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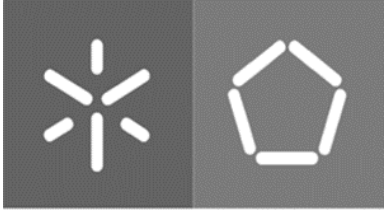

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Study and reformulation of the technical aid device HomeHoist

Dissertação de Mestrado
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Trabalho efetuado sob a orientação de
Professor Doutor Eurico Augusto Rodrigues de Seabra
Professor Doutor Luís Ferreira da Silva

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DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

RESUMO

A paralisia cerebral manifesta-se nos primeiros anos de vida de uma criança e pode ser provocada por lesões cerebrais, ou desenvolvimento cerebral anormal, refletindo-se em distúrbios na capacidade motora da mesma, cada caso variando em termos de severidade e de tipo de disfunções motoras. A esperança média de vida destas crianças tem vindo a aumentar, o que significa que é relevante encontrar alternativas para melhorar a qualidade de vida daqueles afetados por esta condição.

Assim, surgiu o projeto HomeHoist, que tinha como objetivo funcionar como dispositivo único para a transferência de pacientes com paralisia cerebral, sem sobrecarregar o prestador de cuidados. O dispositivo HomeHoist consistia numa cadeira de rodas elétrica, com uma grua incorporada, assento removível e o espaço interior livre, o que permitia transferir o paciente entre várias superfícies, como a cama e vasos sanitários. No seguimento de um estágio na empresa Orthos XXI, surgiu o interesse em reavivar este projeto, que tinha sido concluído em 2014.

Os aspetos identificados para a melhoria do dispositivo foram incorporar a função de verticalização; adicionar a elevação de pernas, que apesar de ser um objetivo no projeto original, não foi alcançado; dividir o assento e o encosto de costas, para personalizar o funcionamento do dispositivo; libertar o espaço lateral no assento, para facilitar o manuseamento do paciente; e alterar a estrutura e componentes para irem de encontro à produção da empresa, reduzindo o tempo e custo de produção.

Usando metodologias de projeto, como a árvore de objetivos, análise de funções e o método dos objetivos ponderados, foi possível de entre várias soluções, compreender quais as que melhor se enquadravam nos objetivos pretendidos, seguindo-se então a determinação das restrições dimensionais e de seleção e colocação de componentes mecânicos, para obter um modelo 3D do dispositivo final. Com o modelo foi possível obter verticalização de 65°; reclinação de 155°; as dimensões do dispositivo foram ao encontro do pretendido; e a elevação de pés foi incorporada, apesar de não permitir esticar completamente as pernas. De seguida, foi feita uma breve análise dos componentes elétricos a ser incorporados, seguida da simulação FEM de dois componentes, sendo que, com a simulação de um deles, o arco, percebeu-se que o mesmo teria de ser alterado de modo a aguentar a carga que lhe era aplicada, aumentando-se o diâmetro do tubo e o posicionamento das argolas.

Por fim, com a produção do protótipo foi possível perceber o que deveria ser melhorado para facilitar a produção do dispositivo, tanto em termos de produção como de montagem. Foi também testado o funcionamento do dispositivo, para confirmar a informação obtida com o modelo 3D.

Palavras-chaves: cadeira de rodas, grua integrada, paralisia cerebral, transferência.

ABSTRACT

Cerebral palsy manifests itself in the first years of a child's life and may be caused by brain injuries, or abnormal brain development, reflecting in disorders in the child's motor capacity, each case varying in terms of severity and type of motor disorders. The average life expectancy of these children has been increasing, which means that it is relevant to find alternatives to improve the quality of life of those affected by this condition.

Thus, the HomeHoist project emerged, which aimed to function as a single device for transferring patients with cerebral palsy without burdening the caregiver. The HomeHoist device consisted of an electric wheelchair, with a built-in hoist, removable seat, and free interior space, which allowed the patient to be transferred between various surfaces, such as beds and toilets. Following an internship at the company Orthos XXI, the interest arose to revive this project, which had been concluded in 2014.

The aspects identified for improving the device were to incorporate verticalization; include leg raising, which despite being a goal in the original project, was not achieved; split the seat and backrest to customize the operation of the device; free up the lateral space on the seat to facilitate patient handling; and change the structure and components to meet the company's production, reducing production time and cost.

Using project methodologies such as the goal tree, analysis of functions, and the method of weighted goals, it was possible, among several solutions, to understand which ones best fit the intended goals, followed by the determination of dimensional constraints and the selection and placement of mechanical components, to obtain a 3D model of the final device. With the model it was possible to obtain 65° verticalization; 155° reclination; the dimensions of the device were as intended; and the foot elevation was incorporated, although it did not allow to completely stretch the legs. Then, a brief analysis of the electrical components to be incorporated was made, followed by the simulation of two components, and with the simulation of one of them, the arch, it was realised that it would have to be redesigned to withstand the load that was applied to it, by increasing the diameter of the tube and the positioning of the rings.

Finally, with the production of the prototype, it was possible to understand what should be improved to facilitate the production of the device, both in terms of production and assembly. The functioning of the device was also tested, to confirm the information obtained with the 3D model.

Keywords: cerebral palsy, integrated hoist, transfer, wheelchair.

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LIST OF ABBREVIATIONS

CP – Cerebral Palsy

IBV – Instituto de Biomecánica de Valencia

SCPE – Surveillance Cerebral Palsy Europe

PVNPC5A – Plano de Vigilância Nacional da Paralisia Cerebral aos 5 Anos de Idade

BFMF – Bimanual Fine Motor Function

MACS – The Manual Ability Classification System

MRICS – MRI classification system

MRI – Magnetic Resonance Imaging

VSS – Viking Speech Scale

GMFCS – Gross Motor Function Classification System

RATD – Robotic Assisted Transfer Device

1. CHAPTER I – Introduction

Chapter 1 aims to provide a basic understanding of the subject of this project, the transfer process of patients with cerebral palsy, beginning with a brief explanation of this disorder, as well as the obstacles that both the patients and their caregivers struggle with, along with an introduction to the HomeHoist project, the foundation of this dissertation. The motivation and goals will also be stated, in addition to the structure of this dissertation and a description of the internship at Orthos XXI.

1.1. Background

Cerebral palsy (CP) is the most frequent motor disability in childhood, and a child with this condition displays disorders in the control of posture and movement, which may be reflected in poor coordination, balance and abnormal movement patterns, due to abnormal and/or irregular variations in muscle tone. CP originates from brain injuries that occur during the early stages of brain development and, therefore, may develop before, during, or shortly after birth, thus, CP cannot be developed in adulthood. Nonetheless, depending on the severity of their condition, many of these children will reach adult age [1–4].

Often the CP patient develops other conditions associated with the CP, namely, epilepsy; communication, learning, and attention disabilities; spine problems; and vision, hearing, speech, or breathing impairments, among others [2, 5].

This condition has a complex nature, which means that each case has its peculiarities and level of severity and because of that, it can, sometimes, be difficult to classify and group the various forms of manifestation of CP according to their characteristics. However, the current knowledge in this matter has allowed the categorization of CP into three types: spastic, the most common; dyskinesia and ataxia, which will be addressed in more detail later [6].

Depending on the severity of their condition, patients with reduced mobility may need assistance to perform everyday tasks, for this reason, they rely on a family member, healthcare worker, or another person to facilitate those tasks and aid them in their daily life, from now on referred to as caregivers. A relevant aspect of daily living is the process of transferring the patient. A transfer consists of moving a patient from one surface to another, for example, from a bed to a bath seat, or from a wheelchair to bed, and vice versa. To perform the transfer, either the caregiver can hold the patient, and bear all the weight, to move him from one place to the other, or an auxiliary device may be used, the most common being mobile, ceiling, or static hoists. However, these devices have disadvantages such as some require

installation where it's intended to use them, which may not always be possible; human or mechanical errors may occur in the use of these devices, which lead to potentially serious accidents; and due to their size, they may be difficult to store and transport [7].

It was with all this in mind that the HomeHoist project, with identification number FP7-SME-2012-313976, a collaboration between several companies, namely Technik, HiTech, Instituto de Biomecánica de Valencia (IBV), HERI, Orthos XXI, and Arti Endüstriyel Elektronik (Arti), financed by the Seventh Programme - European Union Framework, was born. This project entailed the development of a wheelchair with an incorporated hoisting system, with the main goal of assisting caregivers and patients in the transfer process. The concept foreseen for the HomeHoist project eliminated the need for several devices and alterations in the structure of the residence, to meet the wishes and needs of the target audience, individuals with CP and their caregivers, improving their lives without altering their home and still respecting the dignity of the patient.

Orthos XXI was one of the companies involved in the project, which lasted from 2013 to 2014, and following an internship carried out in the company, an interest in the HomeHoist project arose, to enable its production by the company, as well as improve it.

As a result, a review of the documentation archived in the company, concerning this project, was carried out, to gather relevant information relating to the mode of operation of the device, and which expectations it was intended to meet. With this information, a new device was designed, maintaining the main goal, to assist in the transfer process, though, the design and certain features were improved and a new feature, verticalization, was added.

1.2. Motivation and goals

As previously stated, CP is the most common cause of motor disability in young children, for that reason, the need to understand the trends of prevalence over time; the causes of this disability; and the most adequate way to classify the patient's symptoms, led to the establishment of the Surveillance of Cerebral Palsy in Europe (SCPE) in 1998. This network is a collaboration of professionals and researchers working with CP registries from across Europe. As of 2017, the SCPE Common Database contains anonymized population data on more than 20 000 children with CP. The last published study of prevalence conducted by the SCPE was in 2003, and it presents a prevalence of 1.77 per 1000 live births [8, 9].

For a better perception of the prevalence at an international level, a study published in 2018, gathered information from 20 European registries and 11 registries from 7 non-European countries,

specifically from Canada, Japan, China, Australia, USA, Turkey, and India. The average prevalence in non-European countries was 1.9‰ live births [10].

In terms of national data, the National 5-Year-Old Cerebral Palsy Surveillance Program (originally, *Programa de Vigilância Nacional da Paralisia Cerebral aos 5 Anos de Idade* - PVNPC5A), supported by entities and organizations such as the Federation of Portuguese Cerebral Palsy Associations (from the original *Federação das Associações Portuguesas de Paralisia Cerebral*), aims to provide national coverage of children with CP to determine the incidence rate, risk factors and other aspects that may be relevant to the study of this condition. A total of 1787 children born between 2001 and 2010 in Portugal with CP were reported to the PVNPC5A, having obtained an accumulated incidence rate, up to 5 years of age, of 1.55‰ live births, values that are within the expected range in Europe [1].

This brief background on the CP prevalence worldwide is meant to elucidate the reader in terms of market prospects for the project of this dissertation, thereby establishing the significant amount of patients with this disability, who face several daily obstacles, and could benefit from a device that helps improve their quality of life.

Moreover, the caregivers of these children need a better system to assist them with daily tasks, one that doesn't burden them physically and emotionally. The repetitive task of transferring the patient daily often reflects on musculoskeletal injuries and, as the child grows and reaches adulthood, greater is the physical effort made by the caregiver. Furthermore, for the ones caring for a family member at home full-time, the burden of responsibility, routine, and psychological and physical fatigue is an additional form of emotional distress [11, 12].

To make the lives of the ones personally affect by CP easier and improve the HomeHoist design, it's intended to maintain its initial goal, assist patients and caregivers in the transfer process, and add functionalities to obtain, as a final product, not only a transfer aid device, but also a comfortable wheelchair in which the patient can remain for long periods safely and comfortably. Thus, by adding the **verticalization feature**, a more complete device will be designed, to fulfil as many patient's needs as possible. The final design should result in an **intuitive** to use device, **easy to move around the house**, which will **reduce the number of devices used in daily tasks**, as well as alterations to patient's home. Finally, the device should be able to be **produced at Orthos XXI** and have an **appealing appearance**.

1.3. Orthos XXI

The idea to reformulate the HomeHoist device emerged as a consequence of an internship at Orthos XXI. The company was founded in 2007, as a successor of a pre-existing company, and produces

orthopaedic and hospital material. It's a national company based in Guimarães that develops and produces equipment for the national and international market. Although it's a renowned company with a well-established market, both on a national and international level, the company's goal is to keep growing and further expand, spreading its name and the quality of national products around the world.

The warehouse in the AvePark is where most of the components are manufactured. A wide range of equipment is based there, such as bending machines; robotic and manual welding; a laser cutting machine and it's also possible the CNC machining of components. The painting equipment and the testing facilities can also be found at this location.

At the headquarters of the company, in Santa Leocádia, are based the offices, where the developers are stationed, as well as the marketing, commercial and financial departments, among others. This is also the final station of assembly for the products the company produces.

Many of the company's products are classified as class 1 medical devices, and have the CE certification[1], following the directives 93/42/CEE and 2007/47/CE, in addition to being recognised by the INFARMED. The company is also certified by the EN ISO 9001:2008 standard. To ensure the safety and efficiency of new products, they are often tested by credited and independent entities, such as the IBV.

Besides the concern to make quality products, human resources are also a valued piece of the company. To that end, the company invests in training and activities to keep the staff informed and satisfied [13].

1.4. Structure

The first chapter pertains to the Introduction of this dissertation. The subchapter Background serves to give the reader a brief explanation of what constitutes cerebral palsy, plus the challenges that both the patients and caregivers face, as well as introduce the HomeHoist project, the predecessor of the present project. Next, the motivation and goals are presented, by giving a sense of the prevalence of CP in Portugal and Europe, and by asserting in what the final device should consist. Then, the company in which this project was carried out, Orthos XXI, is presented. Finally, the subchapter structure shares the organization of this dissertation for a better overview of the work undertaken.

In the second chapter, cerebral palsy in the lives of patients and caregivers, a more detailed explanation of what CP involves, in terms of causes, symptoms, and types, is given in the subchapter

[1] This mark means that the products traded on the extended Single Market in the European Economic Area (EEA) have been assessed to meet high safety, health, and environmental protection requirements.

cerebral palsy, definition and types. Followed by the subchapter understanding the patient's motor abilities, which is intended to provide an understanding of how cerebral palsy can limit the movement of the patients and how it affects the transfer process. Then, the subchapter caregivers serves to provide some enlightenment of the struggles of the ones that take care of these patients and, lastly, is the subchapter current transfer process, where is tackled the present way the transfer process is made, as well as the concerns of those involved.

The third chapter, named technical aid devices, is a reflection of the market and bibliographic research made with the intent to understand what's out there in the market in terms of wheelchairs and verticalization devices, as well as what innovations are being developed, guarantying that the device that comes out of this project is innovating.

In the fourth chapter, study and analysis of the HomeHoist device, the previous project is analysed and studied, to understand the original concept and the operation and design of the device built at the end of the project.

The fifth chapter, redesign of the HomeHoist device, is where the idea of the new concept starts to take shape and the project requirements are established, as well as the goals the device should meet, employing the goal tree method. Then, in the subchapter establishment and analysis of functions, the functions the new device should incorporate are presented, and the previous functions of the device are examined, to better grasp the concept of operation and how it can be improved. Afterwards, different solutions for the various functions will be analysed in the morphological diagram, and four concepts, which comprise these solutions, are selected. Finally, using the weighted goals method, one of the concepts is selected for further development.

Next, the sixth chapter concerns the development of the selected concept. In this chapter, various aspects of the development are analysed individually, for subsequent implementation in the final device, namely, the structural sizing of the overall device, the addition of the verticalization feature, the mechanical components to be incorporated, and the materials of the various components.

