear charger (neutral grip) and (D) Rear charger (support arm).

Source: Own preparation, 2023.

configured to her percentile, with different configurations of the front loader (neutral grip) and the rear (supinated grip, neutral grip and neutral grip on the support arm (optional)) respectively Figures 5(A), 5(B), 5(C), and 5(D). All forces presented in the analysis are also greater than the calculated forces (force to break static friction (start movement) = 113.98N and force to break dynamic friction (continue movement) = 48.45N) by around 20%, meaning the P95 charger can easily use the chair.

RULA — RAPID UPPER LIMB ASSESSMENT

The RULA Analysis tool can analyze and indicate the skeletal muscle risk level of each member of the mannequin's body in the position in which it was inserted. In the Human Activity Analysis option there are different parameters to be configured, they are:

- Side which refers to the side of the analyzed mannequin (left and right, left and right respectively);
- Posture, related to the frequency of movement that the body will exercise, being Static, Intermittent and Repeated;
- The Arm supported/Person leaning option dictates whether the mannequin has its arms supported or the mannequin is inclined;
- The Arms are working across midline option dictates whether the mannequin is working with its arms above the midline;
- The Check balance option can be selected to check the balance of the mannequin;
- The Load option indicates the load that the mannequin is supporting.

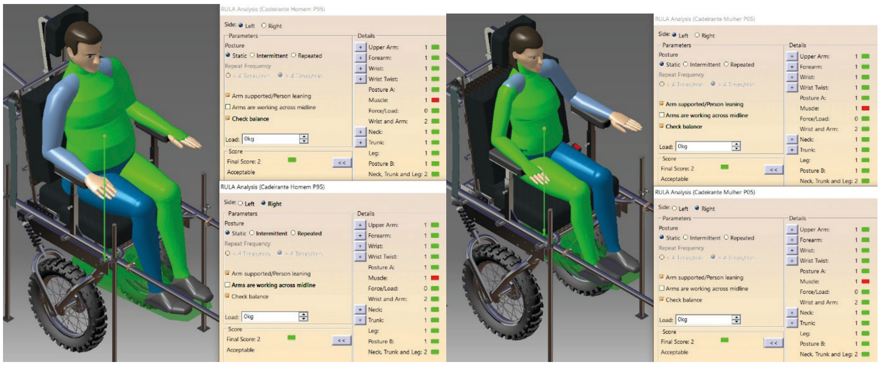
After all parameters are configured, the tool generates a diagram indicating scores that allow the assessment of exposure to risk factors (number from 1 to 6 and square colored from green to red).

For the PwD mannequins, both the man with the 95% percentile and the woman with the 5% percentile, the parameters were set to a static movement frequency, given that the PwDs are seated and move very little. The Arm supported/Person leaning option was selected because the mannequin can rest its forearm on the armrest and as it has height adjustment, it meets the two percentiles (P95 and P5) analyzed. See figure 8 (A and B).

For the charger mannequins, both the man with the 95% percentile and the woman with the 5% percentile, the parameters were configured for an intermittent movement frequency, given that PwDs move (ambulation). The check balance option was selected, thus verifying the participation of the mannequin's balance in the postural analysis. Due to the loads to hold and push the chair, previously calculated, in the Load option an additional load of 12.5kg was applied to break the static friction (start the movement) and 6.4kg to break the dynamic friction (continue the movement), similar to the loads configured in the Load tool. See Figures 9 and 10.

In order to make the rear charger more comfortable, two types of support arms were developed, one attached to the backrest structure, at the height of the mannequins' chest, this facilitates the act of pushing, the other rods similar to the support arms front.

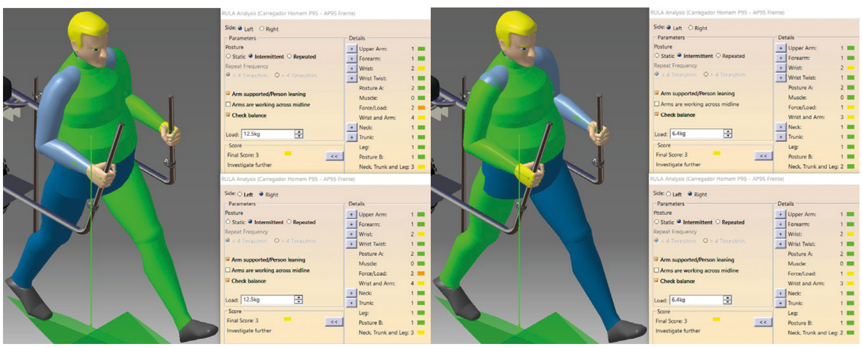
Note that in the four analyzes above, Figure 11, the posture has a final score of 4 on both sides (left and right) and requires an investigation (Investigate Further), a common factor in all analyzes is wrist twisting (Wrist Twist). To correct this, the rear support arm has side arms where the mannequin can make a neutral grip, thus reducing wrist twisting, which can be seen in Figure 12.