The seventh chapter is where the final result is presented, and the fundamental components are explained individually in more detail, followed by a description of the operation of the device, in terms of the different functions it encompasses. Then, the electric system will be approached, to provide a sense of the electrical requirements of the device and, to complete the final concept analysis, simulations will be run with the most critical components, to understand if they are well designed.

The eighth chapter pertains to the manufacturing of the prototype. An overview of the manufacturing process at Orthos XXI will be carried out, to introduce the manufacturing and testing of the prototype built in the scope of this project.

The last chapter relates to the conclusions of this dissertation, as well as the future prospects for the device developed.

Concerning the annexes of this document, Annex I relates to Infarmed's information notices about hoisting devices; Annex II concerns the market research for hoists and slings; Annex III contains anthropometric measurements for patients with neurological impairments, who are wheelchairs users; Annex IV contains the market research for both beds and toilet sizes; Annex V serves to better illustrate the movements referenced in the verticalization study presented in Chapter VI; Annex VI display the calculations carried out for the selection of actuators and gas springs; Annex VII contains the calculations for the validation of the batteries chosen; Annex VIII refers to the mechanical properties of the material used for the metallic components of the device; Annex IX pertains to illustrative images for most relevant overall dimensions; Annex X relates to both pairs of actuators length during verticalization, and, lastly, Annex XI, pertains to the technical drawings for the production of the prototype.

2. CHAPTER II – Cerebral palsy in the lives of patients and caregivers

In order to develop a device capable of improving the quality of life of individuals with cerebral palsy, it is important to understand the implications that this disorder has, not only on patients but also on their caregivers. Cerebral palsy is a very complex disorder which means that it is important to understand the different forms that cerebral palsy can manifest. In this chapter, basic notions of cerebral palsy will be addressed, as well as, the target audience of this project, with respect to their needs and wishes.

2.1. Cerebral palsy, definition, and types

Cerebral palsy is an umbrella term used to describe a group of disorders that affect the motor ability of an individual. Occurs in the early stages of brain development, due to brain injury or abnormal brain development either before, during, or after birth, up to 2 years of age, and manifest as a disturbance in the control of posture and movement. CP is the most common motor disability in childhood, being diagnosed in the first years of a child's life, with 5 years of age being the optimal age for diagnosing, according to de SCPE. In this way, an adult cannot develop CP, however, children with this disorder can grow into adults. CP is a permanent condition, being that the brain damage is non-progressive, however, it's not unchanging, this means that the CP doesn't get worse over time, but the patient may experience changing symptoms over time [2, 3, 14].

Congenital CP refers to brain damage that occurred before or during birth, this being most often the case. Factors such as premature birth, infections during pregnancy, and jaundice may lead to the child developing congenital CP. When brain damage occurs more than 28 days after birth, it's a matter of post-neonatally acquired CP, which may be due to infections such as meningitis, head injuries, or blood flow deficits in the brain [2].

The brain damage that causes CP affects the individual's motor system, in a way that the individual has little coordination and balance, abnormal movement patterns, or a combination of these issues [15]. The individual may also develop other conditions, related to the CP, such as epilepsy, learning and communication disabilities, attention deficit or hyperactivity, spine problems, such as scoliosis, vision, hearing, speech, or breathing impairments, among others [2, 5]. CP does not imply that the individual has an intelligence deficit but may cause an intellectual disability due to the lack of experience resulting from living with cerebral palsy [16].

Since cerebral palsy is a complex problem that can manifest itself in various ways, in which no two cases are the same, there are different aspects to be taken into consideration when classifying the type of CP the patient displays. This can prove to be a difficult task and is reflected in the PVNPC5A report since 1.8% of the cases registered were deemed unclassifiable [1].

Cerebral palsy can be divided into different types, according to the impact it has on the individual's movement. To better understand the types of CP, it is important to clarify two concepts. First, the concept of muscle tone, which can be defined as the slight contraction of a muscle that occurs continuously, passively [17]. Second, the concept of hypotonia and hypertonia. Hypotonia refers to the reduction of muscle tone, which causes loss of strength and firmness, hypertonia, on the other hand, is the increase of muscle tone, which causes stiffness and spastic movements [18].

The SCPE recognises three main types of cerebral palsy: spastic, dyskinetic, and ataxia, which follow the same line as the ones identified by the PVNPC5A. Below, each type will be addressed in more detail with regards to the symptoms exhibited and the type of injury that triggers each one of them.

- **Spastic**

In this situation, the individual presents hypertonia. Due to excessive muscle tone, the muscles are more rigid, and the individual's movements and posture become anomalous. The individual also presents pathological reflexes, this meaning, excessive reflexes [2, 6]. This type of CP is caused by an injury in the motor cortex of the brain, responsible for controlling voluntary movement [18]. Spastic CP may still be divided unilateral and bilateral. In the first instance, only one side of the body is affected, known as spastic hemiplegia; in the second, the lower limbs are usually the most affected, and it's referred to as spastic diplegia. The most aggressive case, spastic tetraplegia, occurs when the four limbs, face, and trunk are affected [2, 6, 16]. This is the most common type of CP, pertaining to approximately 82.4% of the cases recorded by PVNPC5A [1].

- **Dyskinesia**

According to the SCPE, dyskinetic CP may be subgrouped into dystonic CP and choreo-athetotic CP. Both are characterized by tone fluctuation, though, in the former, hypertonia is predominant, contrary to the latter, in which hypotonia is the main state. Dystonic CP is also characterized by abnormal posture, due to prolonged muscle contractions, involuntary movements, and distorted voluntary movements, at a slow pace. Choreo-athetotic CP is defined by a higher rate of activity, rapid, involuntary, and often fragmented, movements (choreo) or slower, and constantly changing, movements (athetosis) [1, 6, 16].

This type of CP is caused by damage to the basal ganglia, and the cerebellum may or may not be damaged as well [18]. Of all the cases registered by the PVNPC5A, 11.1 % relate to this type of CP [1].

- **Ataxia**

In this scenario, hypotonia prevails, which means the patient has difficulty balancing and coordinating movements. The patient has great difficulty performing fast movements or those requiring considerable control, for example, writing, being the movements abnormal in force, rhythm, and accuracy. Another symptom may be slow tremors [2, 6, 16]. Ataxia happens when injuries in the cerebellum or the cerebellar pathways occur [16]. According to the PVNPC5A, only 4,7% of individuals presented this type of CP, making it the rarest kind [1].

Nevertheless, one key aspect to bear in mind is that a significant amount of these patients will become adults and it's important to understand how their needs will evolve as they age. A 2014 study, intended to find a pattern of survival up to 30 years of age in children with CP, and relate it to the severity of their condition. In cases where the child walks un-aided, the rate of survival was between 81-90%, the most optimistic situation. When the children were unable to walk on their own, but still displayed some motor abilities, the rate of survival to 30 years of age was between 43% and 92%. Only in more severe cases, where the children weren't able to lift their heads and were fed by a tube, did the rate of survival dropped below 40% (between 26% to 40%) [4]. Another study, conducted within the population of children with CP in southern Sweden, born between 1990 and 2005, concluded that 96% of those children (683 of 713) reached 19 years of age [19].

2.2. Understanding the patient's motor abilities

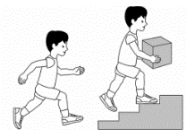
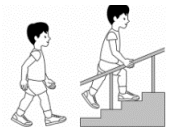
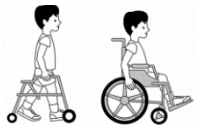
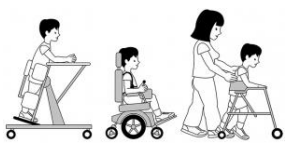
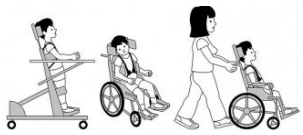
It's important to realize that a patient's condition is very unique, each one will have its limitations and traits and, besides assessing the type of CP that the patient exhibits, it's also of interest to classify or describe the motor abilities displayed. To this end, the SCPE recognises five tools to classify different types of motor abilities that may be impaired because of this disorder. These tools are used while the patient is still a child, to better evaluate and attend to the disorder in the first years of life [20]. Below is a brief description of the tools aforementioned, with a more in-depth analysis of the Gross Motor Function Classification System.

The Bimanual Fine Motor Function (BFMF) is a scoring system for fine motor function. This classification takes into consideration the symmetrical or asymmetrical movement of the upper limbs.

The Manual Ability Classification System (MACS) evaluates the behavior of both hands in different activities. The MRI classification system (MRICS) was developed to harmonize the classification of magnetic resonance imaging (MRI), based on pathogenic patterns as proposed by the SCPE network. The Viking Speech Scale (VSS) was developed to classify the patient's speech production. This scale only considers the individual's ability to speak, not the ability to communicate in alternative methods [20].

And, finally, the Gross Motor Function Classification System (GMFCS), which is the most relevant for the project in hands, as it describes functional abilities, assessing the need for mobility aid devices and, incidentally, quality of movement and independence. The GMFCS comprises 5 levels, which are described in **Table 1**, given that Level I concerns more independent children with fewer limitations in their movements, and Level V is the opposite. Recent studies reveal that this classification system can also be applied to adults with CP and therefore, from now on, when talking about the different levels of GMFCS, both children and adults are covered [20, 21].

Table 1 *- Gross Motor Function Classification System [22, 23].*

Level	Description
Level I 	- Goes up and down the stairs without assistance. - Walks indoors and outdoors. - Can run and jump. - Reduced balance, speed, and coordination.
Level II 	- Goes up and down the stairs with a handrail. - Walks indoors and outdoors with limitations on uneven surfaces, slopes, and crowds. - Reduced ability to run and jump.
Level III 	- Uses walking aids indoors and outdoors on level surfaces. - May be able to climb stairs with a handrail. - May operate a manual wheelchair with help in longer distances and uneven surfaces.
Level IV 	- Limited walking ability even with assistive devices. - Uses a wheelchair most of the time and can control an electric chair. - Can participate in standing transfers.
Level V 	- Unable to walk independently, needs an electric wheelchair. - Severe movement impairment, difficulty in voluntary movements, and in keeping head and neck upright.

With the classification described in **Table 1**, it's possible to understand that the spectrum of capabilities of patients with CP is vast, from patients with a lot of independence and few limitations to patients who require full assistance for daily tasks. According to the GMFCS, level III, IV, and V patients are those who will need a walking aid or wheelchair to have mobility, whether assisted or not. To better understand what this translates into, in terms of volume of patients, a study published in 2008, conducted with data gathered by the SCPE, analysed 9 012 cases to correlate the type of cerebral palsy, and impairments associated, with the probability of walking of these patients. The study concluded that 46% of them would need a walking aid (16%) or would not be able to walk at all (30%) [16].

Nonetheless, the SCPE does not limit the use of other tools to classify the motor ability of a patient and, in the scope of the HomeHoist project, a new classification system was created and used, to group CP patients in a more significant way, according to their limitations and abilities, to better relate to the requirements intended for the project. This classification was carried out by health professionals and accompanied by the IBV. Five user profiles were identified and are described in detail in **Table 2.** The term "users" pertains to the patients that use wheelchairs or transfer devices.

Table 2 - *Patient profiles according to health professionals [24].*

Patient Profile	Main Characteristics
Profile 1: Highly Dependent without Hip Bending	- Not able to cooperate in a transfer process performed by two caregivers. - The user has stiffness/spasticity, without the capability for hip bending and extension reflex inhibition. - Usual transfer process employed: by hand.
Profile 2: Highly Dependent with Hip Bending	- Not able to cooperate in a transfer process performed by two caregivers. - The user has stiffness and may have spasticity, with capability for hip bending and without the capability for extension reflex inhibition. - Usual transfer process employed: hoist.
Profile 3: Highly Dependent without Stiffness	- Not able to cooperate in a transfer process performed by one/two caregivers. - The user has low mobility and force in lower limbs, without the capability to stand. - Usual transfer process employed: hoist.
Profile 4: Standing without Autonomy	- Able to cooperate in a transfer process performed by one/two caregivers. - The user has severe limitations of force and mobility in lower limbs, capability to stand - Usual transfer process employed: hoist/assistive devices.
Profile 5: Standing with Autonomy	- Able to cooperate actively in a transfer process assisted one caregiver. - The user has reduced mobility and force in lower limbs, capability to stand. - Usual transfer process employed: assistive devices.

The ability to bend the hip is considered essential when transferring a patient while using a hoist, thereby, the condition of patients with Profile 1 is not suitable for the use of a hoist and, therefore, the HomeHoist device is not appropriate for these cases. The HomeHoist can be used by patients with Profile 2 to 5, however, the target audience for the device is patients of Profile 2 and 3, since their lack of ability to cooperate with the caregiver makes these patients the ones with a more urgent need for a new alternative of assistance during the transfer process.

2.3. Caregivers

Wheelchair dependent patients should have the freedom to move around, both indoors and in a community setting. According to the patient's control and ability to move, performing transfers independently may be more or less reasonable, even with the help of some assistive device.

Regarding patients with CP, this situation is aggravated because of their lack of control over the body's movements. If a patient attempts to make the transfer by themselves, an accident that leads to serious injury may occur. Thus, the target audience of this project presupposes the assistance of another individual to make the transfer safely. In this way, the concern for those who take care of these patients, the caregivers, arises, whether they are taking care of a relative in a domestic environment, or are healthcare workers, such as nurses, looking after patients in a healthcare-related facility.

For a better explanation of what it means to be a caregiver of a patient in a domestic setting, in other words, informal caregivers, on September 6th, 2019, the Statute of the Informal Caregiver[2] was published, following Law no. 100/2019. The main informal caregiver is considered to be the spouse or cohabitant, relative or kin up to the 4th degree of the straight or collateral line of the person cared for, who accompanies and looks after the person cared for permanently, and who does not receive any remuneration for the professional activity or the care provided to the cared-for person [25].

Transfers assisted by a caregiver can be purely manually, where the caregiver carries the patient with the arms, or can be assisted by a device, in which case, there is less effort required by the caregiver, thus, the transfer is performed safely. Even so, the options are limited, between ceiling and mobile hoists, which can require alterations in the household, and add up to the number of devices required daily to assist the patient. Additionally, during both types of transfer, there is always a risk of long-term, acute or cumulative, injury to both the patient and the caregiver, since it is a repetitive task that requires extensive physical effort on the part of the latter [11]. Several studies have proved that the continuous management

[2] Translated from the original Portuguese (Portugal) version *"Estatuto do Cuidador Informal"*.

of patients has a high musculoskeletal impact on caregivers, the most frequent type of lesion being that of the lumbar spine, often associated with problems in other areas of the body, such as neck, shoulders, wrists, among others [12, 26]. To better illustrate the amount of effort to which a caregiver is subjected, a study found that in a single bed to chair transfer, the caregiver experiences compressive forces up to 3500N [11].

In addition to the physical effort required to care for a patient using a wheelchair, there is an added aggravating factor for those caring for a family member at home full-time, namely the emotional burden that comes with the responsibility, routine, and psychological and physical fatigue of caring for someone 24 hours a day, every day [27].

Taking all this into account, to develop a device that assists in the task of transferring patients, not only must the safety and comfort of the patient be assured, which are two key aspects, but the role of the caregiver must also be taken into account, ensuring that this new device facilitates the work of the caregiver, reducing to a minimum their physical effort and attenuating the emotional aggravating factors that arise from these routine tasks.

2.4. The current transfer process

Following the HomeHoist project, the IBV, one of the project partners, conducted a study with CP patients to better understand the difficulties faced by them and their caregivers. First, an observation stage was carried out, where nine patients, older than eighteen, and their caregivers would conduct the transfer process as they normally would in their daily routines, but in a controlled environment.

The method of transferring patients with CP differs according to the severity of their medical condition. When the severity of the patient's CP is higher, and the patient is unable to cooperate, two caregivers are required, as the transfer has to be performed **manually.** The caregivers carry the patient's entire weight, wrapping the body with their arms. This procedure leads to heavy and unsafe transfers, even for two caregivers since the patient has erratic and involuntary movements. Besides the most extreme cases, most patients can be transferred using a **hoist**, the essential factor for this transfer being their ability to bend the hips. This process is safer for the caregiver and patient, however, there are complications such as difficulty in placing the sling hooks on the spreader bar[3] of the hoist and difficulty in tightening the sling. This type of transfer allows the patient to be dress and undress with the sling on.

[3] Item used to attach the sling straps in order to distribute the user's weight while lifting.

When the patient is able to **cooperate,** only one caregiver is needed, who helps the patient to stand and turn. In this scenario, the patient still needs help to dress and undress [24].

After the observation stage, an additional seven patients, also older than eighteen, were interviewed in order to understand their wishes, as well as the most relevant aspects, positive or negative, of the transference process, in their point of view. These interviews were conducted in person and using the Context Mapping[4] technique.

Overall, the central aspects of the transference process, highlighted by the patients, were that excessive effort on the part of the caregiver should be avoided; the faster the process, the less safe they feel; the placement of the sling should be simple; the location of the spreader bar is not adequate and therefore should be reconsidered; the comfort granted by personal contact makes them feel safer during the transfer process; current transfer methods do not allow them sufficient autonomy as they always need the help of a caregiver; transfers with a sling can be uncomfortable if the sling is not correctly positioned or suitable for the patient's situation [24].

Both patients and caregivers are not satisfied with the current mechanisms for transfer assistance, which demonstrates the need to develop a better alternative for these individuals [7]. In addition to the discontent with these devices, the use of hoists for transferring patients has associated risks. A research carried out on the INFARMED's website provided information on accidents associated with the use of hoists for the transfer of patients, regarding the reasons why they happened and the cautionary measures that should be taken to avoid future accidents. The informational newsletters that were considered relevant for further analysis were as follows: *Hoists and seats for the transfer of patients*, no. 055/CD (24/04/2007); *Birdie transfer hoists, suspension hook*, no. 197/CD/8.1.7. (05/09/2014); *Hoist connection hooks for patient transfer*, no. CA /139 (28/12/2006) and *Electric hoists for the transfer of patients*, no. 059/CA (17-05-2005), of which a brief explanation is provided in **Annex I**. The source of the errors was in some cases technical and others due to misuse of the device. Some of the problems that arose were low compatibility between different devices used in the transfer process; incorrect maintenance; wear of components and human error [28–31]. Thus, it's important to understand the need to develop a device that is not only intuitive to use but also straightforward to maintain, to ensure that the device is safe and will not cause serious incidents if any component fails.

[4] Technique used in the field of user experience research. This technique allows for better understanding of the deeper emotions and needs of real users.

3. CHAPTER III – Technical aid devices

This chapter contains the market research carried out, as well as a list of patents that may be relevant for the project at hand. This analysis aimed to determine the most relevant characteristics of each device found, and to understand the best way to embrace them into the final device, as well as the improvements that can be applied.

After preliminary research, no other device was found on the market that incorporated the features that make HomeHoist unique. Thus, since the goal is to obtain a hoisting device, incorporated in a wheelchair, the market research included wheelchairs, hoists, and slings. However, since both the hoist and sling information obtained wasn't of great impact on the development of the device, both can be found in **Annex II**.

The following figures were subjected to unit conversions, and to simplify the content of the chapter, the same figures have been rounded to the nearest unit.

3.1. Existing devices on the market

In order to properly develop a new product, it's essential to understand what the market has to offer, as well as the consumer needs, to create a product that provides some improvement over the existing products. A wheelchair is a common device among patients with reduced mobility, however, since there are different kinds of circumstances that can lead to the need for a wheelchair, there is a wide range of options available on the market.

To better understand the needs and desires of wheelchair users, different types of wheelchairs were sought, regarding price, comfort, and relevant features that may be useful for the subject of this study. Four wheelchairs will be presented for this purpose, two adult-sized and two designed for children, since CP is a problem that affects the person from a very early age, and it's pertinent to understand what the market as to offer during all stages of the patient's life. Since no wheelchair specifically designed to assist in the transfer process was found, the wheelchairs presented below will focus on the verticalization aspect, their suitability to CP patients, and their ability to accompany the child's growth.

- **XO-202 Power Wheelchair**

The Karman XO-202 Power Wheelchair, **Figure 1**, is a powered wheelchair with a stand-up feature that allows the verticalization of the user, as well as, all the positions between seated and verticalized.

This feature improves comfort, provides better blood circulation, and also alleviates pressure, among other benefits.

The operation of this wheelchair is assured by three actuators, one positioned in the centre of the seat, plus one on each side. This powered wheelchair can move around in whatever position the patient chooses, while the patient is secured by a lap seatbelt, a chest strap, and a knee wedge, that serve as support to hold the user in place.

Regarding the technical specifications, this wheelchair has a seat width from 356 to 457 mm, a seat depth of 457 to 508 mm, a seat height of 635 mm, and a total width from 635 to 673 mm, depending on the size bought by the user. The rear wheels diameter is 356 mm and the front wheels, which are casters, have a 203 mm diameter. The chair mass is 50 kg, without batteries, and the device has a maximum user capacity of 113 kg. The armrests are rotating, concave, and feature the controller on the right arm. The retail price of this device is around 7 560€, according to the brand's website [32].

Figure 1 – *XO-202 Power Wheelchair by Karman (adapted from [32]).*

- Oceania Vario

The Oceania Vario (18.70 E) model, as represented in **Figure 2**, is an electric chair, distributed by the company Orthos XXI. This chair was created with the needs of patients with neurological disorders and severe motor disorders in mind, since it allows the verticalization of the patient, which causes an improvement in blood circulation and digestion, thus reducing the risk of problems associated with wheelchair patients, such as decubitus ulcers and muscular atrophy [33].

This wheelchair is capable of verticalization and horizontalization, has a tilt-in-space[5] feature, and also allows the seat to be raised. These features are guaranteed by an actuator positioned in the centre

[5] The entire chair tilts on its frame, whilst the angle of the patient's hips, knees and ankles remains the same. Different from recline.

of the chair, along with an L-shaped metal plate that pivots on the base of the wheelchair and the centre of the seat. There is also an actuator on the base of the seat that conditions the movement of the backrest.

This chair has a maximum mass capacity of 120 kg, with a seat width of 460 mm and depth of 400 to 520 mm, with a seat height between 520 and 760 mm. The overall width of the chair is 660 mm, the diameter of the rear wheels is 300 mm, and the diameter of the front wheels is 200 mm, and the total mass of the wheelchair is 155 kg. The retail price of this device is about 10 133€, depending on the seller. [34].

Figure 2 - *Oceania Vario wheelchair by Orthos XXI (adapted from [33]).*

- KM-CP33

Developed by Karma Medical, the KM-CP33 model, embodied in **Figure 3**, is a chair specifically built to meet the needs of children suffering from cerebral palsy.

This chair has a tilt-in-space system, achieved by two side actuators that connect the chair base to the seat base, allowing comfortable long-term use for the patient, since the risk of decubitus ulcers is reduced by the possibility of different body positions. Still regarding the user's comfort, the head support of this chair is curved and adjustable and the foot support can be placed in several positions [35].

The maximum user mass for this chair is 80 kg, and the chair itself has a minimum mass of 11 kg, which can increase depending on the accessories, such as footrests or headrests, among others [35]. The width of the seat may vary from 205 to 380 mm, its depth from 230 to 405 mm, and its distance from the floor is 450 mm. Concerning the wheels, the diameter of the rear wheels may vary from 356 mm to 508 mm and the front wheels are 152 mm in diameter. The total width of the chair can vary between 430 and 610 mm and the market price of this chair is around 1 508€ [36].

Figure 3 - *KM-CP33 wheelchair by Karma Medical (adapted from [35]).*

- **Zippie® GS™**

The Zippie® GS™ wheelchair is of interest for this research because it´s designed to grow along with the child. Unlike the wheelchairs presented above, this is a manual chair and was developed by Sunrise Medical®. This chair allows size adjustments of essential parts such as the depth and width of the seat. In terms of dimensions, this wheelchair has a seat width ranging from 254 up to 457 mm, a seat depth of 279 up to 508 mm, a total seat width of 483 up to 686 mm, and a height, from floor to seat, of 356 up to 514 mm, with an overall mass of 13 kg and a user mass capacity of 75 kg. It has two rear wheels with diameters between 305 and 610 mm and two front wheels with diameters between 76 and 203 mm [37].

Furthermore, this wheelchair folds in a compact way, which facilitates transport, and has also been tested for use in public transports, namely buses. This device is illustrated in **Figure 4** and its price is around 1 953€ [37].

Figure 4 - *Zippie® GS™ wheelchair by Sunrise Medical® (adapted from [37]).*

- **Overall conclusions**

With the presented market research, it was possible to understand some negative and positive aspects of the equipment available in the market, and an overview of the information gathered can be found in **Table 3**. Some of the advantages of these devices can become useful for improving the HomeHoist device. Long term comfort, as the device is intended to be used for long periods, is an important factor, therefore, different positions, such as verticalization, horizontalization (reclination with legs raised), tilt-in-space, and ergonomic components are aspects to take into account in the future design of the device.

Table 3 - Wheelchair market research overview.

Specifications \ Product		XO-202 Power Wheelchair 	Oceania Vario 	KM - CP33 	Zippie® GS™ 
Company		Karman	Orthos XXI	Karma Medical	Sunrise Medical®
Dimensions	**Seat width**	356 to 457 mm	460 mm	205 to 380 mm	254 to 457 mm
	Seat depth	457 to 508 mm	400 to 520 mm	230 to 405 mm	279 to 508 mm
	Seat height	635 mm	520 to 760 mm	450 mm	356 to 514 mm
	Total width	635 to 673 mm	660 mm	430 to 610 mm	483 to 686 mm
	Rear wheels	Diameter (Ø) = 356 mm (pneumatic)	Ø = 300 mm (pneumatic)	Ø = 356 to 508 mm (pneumatic)	Ø = 305 to 610
	Front wheels	Ø = 203 mm (casters)	Ø = 200 mm (pneumatic, casters)	Ø = 152 mm (pneumatic, casters)	Ø = 76 to 203 mm (casters)
	Chair mass	50 kg w/o batteries	115 kg	11 kg	13 kg
	Mass capacity	113 kg	120 kg	80 kg	75 kg
Price		7560€	10 133€	1 508 €	1 953 €
Advantages		Verticalization; stand-up feature in various angles; can move while standing up; safety for user	Verticalization; horizontalization; seat raise; tilt-in-space.	Designed for children with CP; tilt-in-space.	Grows with the child; easy transportation; suitable for public transports.
Disadvantages		Not designed for CP patients; does not have integrated hoist; expensive	Expensive; does not have integrated hoist.	Can only be used for a short period of time because of the child's growth; does not have integrated hoist.	Manual; does not have integrated hoist.

3.2. Patents and articles

To guarantee that the project at hand is an innovation, in other words, that there is no patent covering any of the specific aspects of the resulting device, and to better understand the scientific advances that are being made in this area, a search was made on Google Scholar, Espacenet and Derwent Innovation, the latter available at TecMinho in Azurém, for patents and published articles that could be relevant.

The search was carried out for publications after and including the year 2000, and several combinations of the following keywords were used: wheelchair; removable seat; transfer; patient; lift; integrated; self; independent; mobility assistive device; chair; robotic; assistance; hoist; device. From the results obtained, 122 documents were selected and analysed, among which, those that were not related to the subject under study, those that presented similar or duplicated devices, and those that referred to older versions of documents that were also in the group were eliminated. With this, 47 publications were marked as of highest interest. After this initial assortment, 6 requirements, were determined to ascertain which patents and articles were relevant to this research, and **Table 4** refers to the number of publications that presented each of the requirements, bearing in mind that the same patent could present more than one. The requirements were as follows: publication date (after 2010), be a lifting mechanism, present a removable seat system, the device should comprise a unique method, the mechanism or device presented should be suitable to adapt to a wheelchair, devices that had a built-in lift system. It should be noted that the requirement Publication date (after 2010) was established because it was realised that the most recent documents contained more relevant information for the study.

Table 4 - *Number of patents that fulfilled each requirement.*

Requirements	Publication date (after 2010)	Lift mechanism	Removable Seat System	Unique method	Suitable to adapt to a wheelchair	Built-in lift system
No. of publications	21	17	5	10	21	15

Finally, the publications with the highest number of requirements were selected (between 4 and 6 requirements, none of the publications presented 6 requirements) and, among them, the non-active patents, and devices that required a considerable amount of motor skills by the user were eliminated. In this way, the research was summarized in 6 articles and patents that are discerned in more detail in **Table 5**.

Table 5 - Detailed view of the patents and articles selected.

Name	Author	Date	Subject	Keywords
Wheelchair with lift	Emma Pivato, Jonathan Tyler	07/01/2014	Wheelchair with a removable seat that reveals toilet seat	Wheelchair + removable + seat + lift
Wheelchair	Ran Ganel	19/07/2016	Wheelchair with removable seat and divided into 2 parts	Wheelchair + removable + seat
Wheelchair with lift transfer device	Harold Robert Wilson	16/12/2014	A device with a lifting system, controlled by the patient, with moving capability.	Wheelchair + lift + transfer
Wheelchair with a lifting function	Yoshikazu Mori; Norikatsu Sakai; Kaoru Katsumura	21/04/2012	Wheelchair with integrated hoisting system.	Mobility + assistive + devices
Robotic Patient Transfer and Rehabilitation Device for Patient Care Facilities or the Home	Roger Bostelman; James Albus	02/04/2012	Wheelchair inspired by a forklift with the ability to vary the height and rotate the patient's seat.	Transfer + wheelchair + robotic
Design and User Evaluation of a Wheelchair Mounted Robotic Assisted Transfer Device	Garrett G. Grindle; Hongwu Wang; Hervens Jeannis; Emily Teodorski; Rory A. Cooper	11/04/2014	Robotic arm to assist wheelchair users to move to other surfaces.	Transfer + wheelchair + robotic

After this presentation of the selected patents and articles, follows a more detailed analysis of each one of them.

- First device: *Wheelchair with lift*

The "Wheelchair with Lift" patent, published on January 7, 2014, under patent number US8622412B2, describes the invention of a wheelchair with a removable seat which, when removed, reveals a toilet seat with a container for the user's waste. This device also has an incorporated lift in which a sling is placed, to move the user up and down. When the user is lifted, the seat can then be removed, and the user can be moved down to the initial position to use the toilet seat. The user is raised again, when ready so that the container can be removed and cleaned, and the normal seat placed. The lift function of this patent is accomplished by an actuator that is placed on the back of the backrest, and an arm that articulates and passes over the head of the user, in which the sling is attached. The use of this

wheelchair is enabled by an assistant who handles the removable seat and the container. **Figure 5** concerns one of the ways in which this invention can be presented [38].