(A) (B)

Figure 8 – RULA analysis of male P95 (A) and female P5 (B) PwDs.

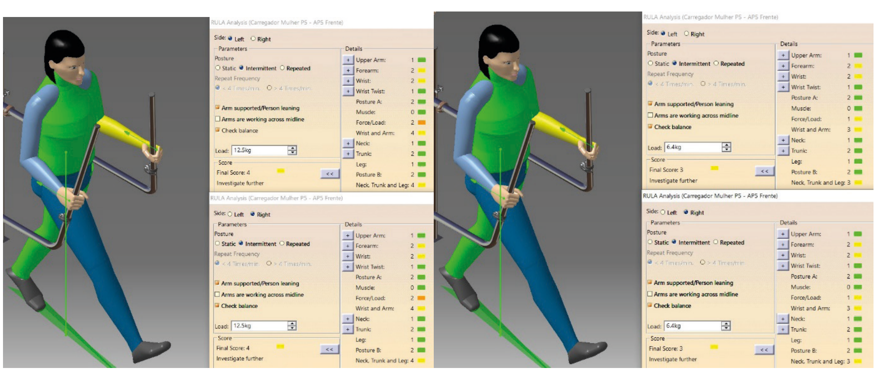
Source: Own preparation, 2023.



(A) Related to static friction (B) Related to dynamic friction

Figure 9 – RULA analysis of the P95 male charger for a chair determined by its percentile.

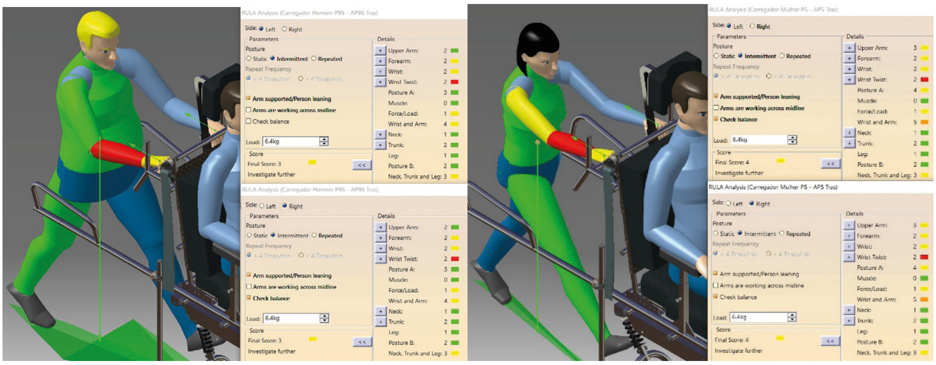
Source: Own preparation, 2023.



(A) Related to static friction (B) Related to dynamic friction

Figure 10 – RULA analysis of the P5 women's charger for chair configured to its percentile.

Source: Own preparation, 2023.



(A) (B)

Figure 11 – RULA analysis of rear chargers for chairs configured to their percentile. (A) for male 95th percentile and (B) for female percentile.

Source: Own preparation, 2023.

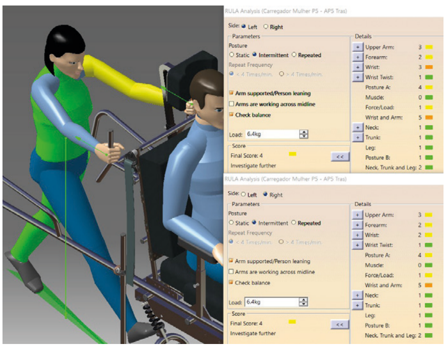


Figure 12 – RULA analysis of the P5 women's charger for a chair configured to its percentile using a neutral grip.
Source: Own preparation, 2023.

The following reviews cover dummies using the second rear support arm option. See Figure 13 to 16.

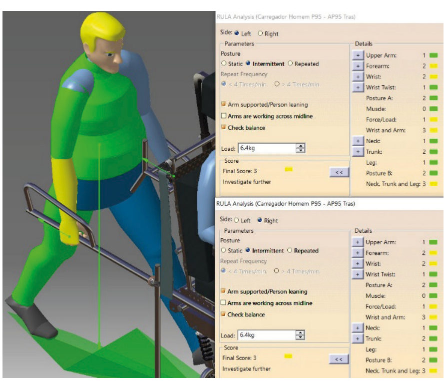


Figure 13 – RULA analysis of the P95 male charger using the support arm of the chair configured to its percentile.
Source: Own preparation, 2023.