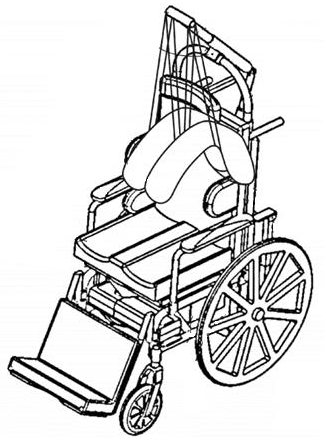


Figure 5 – *Sketch of wheelchair with lift (adapted from [38]).*

- Second device: *Wheelchair*

The "Wheelchair" patent, with patent number US9393167B2, published on July 19, 2016, concerns an invention comprising a wheelchair whose seat can be removed and divided into two parts: the backrest and the seat itself, along with detachable armrests and C-shaped legs, which allow the chair to be fitted in certain surfaces. Therewith, the wheelchair can be placed on top of the bed, with only the lower seat attached, and the patient moved to sit on the bed. In addition, there are actuators diagonally positioned on both legs of the chair that pivot on the base of the seat, allowing it to move up and down. This movement requires less physical effort on the part of the caregiver than having to carry the patient for the transfer. After the patient is seated, the rest of the chair structure is attached to the seat, which can then be moved from the bed. Another interesting aspect of this patent is that the lower part can be removed and the chair positioned above a toilet, which allows the patient to use the toilet without the need to transfer from the chair [39]. **Figure 6** pertains to a sketch of the device described.

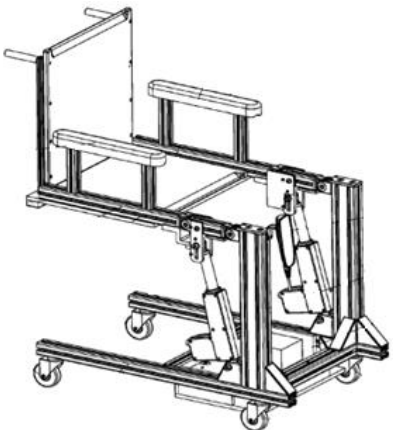
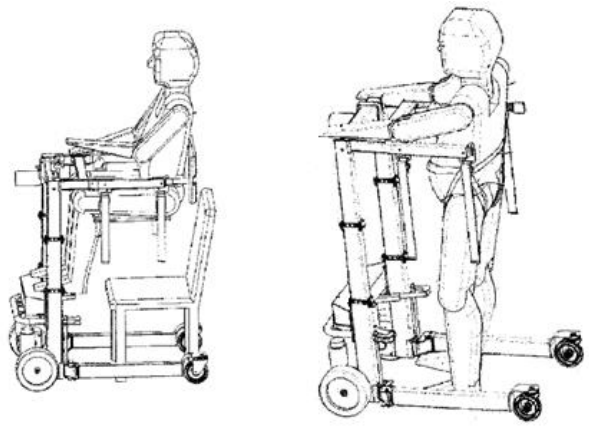


Figure 6 – *Sketch of wheelchair with removable seat (adapted from [39]).*

- Third device: *Wheelchair lift transfer device*

The patent "Wheelchair lift device transfer", with patent number US8910326B2 and published on December 16, 2014, concerns not a wheelchair, but a device that functions as a lift for a patient in a wheelchair. The user has full control over the device, represented in **Figure 7**, choosing whether to raise it or lower it over different surfaces and also moving around while using it, as is showed in **Figure 7 b)**.

The patient is held to the device by a harness that is placed by the hips, dressed as if it was a piece of clothing. This device requires some control by the user if they wish to use it independently [40].



(a) (b)

Figure 7 – *Sketch of device to lift and move patients, (a) lifting patient, (b) moving patient (adapted from [40]).*

- Fourth device: *Wheelchair with a Lifting Function*

The device depicted in **Figure 8**, refers to a wheelchair with an integrated lift system, from an article published in 2012. The main function of this device is to help the caregiver move the patient to a bed or toilet. For this to happen, a sling is applied to the user, which is then attached to ropes that sit on pulleys, over the user's head, which in turn, are connected to a motor in the front of the device. Pulling the rope results in lifting the user. The patient is then lifted and the seat (backrest and bottom) can be removed, leaving only the wheelchair's structure. Both the wheelchair and the armrests can be folded, the first for easier transport and the latter to facilitate the transfer process. In the raised position and with the seat folded, the device can be placed on the toilet, which needs no specific alteration to be used by the patient, and by folding the armrests it can also be used for transfers to a bed surface. This device has front driving wheels and back caster wheels. The former allows the device to be used as an electric wheelchair and move outside, even climb steps that may appear, the latter provides the chair greater manoeuvrability [41].

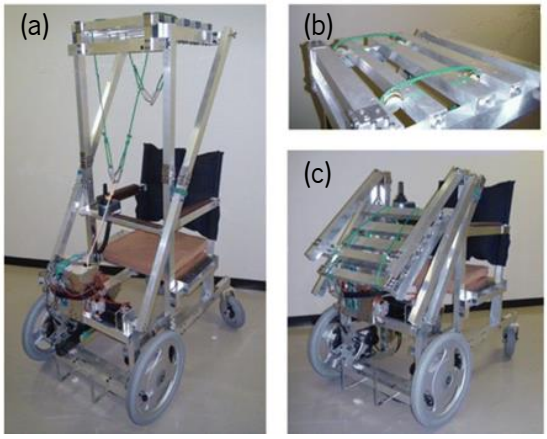


Figure 8 – *Wheelchair with a lifting function. (a) Fully open wheelchair, (b) Rode and pulley system, (c) Folded wheelchair (adapted from [41]).*

- Fifth device: *Robotic Patient Transfer and Rehabilitation Device for Patient Care Facilities or the Home*

Altered from a forklift, this device has the ability to raise and lower the seat, using the forklift's original design; rotate the user by 180°, by means of a turntable-like mechanism, located over the user's head; and also has a retractable seat system. With this equipment, a patient with mobility in the upper limbs can simply move from the bed to the device, or from the device to a toilet and vice versa, and all the transfer procedures are simplified by the retractable seat system, which allows, for instance, the patient to use the toilet without leaving the device.

The device can be controlled by the patient himself or by an assistant and **Figure 9** pertains to a concept design of the device in question, as published in 2012 [42].

Figure 9 - *3D model of robotic Patient Transfer and Rehabilitation Device (adapted from [42]).*

- Sixth device: *Design and User Evaluation of a Wheelchair Mounted Robotic Assisted Transfer Device*

The RATD (Robotic Assisted Transfer Device), published in 2015, was developed to help people with reduced mobility to move between their electric wheelchair and other surfaces, such as a bed or toilet. This device can be used by patients who can stand up and need some support to move around or by completely dependent patients, in which case, the use of a sling attached to the distal segment is associated. The RADT must be coupled to an electric wheelchair and can be used indoors or outdoors.

The RADT consists of a proximal segment, marked with *A*, and a distal segment, marked with *B,* in **Figure 10**. The proximal segment moves around the wheelchair and can either be placed on its side or back, the latter being used to reduce the lateral space the system occupies, allowing the wheelchair to pass through doors. In addition to this movement, the proximal segment has the ability to increase and decrease its size, which consequently raises and lowers the distal segment. As for the distal segment, it moves around the point of rotation represented in **Figure 10** with a *C*. With the movements previously described, the RATD allows the patient to be moved from the starting point to the final location [43].

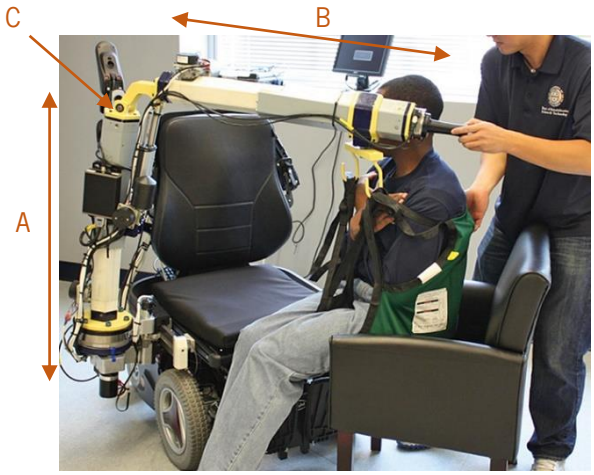
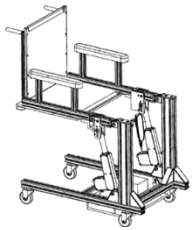
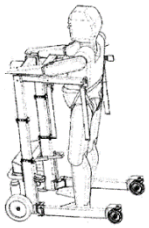


Figure 10 – *Example of operation of the Robotic Assisted Transfer Device (adapted from [43]).*

- Overall conclusions

To date, no patent contemplates the particular aspects of the HomeHoist, nor the way they are executed, there are, however, some articles, such as those mentioned above, that introduce advances in the problem of patient transference. No records of commercialization of these devices were found, and the prototypes developed in the scope of the articles aforementioned served only as proof of concept. **Table 6**, depicted below, serves as a summary of the advantages and disadvantages of the antecedent devices.

Table 6 - *Patents and articles overview*

Device / Assessment	First device	Second device	Third device	Fourth device	Fifth device	Sixth device
						
Advantages	Wheelchair with integrated hoist; the patient doesn't need to be transferred to use the bathroom.	Removable seat (backrest and seat); detachable armrests; C-shaped legs.	The patient can move while mounting the device; the harness makes for a balanced transfer.	Wheelchair with integrated hoist; foldable armrests and hoisting mechanism.	Rotates patient 180°; raises and lowers the seat; retractable seat.	Suitable for patients with different degrees of mobility; adaptable to different electric wheelchairs.
Disadvantages	Only lifts patient to remove seat; doesn't perform transfers.	No lifting system, not an electric wheelchair.	Not a wheelchair.	Not aesthetically pleasing; primitive system for lifting (rope).	Too bulky; may be uncomfortable; no sling is used so the weight lies on the armpits.	Not a wheelchair.

4. CHAPTER IV – Study and analysis of the HomeHoist device

The HomeHoist project started in February 2013, a collaboration between several companies, namely, Technik, HiTech, IBV, HERI, Orthos XXI, and Arti. The last meeting took place in January 2015, for the final analysis of the prototype produced in the scope of the project. At Orthos XXI there were records of minutes and presentations of the meetings, as well as documents with other sorts of information about the project. This information was analysed in order to understand the process of development, along with the final concept, design, and mode of operation of the HomeHoist device. Since the CAD model of the prototype was not available, using the information gathered, a replica was designed in *SolidWorks*, for the sake of this chapter and to better comprehend the device's operation.

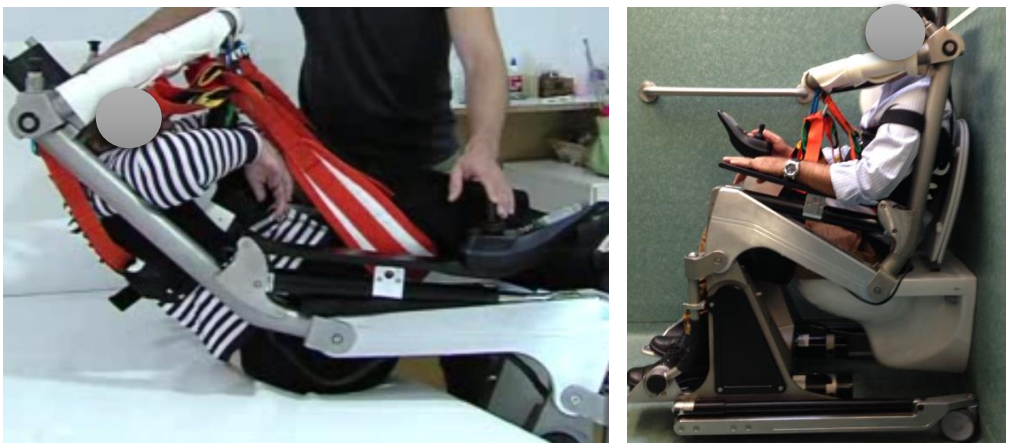
4.1. Concept

The HomeHoist project contemplated a device that would function as a normal electric wheelchair, but with a hoist attached to it, to transfer a patient with cerebral palsy inside his home or place of residence. In this way, it would be possible to reduce the need to acquire different types of equipment to assist in the transfers, avoiding changes in the home, always taking into account the comfort and dignity of the patient. To ensure that the device can be used for long periods, as a common wheelchair, it would also have a reclining feature, thus ensuring the comfort of the patient, by avoiding bedsores (pressure ulcers), through changing pressure points. **Figure 11** pertains to the prototype built within the HomeHoist project.[6]

Figure 11 *- Prototype built within the scope of the HomeHoist project.*[6]

[6] Figure obtained from media (pictures and video) contained in the HomeHoist files at Orthos XXI, dating back to 2014.

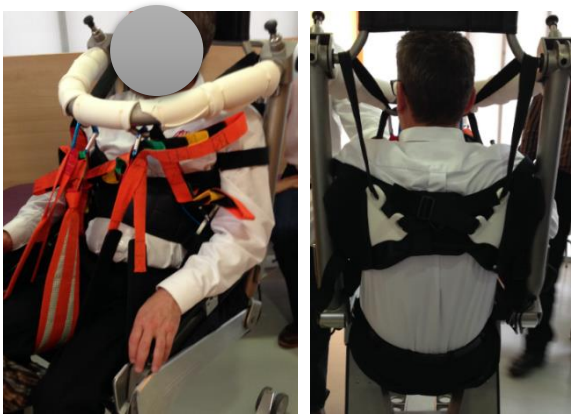
For its correct and safe operation, this device would require the assistance of a caregiver, who would be responsible for controlling the transfer process, without ever having to undertake intensive physical effort. It was intended that the device would allow transfers to and from a bed, toilet, shower seat, or common chair. Two fundamental aspects of the design are the removable seat and the free space between the rear wheels. The fact that the seat can be removed is what eliminates the need for additional equipment since the patient never has to leave the HomeHoist until it reaches the surface to which he's being transferred. The seat is removed in its entirety, this means both the backrest and the seat itself are removed, as they're inherently connected. As for the space between the rear wheels, this becomes essential for transfers to the toilet as it allows the patient, while being hoisted, to be positioned comfortably over the toilet. **Figure 12 a)** is an example of a bed transfer and **Figure 12 b)** is an example of a toilet transfer. These images make clear the need for the removable seat and the space between the rear wheels.



(a) (b)

Figure 12 *- HomeHoist mode of operation. (a) Transfer to bed, (b) Transfer to toilet.* [6]

The project also had the goal to design a harness that would be used along with the HomeHoist, since the project partners intended to follow a different approach than is usual with hoist transfers. The idea was to create a vest-type harness, instead of a sling, like the ones presented in **Annex II**, where the weight was placed on the patient's torso, always bearing in mind that the force exerted should not cause pain or discomfort to the patient. This design provided a solution to facilitate the task of dressing and undressing the patient, to speed up the transfer process to a toilet, without compromising the patient's dignity. As the development of the device advanced, it was concluded that the vest-type harness would not be sufficient to transfer the patient comfortably, therefore, straps were added to wrap each leg individually, so they would also be lifted by the hoist, better distributing the patient's weight. **Figure 13** concerns the front and rear view of the harness and straps when attached to the HomeHoist.



(a) (b)

Figure 13 - *Harness view when worn by the patient: (a) front view, (b) rear view.* [6]

4.2. Operation and design

For a better understanding of the HomeHoist functioning, it's essential to understand the mechanisms that allow it to work in the desired way, as well as how the different parts relate to each other. After an overview of the operating positions of the device, the different parts that make up the HomeHoist will be addressed in greater detail.

Regarding the different operating positions of the HomeHoist, **Figure 14** relates to the three key positions of the device, illustrated with the 3D model previously mentioned. The arch, that connects to the sling, is in place to perform the transfer in all three cases since it is positioned at an angle of 90° to the backrest structure. Position 1, represented in **Figure 14 a)**, concerns the minimum height that can be reached by the device, 352 mm from the floor to the rotation point near the hips. Position 2, **Figure 14 b)**, refers to the reclining feature, 150° between the seat and the backrest, ideal for transfers to and from the bed. Finally, **Figure 14 c)** refers to position 3, the maximum height allowed by the HomeHoist, 704 mm from the floor to the rotation point near the hips.

(a) (b) (c)

Figure 14 - *HomeHoist in critical positions: (a) position 1, (b) position 2, (c) position 3.*

For a general overview of the different components that make the HomeHoist device, different parts of interest were pointed out in **Figure 15**, to be described in more detail afterwards.

These parts have been identified as section A, the hoist mechanism; section B, the actuator placement; section C, the extendable rear wheels; section D, electrical storage; and section E, the footrests.

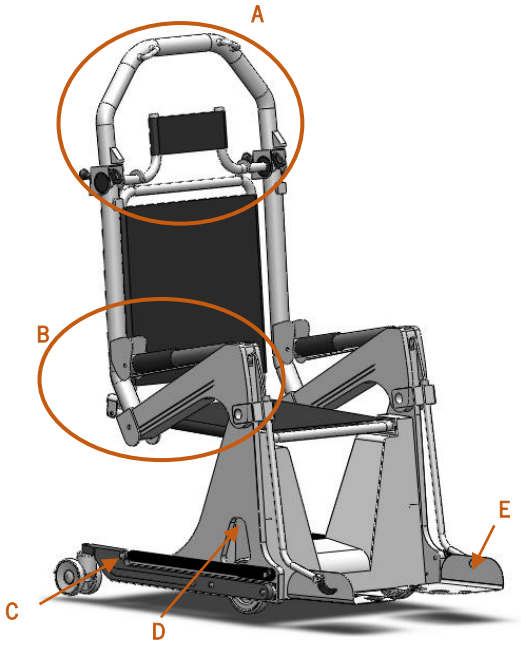


***Figure 15** - Identification of HomeHoist essential parts and components.*

In section A, the **hoist mechanism** can be observed. The arch is in the neutral or upper position, namely when it is not being used to perform transfers. For the sling and leg straps to be attached, the arch must be positioned 90° from the backrest, the correct position to start the transfer process.

In **Figure 16**, the details of the mechanism can be observed. The hoops marked with the number 1 refer to where the sling and leg straps are attached, using carabiners. The mechanism marked with the number 2 refers to the system that allows changing the position of the arch. It consists of two spring-loaded index plungers, one on each side, and a path along which the arch can slide. This system allows two positions for the arch, the upper position, present in **Figure 16**, and the lower position, present in **Figure 14**, meaning that the plungers have only two points onto which they can be fixed. The points marked 3a and 3b refer to the loading points where the load that the arch carries is distributed to the wheelchair frame when the arch is in the lower position. The seat is secured in two points, marked with 4 is the upper one, where the seat is hooked on the headrest structure bars. The second one is at the bottom and works by fitting the seat structure into guide slots.

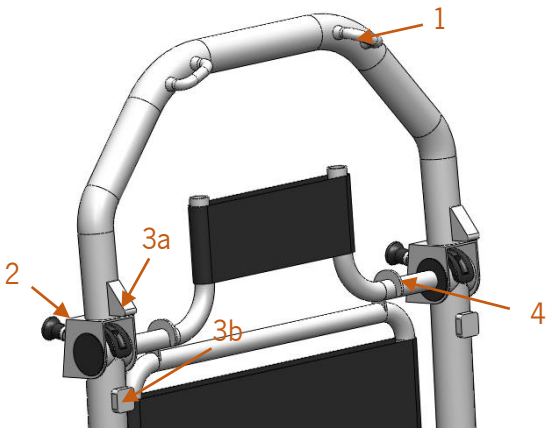


Figure 16 - Hoist and removable seat mechanism.

Section B, signalled in **Figure 15**, is the **mechanism** that allows the HomeHoist to **recline** and **vary in height**. Represented with the numbers 5a and 5b, in **Figure 17**, are the upper and lower right linear actuators, respectively, which have a symmetric pair on the left side. These actuators, combined with the respective joints, are the components that allow height variation and reclination. To **lower** the device, which corresponds to position 1, the lower actuator extends, and the upper actuator retracts. To reach position 2, that is, to **recline** up to 150°, the lower actuator stands still, and the upper actuator extends. For **lifting**, position 3, the lower actuator retracts, and the upper actuator extends. All the positions mentioned refer to the positions described in **Figure 14**. This mechanism rotates over two pivots, one that's close to the user's hip, marked with number 6 in **Figure 17**, which rotates while lifting, lowering, and reclining, and another at the front of the structure, marked with number 7 in **Figure 17**, that allows the lifting and lowering of the upper part of the device.

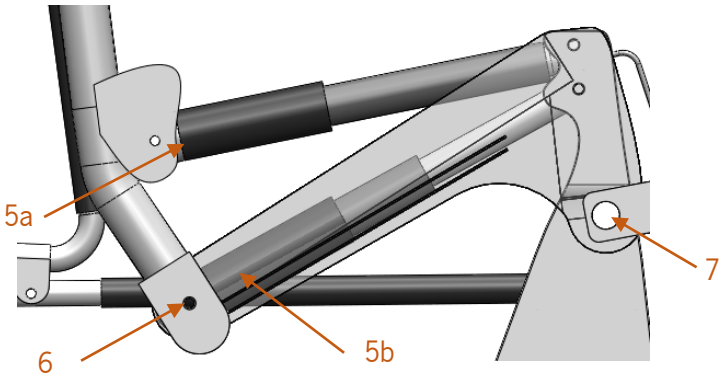


Figure 17 - Right side actuator set up.

The rear wheels, identified with C in **Figure 15**, are extendable to stabilize the system during transfers. In **Figure 14**, it's possible to verify the difference between the wheels when retracted and extended, between positions 2 and 3, for example. This system is also controlled by an actuator. Front stabilization is not necessary because the centre of gravity is always behind the front wheels. All the

actuators are controlled by an off-the-shelf electrical system by *Dynamic Controls*, which is also responsible for the operation of the engine driver.

Still in **Figure 15**, identified with the letter D, is the storage location of the batteries and engine, which are positioned at the front to act as a counterweight for when the patient is reclined, and finally, marked with E, are the footrests, which are attached to the HomeHoist in the front structure pivot. The footrests encompass a quick release system with a lever, which allows adjustment of the angle of the footrests, along with a cable and adjustment screw system to raise the legs while reclining.

- **Overall conclusions**

This device has introduced several features that not only make it a novelty in the market but also bring significant improvements in the lives of patients and respective caregivers. However, this device is the first version of its kind, which means that there are still aspects that can be improved. After analysing the prototype obtained within the HomeHoist project, some aspects were identified, with the help of Orthos XXI, which, throughout this project, were sought to be solved or improved.

The first aspect is the fact that the base structure of the device is mainly made of machined parts. At Orthos XXI, the wheelchair structures are mainly made of tubes and metal plates. This not only results in parts that are quicker to produce but also at a lower cost. In this way, it is intended to replace the machined components with tubes and metal plates, which are more commonly used in the company's production. Next, another aspect to be studied is the fact that the actuators are positioned on the sides of the patient. This makes handling difficult, as the patient is inaccessible from the sides, and eliminates the possibility of performing lateral transfers, if necessary. Thus, the idea is to free as much space as possible on the sides of the patient. Another aspect considered is the reduction in the number of actuators used by the device, whereby, the concept previously described comprises 6 actuators. The raise legs function was part of the design previously described, however, it was not possible to incorporate the function in the final prototype, and therefore, a new approach to this feature should be studied. The use of the arch to transfer the patient was also questioned and, ideally, it will be attempted to overcome it, since it takes up space around the patient, and there is a risk that, because of the patient's irregular movements, the patient may injure their head on the arch. In terms of aesthetics, in the concept detailed in this chapter the arch's stored position, which is above the patient's head, is very visually impacting. Finally, the idea of adding new features emerged, as it is intended to meet all the patient's needs with one device, thus, the incorporation of a verticalization feature would add value. These aspects will be expressed in goals that will be addressed in more detail in the following chapter.

5. CHAPTER V – Redesign of the HomeHoist device

Hereunder, some fundamental steps in the development of a device will be presented and explained, namely, the establishment of goals, proposed functions, project specifications, and finally, a morphological diagram and subsequently the weighted goals method will be used, in order to determine which of the concepts obtained in the morphological diagram, should be selected [44–48]. The redesign of the device presented in the previous chapter took into account the initial HomeHoist project, but since this project is being carried out at Orthos XXI, to obtain a manufacturable and marketable device, some aspects were changed, removed, or added according to what was intended by the company.

5.1. Goal Tree

When developing a new product, it's key to keep in mind which features the final product should have, meaning, its goals must be well defined and understood, to prevent any aspect from being overlooked. In order to organize and simplify this process, the Goal Tree method was used, as it provides a schematic way to summarize the goals for the product. For the main goal to be successfully achieved, a series of subgoals must be taken into account. Considering the main goal as the first level goal, the subgoals that follow directly from this one are the second-level goals, the subgoals that come from each of the second level goals are the third level goals, and so forth [44].

Regarding the project under development, the main goal, or 1st level goal, is to **mobilize a patient**, whether it's by transferring between surfaces, changing position (verticalizing and reclining), or by moving around the house or exterior. The first 2nd level goal is **economic** since the resulting product should have a convenient production cost and, therefore, a competitive price, allowing to reach a wider audience, which is followed by the 3rd level goals: reduced production cost and few external components. Afterwards, the **manufacturing** was considered as a 2nd level goal, since it's important to ensure that all steps of this stage are cost-effective and will be possible to replicate with minimal deviations, being the 3rd level goals of manufacturing: reduced number of components, simple manufacturing and components manufacturable at Orthos XXI. Thereafter, the 2nd level goal **control** was determined, due to the fact that the transfer and mobilization processes must be managed by the patient or caregiver, ensured by the 3rd level goals: transfers controlled by the caregiver and the patient should be able to operate the wheelchair. The 2nd level goal **reliability** was established for the product to be safe to be sold and used, even by a layman, guaranteeing customer satisfaction, the 3rd level goals that ensure the reliability of the product are safety and operation. **Maintenance** is also a 2nd level goal, since the product may need to be repaired

sometime in the future, and the continuous process of maintenance, such as cleaning, must be simple. To accomplish this, the 3rd level goals are hygienic and straightforward, and infrequent maintenance. **Comfort** was also considered a 2nd level goal, to allow the patient to use the device for long periods without discomfort and to allow different user sizes, being the 3rd level goals quick and painless transfers, comfortable seat and backrest, adjustable to different users, and silent engine. Finally, the 2nd level goal **design** was defined, since the product should please the client and must compete against other devices on the market, as well as the dimensions of the final product must allow for moving around with the device to go as smoothly as possible, hence, the 3rd level goals are appealing design and adequate size for home use.

For the sake of safe usage of the device, the 4th level goals are preventing skin or fingers from getting stuck in holes or apertures; a low battery warning, to prevent the caregiver from performing transfers if the device does not have enough power to see them through; mechanical resistance to endure the support and transportation of the patient; and stable while operating, to prevent the device from tilting during the most critical operations, transferring and verticalizing. Relating to operation, the subgoals that were specified were indoor and outdoor use, transfers from and to bed, toilet, shower, and chair, verticalize, function as a regular electric wheelchair, incorporate a removable seat and backrest, and recline. For the product to be hygienic, the 4th level goal to be met is breathable and washable backrest and seat material. Lastly, the 4th level goals pass through doors and wider than a toilet to ensure the adequacy of the device for home use.

Figure 18 pertains to the schematization of the goals mentioned above, in other words, the goal tree.

Figure 18 - *Goal tree.*

5.2. Establishment and analysis of functions

To ensure the device will be able to perform as it's expected, the main functions and consequent subfunctions must be laid out, to keep them in mind during the process of developing the device [45].

Therefore, four main functions were established, considering the previously intended ones, and taking into account new aspects that could be added to improve the device, hence, these functions are **transfer**, **sit**, **verticalize** and **move**, which will be addressed in more detail below. The input for these functions is an immobilized patient with CP and, through the use of this device, the output should be the mobilization of said patient.

For a deeper understanding of the original prototype, towards its improvement, the mechanisms that satisfied each subfunction will be identified, so that, later on, with the morphological diagram, it will be possible to incorporate these mechanisms as solutions to compare their viability with the new solutions presented.

- **Transfer**

It's clear in the description of the device that transferring a patient between the wheelchair and a bed, toilet shower, or chair, as well as the other way around, is a main function to be accomplished.

The subfunctions for this main function are as follows: **accommodate patient (fix and support)**, to secure the patient to the hoist, through a sling or other equivalent mechanism; **balance**, to guarantee the transfer process is safe and that the device will not fall in the course of the transfer; **vary height**; to be able to lift and lower the patient as necessary; **recline**; useful when the patient is to be transferred to a bed or vice versa, as well as to facilitate the process of dressing and undressing the patient; and **remove seat**, which is essential for the particular operation of this device, as mentioned above.

Associated to the subfunctions recline and vary height is the subfunction **structure rotation**, which encompasses the mechanism that allows to vary the height and change the user's position, which in turn is dependent on the will of the user, who digitally **controls the operation**. **Raise legs** is also a subfunction of recline, to follow the movement of the upper body, the legs must also move accordingly, for more comfortable positioning.

Below are listed the components that ensured each subfunction in the prototype that preceded this project:

- Accommodate patient – hoist arch as an attachment place.
- Balance – extendable back wheels.

- Vary height – actuators.
- Recline – actuators.
- Remove seat – a hook attaches the backrest and a slot secures the seat.
- Raise legs – although the final prototype did not include this feature, the project described the use of cable and adjustment screw system, for when the seat was reclined, cables, that would be connected to the footrests and adjustment screws, would lift the footrest and consequently the legs; and the use of quick-release levers to adjust the footrest angle.
- Structure rotation – actuators.
- Control operation – *Dynamic Controls* system.

- **Sit**

For the HomeHoist to serve as a regular wheelchair, meaning, to accommodate the patient for long periods, the subfunctions that must be met are **position properly (back nearly perpendicular to the seat)**, to maintain the patient in a proper sitting position, **comfort for patient**, the seat and backrest must be ergonomic to fit the patient's body, preventing long term discomfort, and, as subfunctions of comfort for patient are **adjustable footrest**, **adjustable armrest**, and **adjustable headrest**, to fit a wider range of user dimensions.

The components which fulfilled these subfunctions in the original HomeHoist prototype were:

- Position properly – actuators since they were responsible for the various seat positions.
- Comfort for patient – the material of both backrest and seat was a breathable fabric with no padding; as for the adjustable components, the footrest allowed angle adjustment through the use of a quick-release lever system. The armrest and headrest were not adjustable.

- **Verticalize**

The patient verticalization will be the most significant upgrade to incorporate into the device. Considering it is meant to be used for long periods, the variation in the patient's position is essential to prevent the appearance of pressure wounds, and to improve the blood flow. To achieve this function, two subfunctions must be taken into consideration: **support knees**, for safe and correct verticalization of the patient's body, since it keeps the legs in the right place; and **seat parallel to the legs**, which must be the final position to complete the verticalization process.

Since the original HomeHoist device, didn't include this function, there are no components to be mentioned.

- **Move**

Movement is essential to ensure that using this wheelchair is a simple and convenient process, allowing the user to move through different rooms, as it may be necessary. Hence, the subfunctions for this main function are the following: **mobility**, for the device to be able to move, and **various angles between seat and back**, to allow the patient to move in different positions, whether it be vertical, seated, elevated, along with others. To control the mobility of the device, a subfunction for mobility was considered which is **control operation**, to guarantee the patient or caregiver will be able to control the movement of the device.