Figure 13 shows the test of a 95% percentile male charger using the support arm of the chair configured to his percentile. The mannequin is in a posture that requires an investigation (Investigate further) with a final score of 3 on both sides (left and right), this is due to the score of each limb varying between 0 and 3, with the wrist twist (Wrist Twist), neck, trunk and legs (Neck, Trunk and Leg) the main aggravating factors.

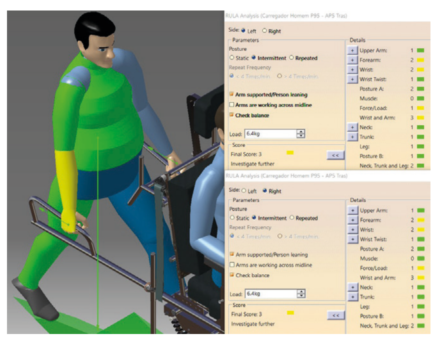


Figure 14 – RULA analysis of the P95 male charger using the support arm of the chair determined for the P5 percentile.

Source: Own preparation, 2023.

To configure the P95 mannequin using the support for P5, see Figure 14, it is noted that the differences in chair height do not impose a negative variation in the mannequin's posture, this is due to the shape of the rear support arm, which has a handle facilitating the grip of the charger without bending over, maintaining an erect posture, shoulders collected and acceptable flexion of the arm, forearm and wrist, configuring a correct and comfortable posture.

Figure 15 shows the test of a woman with a 5% percentile using the support arm of the chair adjusted to her percentile. The mannequin is in a posture that requires an investigation (Investigate further) with a final score of 3 on both sides (left and right), this is due to the score of each limb varying between 0 and 3, with the wrist twist (Wrist Twist), neck, trunk and legs (Neck, Trunk and Leg) the main aggravating factors.

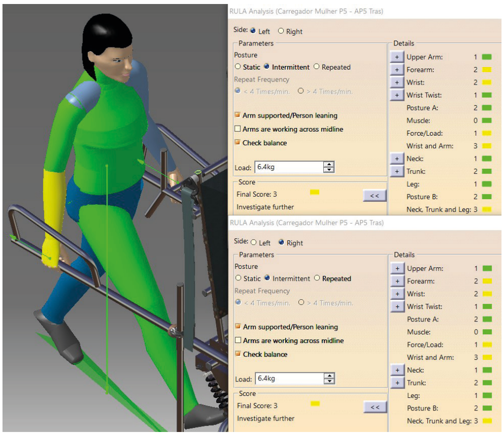


Figure 15 – RULA analysis of the P5 female charger using the support arm of the chair configured to her percentile.

Source: Own preparation, 2023.

Figure 16 shows the test of a woman with a 5% percentile using the support arm of the chair configured for the 95% percentile. The mannequin is in a posture that requires an investigation (Investigate further) with a final score of 4 on both sides (left and right), this is due to the score of each limb varying between 0 and 5, with the wrist twist (Wrist Twist), neck, trunk and legs (Neck, Trunk and Leg) forearm (Forearm) and posture A (Posture A) the main aggravating factors. This is due to the need for the carrier to rotate the shoulders, flex the forearm and wrist to reach the support arm, the members mentioned have the highest scores in the analysis. These changes, even if small, cause discomfort in the limbs, so remaining in this position for a long time can hurt the charger. The analysis proves the importance of adjusting the height of the chair to adapt different percentiles of chargers.

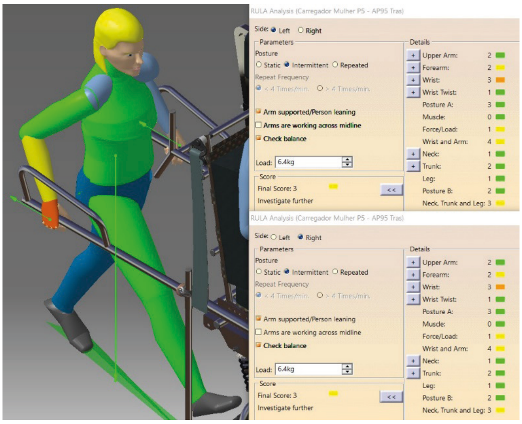


Figure 16 – RULA analysis of the P5 female charger using the support arm of the chair set for the P95 percentile.

Source: Own preparation, 2023.