The components that fulfilled each of these subfunctions in the first HomeHoist prototype were the following:

- Mobility – wheels and *Dynamic Controls* system.
- Various angles between seat and back – actuators.

Figure 19 pertains to the functions and subfunctions aforementioned, displayed through a diagram, to represent their hierarchical relation.

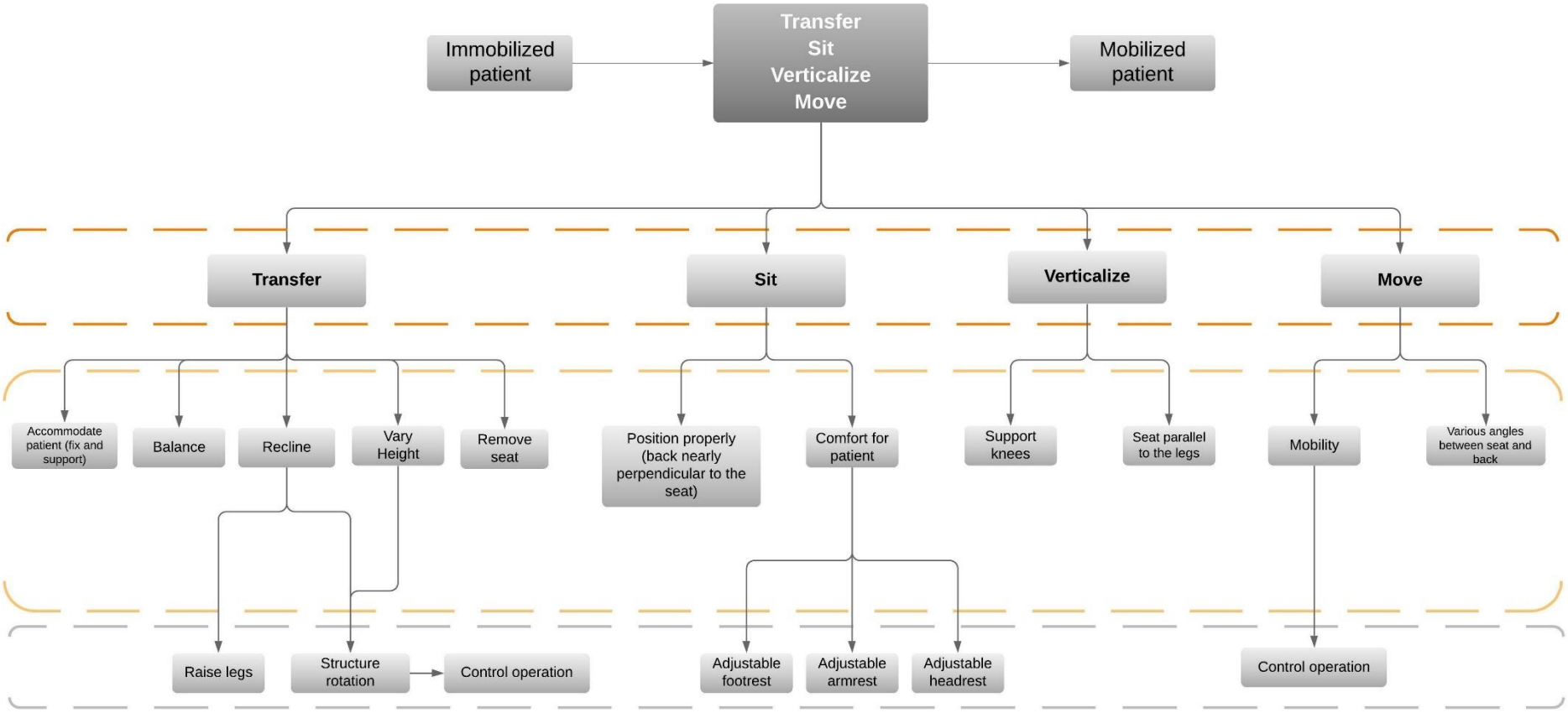


Figure 19 – *Diagram of functions.*

5.3. Project specifications

Table 7 contains the list of requirements that the new device should or must meet, in order to accomplish the user's expectations and become a competitive alternative on the market. The requirements were divided into the following categories: technical, functional, safety, dimensional, and others, according to their nature, for a better organization and comprehension, and it was established if these requirements were required or requested, respectively, demands or wishes. This means that the demanded requirements are fundamental and must be included in the final device, while the wished requirements are not a priority, but must be taken into account and included if possible. These requirements were established taking into consideration the market research, the original design, the company's expectations, and several dimensional details, which are explained in more detail in Chapter VI [46].

Table 7 - *List of requirements.*

Category	Requirement	Demand or wish
Technical	Transfer per day: ≥ 10 (1 transfer=there and back)	Wish
	Autonomy: ≥ 1 km daily	Wish
	Silent: ≤ 50 dB	Wish
	Linear actuators to perform chair movements	**Demand**
Functional	Minimum height: 340 mm (floor to top of seat)	**Demand**
	Removable seat and backrest	**Demand**
	Verticalization range: 65° to 75° (floor to seat)	**Demand**
	Raise legs	**Demand**
	Seat joint: 100 mm from the hips	**Demand**
	Recline: 140 to 170° (seat to backrest)	**Demand**
	Hold user through a sling	**Demand**
	Adjustable for different user sizes	Wish
Safety	Not perform transfer/recline/verticalization if the system isn't stable	**Demand**
	Low battery warning: ≤ 25%	**Demand**
	Not perform transfer/recline/verticalization if the energy isn't enough to complete	**Demand**
	Manual shut down	**Demand**
	Maximum user mass: 95 kg	**Demand**
	Low device weight: ≤ 70 kg	**Demand**
	Holes and apertures: ≤ 8 mm or ≥ 25 mm	**Demand**

Table 7 - List of requirements (Cont.)

Category	Requirement	Demand or wish
Dimensional	Seat height (when parallel to the ground): 480-520 mm	Wish
	Seat width: 396 - 460 mm	**Demand**
	Seat depth: 445 – 520 mm	**Demand**
	Fit into toilet	**Demand**
	Pass through standard house doors: ≤ 770 mm	**Demand**
	Non-obstructive	Wish
Others	Manufacturable at Orthos XXI	**Demand**
	Minimum production cost	**Demand**
	Standards: ISO 7176-5:2008; ISO 7176-21:2009; EN 12184:2009	**Demand**

5.3.1. Standards for the development of the device

For the development of a device, it is important to keep in mind the existing regulations and standards, for the final result to fall in line with the requirements for the device to be certified, which is fundamental to assure safe use and operation for the buyer. In this way, the standards that were considered most relevant for this project were the ISO 7176-5:2008, which specifies the determination of dimensions, mass, and manoeuvring space for wheelchairs; the ISO 7176-21:2009, which establishes requirements and test methods for electromagnetic compatibility of electrically powered wheelchairs and scooters, and battery chargers, and finally, the EN 12184:2009, which refers to the requirements and test methods for electrically powered wheelchairs. During testing, and in a future risk analysis of this device, it will be essential to verify that it meets the mentioned standards.

5.4. Morphological diagram

In order to develop a viable product that meets the previously established functions and goals, it's important to examine different possibilities of concepts to achieve the one that allows a better performance of the device's subfunctions. In this sense, the morphological diagram method was used to define different solutions for each of the subfunctions and, thereafter, evaluate which combination of solutions is the most appropriate and efficient to incorporate in the design [47]. When applicable, the mechanisms used in the original HomeHoist device were included as a possible solution, namely, solution 1, for the respective subfunction.

The solutions proposed for each sub-function were designed taking into consideration the aspects that were inadequately achieved in the original HomeHoist project; the customer's requirements, Orthos XXI; and other ideas that emerged during the development process of these solutions. Moreover, products that are already produced and used at Orthos XXI were kept in mind, to introduce a device that made sense with the wide range of products that the company already markets and, therefore, some components of these solutions are components that are already used by the company.

For the subfunction **accommodate patient (fix and support)**, four solutions were considered. The first one (front arch + hoops), concerns the original solution, which consists of an arch that can be placed in two positions, horizontal and vertical, with its movement being restricted by two index plungers. At the front of the arch are two hoops onto which carabiners are attached, which in turn attach to the sling. Solution 2 (side gas spring + removable arch) consists of two gas springs, the upper structural tubes, and the arch. Each side has one pair of tubes, one smaller that fits inside the larger, and the gas springs are placed inside these tubes, thereby, increasing the gas spring size will force the smaller tubes up, lifting the arch, parallel to the seat. The ends of the arch slide inside the smaller tube, manually, without the need for an external locking mechanism, and thus, the arch can be easily removed and stored in the back of the device, to clear the space around the user. In this scenario, a harness/sling must be used and attached to the arch, for when the gas springs raise the structure, the user follows its movement. Regarding solution 3 (upper arch+ hoops), although similar to the first, it solves two problems. Firstly, the fact that the arch is above the user's head, and not on the front, not only gives more freedom to the user and caregiver but can also prevent injuries if the user's movements are erratic to the point of colliding with the arch. Secondly, the aesthetics of the device, since when not in use, the arch slides down on the lateral structure and is concealed. The last solution (rachet mechanism + hoops) is based on the arch concept, however, since there are two separate arms onto which the sling is to be attached, the space in front of the user's head is free. The arms may be positioned in two settings: lowered, in which the arms are side by side with the tubes that make the upper lateral structure, for a clean look; and raised, when the arms are ready to take in the sling and perform the transfer. The rachet mechanism only allows the arms to rotate upwards, to prevent them from falling during the transfer, however, to return them to the lowered position, the pawl, which is attached to a spring, must be pulled to release the mechanism, and arms to rotate downwards. Each arm works independently as they are operated manually.

The original solution to the subfunction **balance** was extendable wheels that worked through two actuators, which were activated whenever the system was raising or lowering the user. The wheels extended to the back of the device, to provide a larger support area on the floor. During the testing of the

original prototype, it was concluded that this system was unnecessary, being that the front of the device provided enough counterweight to avoid tilting the device. Because of that, the second solution (front-drive wheels + AGM batteries[7]), offers a more cost-effective solution, since eliminating the extendable wheels also eliminates the need for the two actuators. This solution is based on the idea that positioning the motor wheels on the front, as well as the batteries, will provide enough weight on the front of the wheelchair, to keep the system balanced. The third solution (front-drive wheels + lithium batteries[8]) follows the same concept as the solutions above, keeping the drive wheels on the front, for counterweight and to keep the back of the wheelchair clear, for a better fit onto the transfer surfaces, however, it uses a different motor drive system and lithium batteries, which are positioned on the sides of the chair. This solution will reduce the overall weight of the device, since lithium batteries are lighter, and will provide more free space beneath the seat.

The subfunction **remove seat**, was met in the original device by two hooks on top of the backrest that attached to the headrest frame, plus two slots on the base of the chair onto which the seat slides and is secured. In this previous configuration, the backrest and seat were interlocked, meaning that they worked as one piece. Both the second and third solutions proposed for the remove seat function are based on the idea that the backrest and seat should be removed separately, functioning as individual parts. For that, the second solution consists of double hooks (one on top and one on the bottom) on the sides of the backrest, that fasten to cut-outs on the upper structure of the wheelchair. For the seat, a telescopic slide would be used, for it to slide in and out of place, as necessary. To prevent the seat from sliding out of place, there would be a small component on the back that the caregiver could take out, freeing the seat for it to slide. The third solution, sliding slots, uses the same mechanism for both the backrest and seat. The upper lateral structure has slots cut out on the inside face of the structure, onto which, flaps welded to the seat and backrest slide. To guarantee the seat doesn't slide out of place, there are index plungers, placed on the back of the seat and bottom of the backrest, handled by the caregiver, that keep these components in place, and free them for when necessary.

Concerning the subfunctions **recline**, **vary height**, **position properly**, **seat parallel to the legs** and **various angles between seat and back**, positioning the actuators is the key factor to accomplish them all, thus, the following solutions satisfy all these subfunctions simultaneously. The first solution pertains to the original actuator configuration which is explained in detail in Chapter IV. To summarize, there are four

[7] AGM batteries are built with an ultra-fine fiberglass mat packed between plates that are saturated with battery acid to about 95% of what they can hold. This mat is slightly compressed, then welded/soldered in place. Because the plates and mats are packed fairly tight, they are almost immune to vibration.

[8] Lithium batteries consist of lithium ions that move through an electrolyte between two electrodes, an anode and a cathode. While in use, the battery is discharging, and the ions move from the anode to the cathode. When charging, the opposite occurs.

actuators, two on each side, that work symmetrically. To recline, the lower actuator stays in place and the upper actuator extends; to lower the user, the upper actuator retracts, and the lower actuator extends; and to raise the user, the upper actuator extends, and the lower actuator retracts. The second solution also uses the symmetrical actuator principle, however, the positioning is different. There are two actuators positioned beneath the seat, one on each side, which play the main part in raising and lowering the patient. Furthermore, there are two actuators positioned on each side of the backrest, which regulate the angle between the back and seat during the seat's movement. These backrest actuators are also responsible for reclining. The reasoning behind changing the actuator positioning was to clear the sides of the wheelchair, to facilitate patient handling, to allow side transfers, and to enable user verticalization.

Since **supporting the knees** wasn't previously a function of the HomeHoist device, as it didn't allow verticalization, the two solutions presented are additions to the design. The solutions presented are similar in the sense that both entail individual shin cushions but differ on the means of attaching to the device. In solution 1 (double knee support with centre attachment) the attachment is made in the bottom centre of the wheelchair, whereas in solution 2 (double knee support with lateral attachment) the support connects on the sides of the wheelchair, which provides more free space between the user's legs.

Finally, the subfunctions **raise legs** and **adjust footrest** have been merged in one set of solutions since they are inherently connected. The original solution consisted of a cable and adjustment screw system to raise the legs. One end of the cable was connected to the backrest and the other to the footrest. When the backrest reclined, the footrest would be pulled by the cable, raising. To adjust the footrest height, there was a quick-release lever. Solution 2 consists of an actuator; a metal plate, that works as the footrest; and an index plunger system. The actuator adjusts the footrest height and the index plunger system allows for two footrest configurations: one for neutral sitting position and one to raise the legs. The last solution for this combination of functions is sliding structure + rotating support, namely, solution 3. Elaborating this terminology, the sliding structure refers to the internal tube that slides downwards when the structure of the wheelchair begins to rise, thus decreasing the distance from the footrest to the floor, in order to accompany the user's displacement. The rotating structure portion refers to the fact that this structure is coupled to the wheelchair's structure in two points: a fixed point, which works as a pivot, and another point that can be adjusted in two positions, neutral position and elevated position, to raise the legs. This solution also contains calf supports, which support the user's legs while raised and can also be relevant during transfers, when the seat is removed.

Table 8 contains illustrations for each of the solutions mentioned above, which were specifically designed in *SolidWorks* (except the wheels and batteries used in solution 2 for the balance subfunction, which were designs already available at Orthos XXI), for the purpose of providing a better understanding by making the concepts more tangible. However, these representations are not binding, and the solutions chosen will be refined to better fit the final design.

Table 8 – *Morphological diagram.*

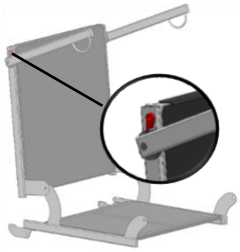
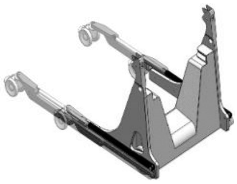
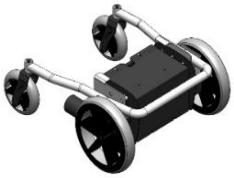
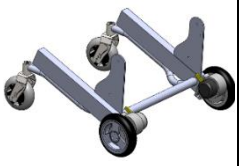
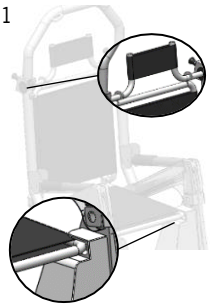
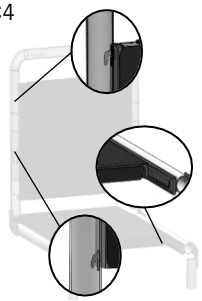
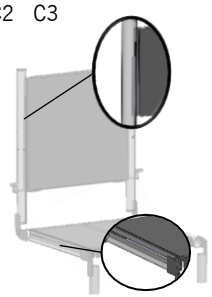
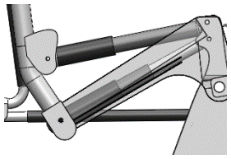
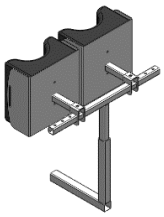
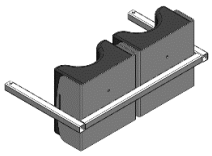
Subfunctions	Solution 1	Solution 2	Solution 3	Solution 4
Accommodate patient (fix and support)	Front arch + hoops	Side gas springs + removable arch	Upper arch + hoops	Rachet mechanism + hoops
	C1 	C2 	C3 	C4 
Balance	Extendable rear wheels	Front drive wheels + AGM batteries	Front drive wheels + lithium batteries	-
	C1 	C4 	C2 C3 	
Remove seat	Hook (backrest) + slot (seat)	Double hook (backrest) + telescopic slide (seat)	Sliding sloths	-
	C1 	C4 	C2 C3 	
• **Recline** • **Vary height** • **Position properly** • **Seat parallel to the legs** • **Various angles between seat and back**	Double lateral actuators	Lateral actuators on seat and backrest	-	-
	C1 	C2 C3 C4 		

Table 8 – Morphological diagram (Cont.).

Subfunctions	Solution 1	Solution 2	Solution 3	Solution 4
Support knees	Double knee support with centre attachment	Double knee support with lateral attachment	-	-
	C4 	C2 C3 		
Raise legs and adjustable footrest	Cable + adjustment screw	Metal plate + actuator	Sliding structure + rotating support	-
	C1 	C4 	C2 C3 	

Following the assessment of each proposed solution in **Table 8**, four different sets of solutions were chosen, to obtain different concepts, which will be assessed in terms of advantages and disadvantages for the project underway, and which will subsequently be compared, using the weight goals method.

Thus, concept 1, which refers to the original solution, was established. This concept, illustrated in **Figure 20**, is explained in more detail in Chapter IV and, the solutions selected for this concept are marked in **Table 8** with a *C1*. The advantages of this concept are the balance, which is ensured by the extendable rear wheels, and the fact that the hoist lifts the patient in the centre of the chair, ensuring that, the centre of mass while lifting is close to that of the wheelchair. As for disadvantages, the production of this device does not meet the company's standards; it does not allow user verticalization; the front and sides of the user are blocked by the arch and actuators, respectively, which may disrupt the usual handling of the user; and despite being a feature of the original project, the prototype produced at the end of the project did not allow the legs to be raised.

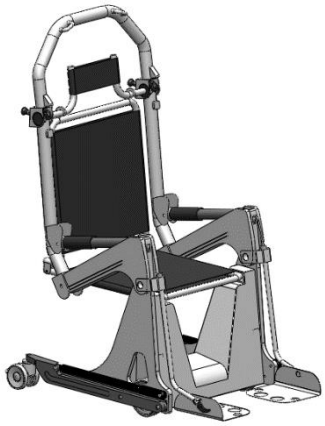


Figure 20 – *3D model of concept 1.*

Then, concept 2 was established. The solutions that concern this concept are marked with a *C2* in **Table 8**. An illustration of the concept can be found in **Figure 21**.

The advantages that this concept brings to the table are stability, without compromising the comfortable handling of the user, since the arch is removable and therefore clears useful space around the wheelchair, and the fact that the arch can be tucked away is also more aesthetically pleasing. The lithium batteries make the device lighter, and given its shape and positioning, allows for more free space under the seat, which will be useful during transfers. The sliding slots for the backrest and seat are individual, which allows a customisable use of the device; the actuator positioning allows verticalization and lowering the user, and, finally, the footrest follows the user's verticalization and allows leg raising, which is a plus in comfort.

Concerning the disadvantages of this concept, the fact that it is necessary to assemble the arch before every transfer may delay the process, although it is a simple task. Aesthetically this design also falls short of what was intended.

Figure 21 – *3D model of concept 2.*

Afterwards, concept 3 was established, which is depicted in **Figure 22** and is marked in **Table 8** with a *C3*. Regarding the advantages of this concept, the fact that, while lifted, the arch is on top of the

patient, and, when not in use, it is retractable, staying concealed within the lateral structure, is a positive aspect both in terms of appearance and functionality, since it allows for more space around the patient, simplifying handling. In terms of batteries, removable seat/backrest, actuators, and footrest, the advantages are the same as the previously mentioned in concept 2.

On the other hand, the disadvantages of this concept are that the lifting method to transfer the user may cause balance problems since the force exerted by the user's mass will be focused on the back of the device, which may lead to it tilting; additionally, the fact that raising the upper arch is done manually leads to the caregiver still having to carry the patient's weight, which is a serious concern.

Figure 22 – *3D model of concept 3.*

Finally, concept 4 was established. The solutions selected for this concept are marked with a *C4* in **Table** 8, and a representation of it can be found in **Figure 23**.

Regarding the advantages of this concept, the fact that the AGM batteries are positioned at the front, and are relatively heavier than the lithium batteries, offers more stability to the wheelchair, as they act as a counterweight when the user is being transferred. The raisable side arms, onto which the harness/sling attach, are also an advantage over the arch, as they clear the space in front of the user's head and can be rotated and aligned with the side structure, to be concealed. On the other hand, the footrest is also worth noting, since the actuator allows the height of the footrest to be changed, which is positive in terms of adjustment for different users and is more precise in accompanying the user's verticalization and leg raising movements.

Concerning the disadvantages of this concept, the side arms mechanism may not be strong enough to hold the user's weight, and since there is no connection between them since they work as separate mechanisms, torsion problems may arise if the weight is not equally distributed. Finally, the AGM batteries take up a lot of space under the seat, thus reducing the free space under the wheelchair. This concept would have to feature a higher overall length to match the same free space as the concepts that incorporate lithium batteries.

Figure 23 – *3D model of concept 4.*

After a brief explanation of each concept, the weighted goals method will be used to conclude which concept is the most appropriate for further development.

5.5. Weighted goals method

After establishing the concepts that, in different ways, offer solutions for the functions proposed for the device in development, follows the comparative analysis of each concept in order to understand which is most suitable to proceed to develop, to accomplish the final device. For this purpose, the weighted goals method was used as a tool to assess and compare the four chosen concepts [48].

For a brief description of this method, the previously proposed goals, as shown in **Figure 18**, will be arranged according to their relevance and priority to the project at hand and, thereupon, a relative weight will be attributed to each goal, in this instance, from 0 to 100%, being the highest percentage attributed to the most relevant goal, and so forth. Subsequently, the concept's ability to meet each goal will be scored from 0 to 10, depending on its performance, with 10 being the best possible result. Finally, the relative weight and score will be multiplied to obtain the goal value for each concept, and then, all values for each concept will be added up, to obtain the comparative factor between concepts. The concept with the highest value sum is the preferential choice.

The first column of **Table 9**, pertains to the goals established for this project, ordered in descending order of relevance, the most relevant being: transfers from and to bed, toilet, shower, and chair; and the least relevant: silent engine. The relative weight column refers to the percentage assigned to each goal, proportional to their importance, and the following columns refer to the score and value of the goals for each concept.

Table 9 – *Weighted goals method.*

Goals	Relative weight	Concept 1		Concept 2		Concept 3		Concept 4	
		Score	Value	Score	Value	Score	Value	Score	Value
Transfers from and to bed, toilet, shower, and chair	9.50%	10	0.95	10	0.95	10	0.95	10	0.95
Wider than a toilet	9.00%	10	0.90	10	0.90	10	0.90	8	0.72
Stable while operating	8.50%	10	0.85	8	0.68	4	0.34	3	0.26
Pass through doors	7.50%	10	0.75	7	0.53	7	0.53	9	0.68
Removable seat and backrest	7.25%	6	0.44	9	0.65	9	0.65	5	0.36
Verticalize	7.00%	0	0.00	8	0.56	8	0.56	5	0.35
Components manufacturable at Orthos XXI	6.50%	5	0.33	9	0.59	9	0.59	9	0.59
Mechanical resistance	6.25%	9	0.56	9	0.56	6	0.38	4	0.25
Regular electric wheelchair	6.00%	10	0.60	10	0.60	10	0.60	10	0.60
Prevent skin or fingers from getting stuck in holes or apertures	5.80%	9	0.52	9	0.52	9	0.52	5	0.29
Quick and painless transfers	5.50%	10	0.55	9	0.50	6	0.33	10	0.55
Reduced number of components	4.00%	6	0.24	7	0.28	8	0.32	6	0.24
Simple manufacturing	3.50%	4	0.14	9	0.32	7	0.25	6	0.21
Adjustable to different users	3.00%	0	0.00	5	0.15	4	0.12	3	0.090
Comfortable seat and backrest	2.50%	7	0.18	7	0.18	7	0.18	7	0.18
Transfers controlled by the caregiver	2.00%	10	0.20	10	0.20	10	0.20	10	0.20
Low production cost	1.95%	6	0.12	7	0.14	8	0.16	8	0.16
Few external components	1.25%	6	0.075	7	0.088	8	0.10	8	0.10
Low battery warning	0.70%	10	0.070	10	0.070	10	0.070	10	0.070
Indoor and outdoor use	0.60%	3	0.018	5	0.030	5	0.030	6	0.036
Patient should be able to operate the wheelchair	0.55%	10	0.055	10	0.055	10	0.055	10	0.055
Breathable and washable seat material	0.50%	8	0.040	8	0.040	8	0.040	8	0.040
Straightforward and infrequent maintenance	0.40%	4	0.016	6	0.024	8	0.032	8	0.032
Appealing design	0.15%	6	0.010	6	0.010	7	0.011	3	0.00
Silent engine	0.10%	7	0.010	7	0.010	7	0.010	7	0.010
Comparative factor	100%	7.61		**8.61**		7.90		7.00	

Through this method and the figures presented in **Table 9**, it became clear that concept 2 was the one that better fulfilled the goals previously defined, since it has the highest comparative factor, and was, because of that, selected to proceed with the device development.

6. CHAPTER VI - Development of the selected concept

Following the decision of the concept to be developed, is the detailed analysis of specific features, to establish guidelines for the design of the wheelchair. The features that required more consideration were the structural sizing of the wheelchair, the verticalization, the actuators and gas spring positioning and selection, and, lastly, the materials to be used in the device.

6.1. Structural sizing

Sizing is a fundamental step in the development of a new device. In this instance, where a wheelchair is to be built for patients with cerebral palsy, to assist them and their caregivers during the transfer process, and also allowing user verticalization, the most relevant sizing factors are:

- The anthropometric measurements of the user, for the chair to be designed comfortably and safely for the target audience.
- The average measurements of the foreseen transfer surfaces (toilet and bed), to ensure the adequate raising and lowering of the user.

Below follows a more detailed description of these factors, as a means to reach a conclusion of which sizes are most appropriate, both for individual components and the overall wheelchair.

6.1.1. Anthropometric measurements

Considering the impact of CP on the patient's movement, as described in Chapter II, it is crucial to understand in what ways the abnormal movement stimuli have affected the musculoskeletal development of the patient who grew up with this condition.

Both the lack of movement control and prolonged use of a wheelchair are factors that weigh on the development of the patient's body and consequently affect its anatomical dimensions. In this sense, as the HomeHoist project partners intended to develop a suitable device for the target audience, research was conducted, which focused on three studies and a database that contained information on anthropometric measurements of patients with neurological impairments who use wheelchairs. The goal was to obtain the basic body measurements for the development of technologies, as described in the UNE EN ISO 7250-1 norm, but with values that would make sense for patients with CP that are also

wheelchair users. The measurements obtained are described in **Table 21**, as well as illustrations in **Figure 98**, for better comprehension, both presented in **Annex III** [49].

Cross-checking this information with that available at Orthos XXI, for the development of wheelchairs, it was concluded that the dimensions used as a reference by the company, which pertain to patients from the age of 17 with an average height of 175 cm, fall within the maximum and minimum dimensions presented in **Table 21**. Therefore, a dummy that represents the anatomical dimensions of the group of patients aforementioned, was used as a reference to determine the appropriate size for various wheelchair components. **Table 10**, presented below, refers to the minimum size some relevant components must meet, for the device to be correctly sized for the dummy used as reference.

Table 10 – *Relevant anthropometric measurements.*

Component	Dimension	Min. value (mm)
Seat	Width	396
	Depth	445
	Height (from ground)	456
Backrest	Width	432
	Height (from hip)	495
Headrest	Width	160
	Depth	97
	Height (from backrest)	100
Armrest	Width	55
	Depth	260
	Height (from seat)	255
Footrest	Width	98
	Depth	279

After obtaining a general outline of the dimensions that the above-mentioned components should have, followed an analysis of the overall measurements the wheelchair would have to meet, to achieve the proposed goals.

6.1.2. Sizing limitations

As the main purpose of this dissertation is to obtain an aid device for transfers between surfaces, it is important to understand which surface dimensions may restrict this task. Therefore, being established

as a goal that the device must be able to assist in the process of transfer to the toilet and bed, research on the relevant characteristics of these surfaces was carried out. Furthermore, as the device is intended to be used indoors, it's noteworthy that the caregiver and patient should be able to move around the house, or another setting, unhindered and with as few limitations as possible. Hence, one aspect to take into account is that the wheelchair must be able to pass through the doors of a usual house. For the transfer between shower and chairs, since several options on the market can be adapted to the final device, the aspects that were taken into consideration were that: the transfer can only occur for showers, in which there is a bath seat, and not for bathtubs, since lifting the patient beyond the height of the bathtub goes against the established operation, which is that the device should fit into the surface; and, as regards chairs, since there is a wide variety, it was not considered a limiting factor.

- **Toilets**

While transferring to a toilet, as illustrated in **Figure 12 b)**, it is necessary for the wheelchair to be able to pass outside the toilet for the user to be positioned on top of it. Thus, the width and depth of clearance inside the wheelchair should be enough to accomplish these goals in as many scenarios as possible. Furthermore, the height of the toilet seat must also be taken into account, as the user must be positioned higher than the toilet seat and then lowered, to facilitate the process. Hence, the toilet's height, width, and depth, as represented in **Figure 24**, were considered the most relevant dimensions.