Overall, RULA reviews reveal the importance of chair ergonomic adjustments for both PwDs and chargers, as user comfort is crucial, especially during outdoor activities. The RULA tool proved to be valuable in evaluating this comfort. An important next step would be to create a Mockup and carry out user testing to validate the results of the computational analyzes and adjust the structure as necessary.

BIOMECHANICS SINGLE ACTION

The Biomechanics Single Action Analysis tool is capable of measuring the biomechanical data of a worker in a given posture, calculating loads on the lumbar spine and forces on the mannequin's joints. It does not require configuration of parameters, taking into consideration, the configurations of the mannequin, posture and applied loads. This tool is used specifically for chargers, considering the forces in the dummy's hands related to pushing/pulling and charging.

It can be verified from these analyzes whether PwDs and chargers have their joint compression and shear values below the limits recommended by the National Institute for Occupational Safety and Health of the United States (NIOSH) and the University of Waterloo (Public Research University in Canada), respectively 3433 N m2 (joint compression) and 500N m2 (joint shear) (Source: CATIADOC, 2022). It can be seen that the values presented in Table 2, 3, 4 and 5 are lower than the acceptable limits.

Joint compression and shear values		
PcDs	Analysis	
	Joint compression (N m2)	Joint shear (N m2)
P5	1212	89 Posterior
P95	417	39 Posterior

Table 2 – Compression and joint shear values of PwDs.

Source: Own preparation, 2023.

Joint compression and shear values		
Chargers	Analysis	
	Joint compression (N m2)	Joint shear (N m2)
P95 charger for chair P5	875	136 Posterior
P95 charger for chair P95	943	130 Posterior
P5 charger for chair P5	357	126 Posterior
P5 charger for chair P95	365	125 Posterior

Table 3 – Compression and joint shear values of the front chargers related to static friction.

Source: Own preparation, 2023.

Joint compression and shear values		
Chargers	Analysis	
	Joint compression (N m2)	Joint shear (N m2)
P95 charger for chair P5	814	81 Posterior
P95 charger for chair P95	882	75 Posterior
P5 charger for chair P5	332	68 Posterior
P5 charger for chair P95	433	60 Posterior

Table 4 – Compression and joint shear values of front loaders related to dynamic friction.

Source: Own preparation, 2023.

Joint compression and shear values		
Charger	Analysis	
	Joint compression (N m2)	Joint shear (N m2)
P95 charger for P5 chair	1512	132 Posterior
P95 charger for P5 chair (support arm)	1623	141 Posterior
P95 charger for P95 chair	1277	115 Posterior
P95 charger for P5 chair (support arm)	1360	110 Posterior
P5 charger for P5 chair	617	69 Posterior
P5 charger for P5 chair (neutral grip)	334	62 Posterior
P5 loader for P5 chair (support arm)	520	86 Posterior
P5 charger for P95 chair	640	76 Posterior
P5 loader for P95 chair (support arm)	368	67 Posterior

Table 5 – Compression and joint shear values of rear loaders related to dynamic friction.

Source: Own preparation, 2023.

Of all the percentages of the population that cannot perform the task, only the largest is presented. For PwDs it is the P95 man. The graph related to PwD can be seen in Figure 26.

As for loaders, it is the P5 front loader when applying force to break static friction (start movement). The graph related to the loader can be seen in Figure 27.

In all other analyzes the percentages are less than 10%, which is expected due to the percentile range that we determined to cover.

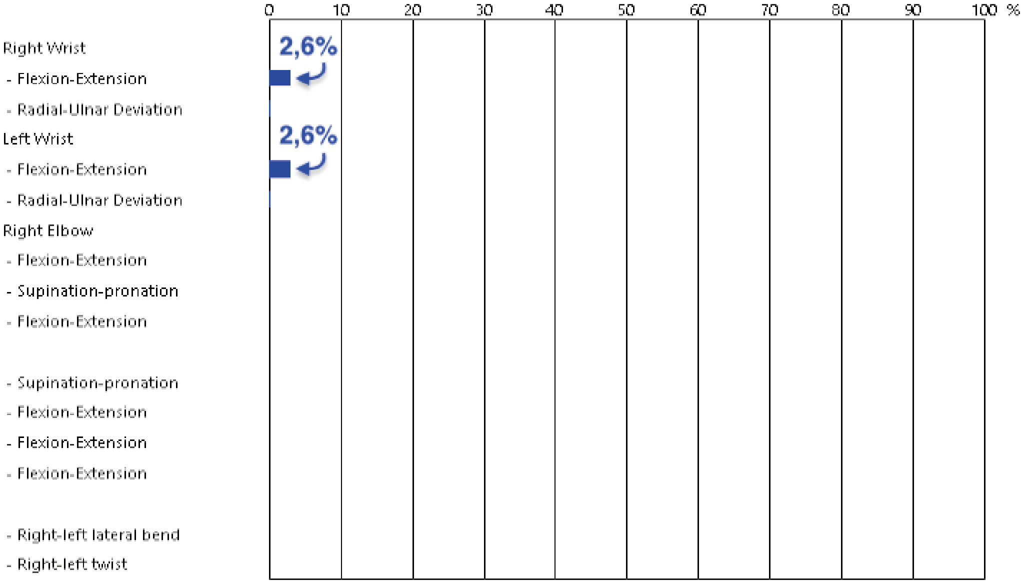


Figure 26 – Graph of the percentage of the population that does not have the strength to perform the task (PwD).

Source: Own preparation, 2023.

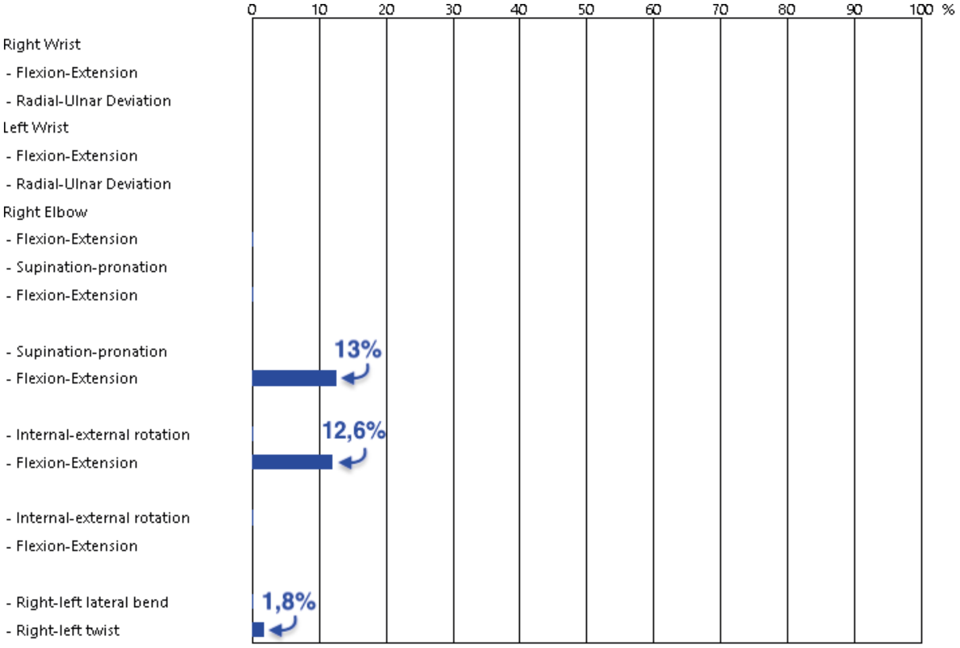


Figure 27 – Graph of the percentage of the population that does not have the strength to carry out the task (carrier).

Source: Own preparation, 2023.

CONCLUSION

The main objective of the work was to design a wheelchair aimed at trails, with an emphasis on ergonomics and affordable cost, aiming to overcome the difficulties faced by people with physical disabilities (PwD) when traveling in unpaved environments, such as trails.

Initially, we developed a conceptual project, identifying the essential requirements to make the chair viable. To do this, we carried out an analysis of options available on the national and international market, considering their limitations. A questionnaire was designed and administered to 25 PwDs, providing valuable insights for the project. Furthermore, we conducted an ergonomic study, focusing on biomechanics and anthropometry, and analyzed the forces acting on the system to size the structure.

To validate the chair in terms of comfort for PwDs and porters, we performed relevant ergonomic analyzes using Catia software, including RULA Analysis, Push/Pull Analysis and Biomechanics Single Action Analysis. In the intermediate stage of the project, all assemblies and components were dimensioned and modeled in 3D in Catia. We then move on to the executive project, creating detailed technical drawings of all components, a list of materials and detailed pricing. We also developed a manual for end users, providing guidance on measures needed to adapt the chair and assembly instructions.

The end result is a model that fully meets the project requirements, offering low cost, adaptable dimensions, adequate postural support, safety and durability. We opted for a collapsible design for easy transport and storage. The final weight of the product is approximately 30 kg, slightly above market values, but we believe this can be reduced in the future. The estimated cost in values for the year 2023 was around R$36,000.00 (including materials and labor), being influenced by investment in development and prototyping, with potential for reduction when in mass production.

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