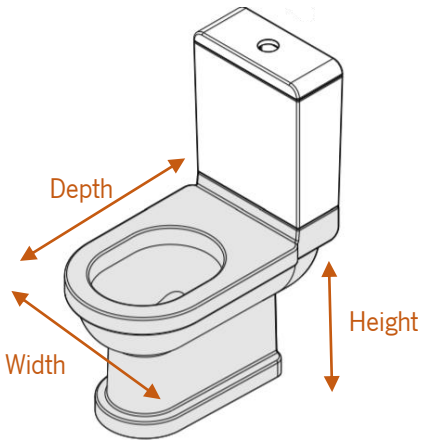


Figure 24 – *Relevant toilet dimensions (adapted from [50]).*

Moreover, there is legislation that dictates the accessibility conditions that the construction of public spaces must follow, namely, the Decree-Law nº 163/2006, August 8th. The directives of this Decree-Law will be taken into account to create a product that meets the specifications required by law. In this decree, it is established that the height of an accessible toilet, from the floor to the top of the seat, should be 450 mm [51].

Since this device is supposed to be used without the need for additional transfer aid devices installed in the house, and in as many settings as possible, research was carried out, to gather the above-mentioned dimensions of several toilets available on the market, collecting a large sample of different toilet vessels to which the patient can be transferred, thus increasing the device's ability to respond to different environments.

To this end, information from four different sellers was collected and the details of the sample obtained are detailed in **Annex IV**. The dimensions gathered were in agreement with the ones detailed above, however, for clarification, it's important to note that the height from the ground to the top of the toilet without the seat, contrary to the value of height established in the Decree-Law nº 163/2006. The reason why the seat wasn't taken into consideration was that the limiting factor is low toilet heights, and by eliminating the variable of different types of seats, it can be assured that the wheelchair will be dimensioned to work in the worst-case scenario, which is low toilets.

Table 11 refers to the maximum and minimum values obtained for each dimension [50, 52–54].

Table 11 – Relevant toilet dimensions.

Dimension	Maximum (mm)	Minimum (mm)
Depth	**510**	392
Width	**420**	320
Height	480	**385**

For both depth and width dimensions, the maximum value, 510 and 420 mm, respectively, is the limiting circumstance since the inner clearance of the device must be enough for it to fit through the outside of the toilet. Regarding the height, the limitation is when the toilet is too low, 385 mm, and the device may not be able to lower the user enough to seat on the surface. Thus, the aim was to comply with the maximum value of width and depth, and the minimum value of height, whenever possible, however, if these values limited the operation of the device in other ways, the next best value, among the values collected and presented in **Annex IV**, would be the one taken into consideration.

- **Beds**

Afterwards, followed the analysis of another transfer surface, the bed. In this instance, only two factors may pose an issue during the transfer process, firstly, there should be enough room under the bed for the back wheels to roll under, allowing a bigger surface to lay down the patient; the second factor is the bed height, which can't be too low, or the wheelchair won't be able to lower the patient enough.

Although it is intended that the device under development is used in a myriad of situations, the focus of this stage of research will be articulated beds, which are used in hospital environment, since there is an uncontrollable variety of sizes and models, if domestic furniture is included. Therefore, since Orthos XXI is a national producer of articulated beds, the models offered by the company were analysed as a reference for the expectations for articulated beds and, in order to obtain a more comprehensive view of the options for this type of product, the two other company's catalogues were examined.

The relevant dimensions for this study were the clearance under the bed and the overall bed height, which will limit the height of the wheels and battery in the final design and will establish to what height it should be possible to lower the patient, respectively. The bed height didn't consider the mattress size, which is always present during the transfer process, therefore, separate research was carried out, to understand what mattress height can be expected, to simulate the transfer environment realistically, keeping in mind that to the bed height must be added the mattress height. The average mattress height considered was 218 mm, a value obtained with a sample of 63 mattresses from different retailers [55–58]

Both bed and mattress researches can be found in more detail in **Annex IV**, and **Table 12** contains the minimum and average value for the clearance under the bed and the bed height + average mattress height [59–61].

Table 12 – *Relevant bed dimensions.*

Dimension	Minimum (mm)	Average (mm)
Clearance under the bed	260	386
Bed height + average mattress height (mm)	478	604

With the research carried out, the lowest bed height (clearance under the bed) found was 260 mm. However, it is important to take into account that in all beds with a minimum height below 330 mm, it is possible to adjust the height, up to at least 730 mm. Thus, the minimum height that will be considered is 330 mm, which translates into an overall bed height (considering the average mattress height) of 548 mm.

- **Doors**

The final sizing limitation to be considered is the usual door size in a common house. To ensure the wheelchair will be able to accomplish the toilet transfer, it may be necessary to increase the overall width of the device, however, the wheelchair must still be able to pass easily through a door.

To this end, the Decree-Law previously mentioned in this chapter (Decree-Law nº 163/2006, August 8th) also contemplates regulations for the sizing of doors. It should be noted that these regulations also extend to residential construction. Nonetheless, the decree stipulates that there should be a usable width of at least 770 mm, with the door opened at 90º, which means that the wheelchair's overall width cannot exceed this value, moreover, it should be less than 770 mm for the wheelchair to pass through the door without difficulties [51].

- **Overall size limitations**

After having collected all the information aforementioned, a better understanding of the sizing limitations for the design of this project was achieved. Therefore, the main guidelines to be followed are represented in **Table 13**.

Table 13 – *Overall size limitations.*

Dimension	Value (mm)
Minimum seat height (from ground to underneath the seat)	≤ 385
Interior depth (clearance underneath the seat)	≥ 510
Interior width (clearance underneath the seat)	≥ 420
Maximum rear components height (wheels and batteries)	≤ 330
Overall width	< 770

It should be taken into consideration that the only restrictive guideline is the overall width, which must not surpass 770 mm, or the device won't be able to move inside the user's home. As for the other guidelines, whenever possible the ideal value, shown in **Table 13**, will be respected, but as stated before, if not possible, the next best value will be considered.

6.2. Verticalization

The most significant addition that this wheelchair will encompass, relative to the HomeHoist device, is the verticalization feature. Nonetheless, the verticalization mechanisms are a complex matter,

and understanding them is essential to properly incorporate this feature in the final concept, considering the other restrictions and limitations that are already at play.

The main issue with verticalization wheelchairs is that, when the patient is being raised or lowered, there is a relative displacement between their anatomical joints, mainly the hip and knee joints, and the wheelchair pivots that simulate their movement. This happens because the wheelchair's axes of rotation don't match with those of the user. This situation is aggravated because, even if the wheelchair's pivot mechanisms are aligned with the user's anatomical joints, the latter doesn't perform in pure rotational movement. If the anatomical joint movement were to be simulated in the wheelchair mechanisms, the result would be a much more complex rotating mechanism, therefore, the goal is to reduce these displacements as much as possible, without losing the straightforwardness of the mechanisms [62, 63].

The study used as a reference for the analysis of the verticalization mechanisms consisted in the use of markers, placed strategically on both the user and wheelchair with standing/verticalization feature, to measure the relative displacements. The electrical wheelchair used in the study had an overall length, with footrests, of 114 cm, a seat height of 56 cm, and a width of 46 cm, rounded to the unit. The maximum angle of verticalization was 80°, measured between the initial and final position of the seat. No particular shear reduction measure was taken on, but a knee restraint was used to prevent the user from falling over [62].

The user sat in a comfortable position, thighs parallel to the floor, and then proceeded to use the wheelchair's standing feature to transition from seating to standing up, and then back to seating. Throughout both movements, the displacements were measured into computed data.

The graphics presented below, in **Figure 25**, show the results collected in this study.

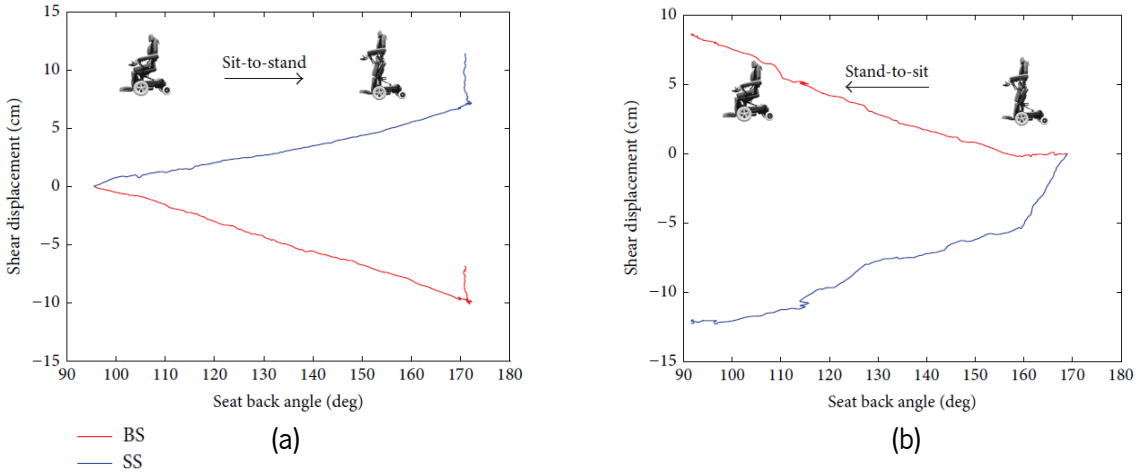


Figure 25 – *User displacement: (a) sit-to-stand, (b) stand-to-sit* [62].

Backrest sliding (BS) concerns the distance between the user's acromion and the backrest structure marker. Positive values refer to upward movement along the backrest, and negative values refer to downward movement along the backrest. During the sit-to-stand/verticalization movement, as can be seen in the graph shown in **Figure 25 a)**, since the shear displacement is negative, the user's acromion has moved down in comparison to its initial position. Conversely, during the stand-to-sit movement, the opposite occurs. Regarding seat sliding (SS), which refers to the distance between the greater trochanter and the seat structure marker, positive values indicate rearward displacements of the greater trochanter along the seat plane, while negative values indicate forward displacements. Based on the graph of **Figure 25 b)**, it can be seen that, during the sit-to-stand movement, rearward displacement occurs, which means, in practical terms, that there was a displacement towards the back, and in the stand-to-sit movement, the opposite occurred. **Annex V** contains illustrations to clarify the anatomical references and displacements referred to in this paragraph.

The study concluded that, while standing up, the displacement between the user's body and the wheelchair backrest/seat surfaces was up to 8,7 cm, and when the wheelchair sat back down, the displacement could be up to 10 cm.

Based on the analysis of this study, and taking into consideration the information and expertise provided by Orthos XXI, which has previous experience with verticalization devices, to implement a feasible verticalization mechanism in the device under development, the following features will be incorporated in the device: the wheelchair rotation points which correspond to the rotation of the hip and knee, will be moved closer the anatomical position, in order to reduce displacement due to this matter; and the footrest will also be designed to lower with the verticalization movement, to relieve the pressure on the user's muscles and joints, otherwise, if the verticalization were to be performed with fixed footrests, the pressure exerted in the user's legs during the movement would be high, which could not only lead to pain but also cause long-term injuries.

Consequently, followed a deeper analysis on how to apply this information to the project at hand. For that matter, a 2D sketch was elaborated, using the *SolidWorks* software, to determine how the displacement of the footrest, while verticalizing the user, would be achieved. Thus, some features were established, such as, the seat height and length, in three positions (lowered, seating, and verticalized); the footrest height while seating and its minimum height, which would happen during verticalization; the footrest angle and positioning were defined because of the front-drive wheels, which would collide if not properly placed (constraint marked with a red line on the sketch); and, through that, it was possible to get a general idea for the placement of the pivot, the length of the connector between the footrest and

the pivot, and some characteristic of both the interior and exterior tubes of the footrest. **Figure 26** relates to the sketch obtained.

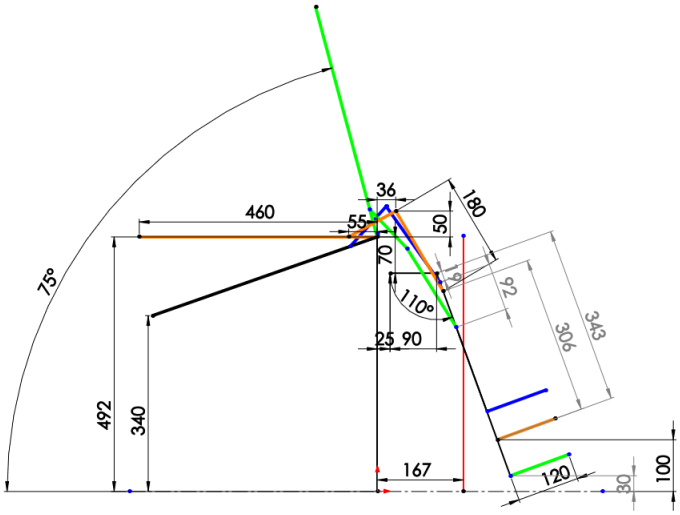


Figure 26 – *2D sketch for the footrest mechanism design.*

With this sketch, the guidelines obtained for the design of the footrest and its respective components were, 180 mm for the length of the connector between the footrest and the pivot, 306 mm for the length of the interior tube, and 92 mm for the opening on the sides of the exterior tube, for the connector to slide. These characteristics will be made clearer in the next chapter when the footrest is described.

6.3. Mechanical components selection

Considering the concept selected through the morphological diagram method and the established requirements, it became clear which mechanical components needed to be dimensioned so that the final concept meets the expected functions.

Thus, follows the sizing of two mechanical components that will be essential for the device operation: the actuators and the gas springs. For the sizing and selection of these components, the catalogue of one of the company's suppliers was analysed to find off-the-shelf components that are easy to acquire and that make sense with those already used by the company, without compromising too much of the intended operation of the device.

6.3.1. Actuators

Actuators are mechanical components capable of producing motion, with several types available in the market, for different purposes. Thus, for application in this project, the most appropriate type is electric linear actuators. Furthermore, since it's intended to have maximum clearance underneath the seat, it was concluded that the use of compact linear actuators would benefit the development of the device. Therefore, since this type of actuator is available with the Orthos XXI supplier, the requested movements and basic dimensions were analysed, for the correct sizing and selection of the actuators required for this project. With regards to the compact linear actuator model available at the supplier, it is possible to choose between three different sizes, which vary according to the diameter and base length of the actuator, the largest of which being able to support higher loads. For application in this device, it was realized that the smallest size would be ideal to incorporate into the selected concept and that the load that it is capable of withstanding is enough for the intended purpose.

As described in the selected concept, two pairs of actuators will be used: the first pair, which is applied below the seat, is responsible for raising and lowering it, and the second pair, which is applied on the back of the backrest, is used for reclining and following the seat movement, to ensure a correct posture during changes in position. The two actuators of each pair work in parallel and simultaneously, thus, the load they support is equally divided by each one. Bearing this information in mind, followed the dimensioning of the two pairs of actuators.

Firstly, the pair of seat actuators was dimensioned, and the limiting factors considered for this purpose were the minimum seat height (340 mm); the seat angle for verticalization (65° to 75°); the seat height when parallel to the floor (480 to 520 mm) and seat depth (445 to 520 mm).

In order to group these constraints and obtain a solution, a 2D sketch was made using *SolidWorks*. **Figure 27** relates to the sketch created, in which the two extreme positions of the seat are represented, verticalization at 75° (green), and lowest seat height at 340 mm (blue), as well as the neutral position, seat parallel to the floor (orange). The seat height and depth were approximately determined following the requirements, and one of the actuator's joints was placed underneath the seat, without locking its position. Afterwards, taking into account the available strokes, for the smallest actuator, two circles were added: the first one, whose centre is marked with an A in **Figure 27**, relates to the maximum actuator length (circumference radius), which occurs when the seat is verticalized at 75°; the second one, whose centre is marked with a B in **Figure 27**, pertains to the minimum actuator length (circumference radius) when the seat is lowered at 340 mm. The point where the two circles should intersect is where the other actuator joint should be placed.

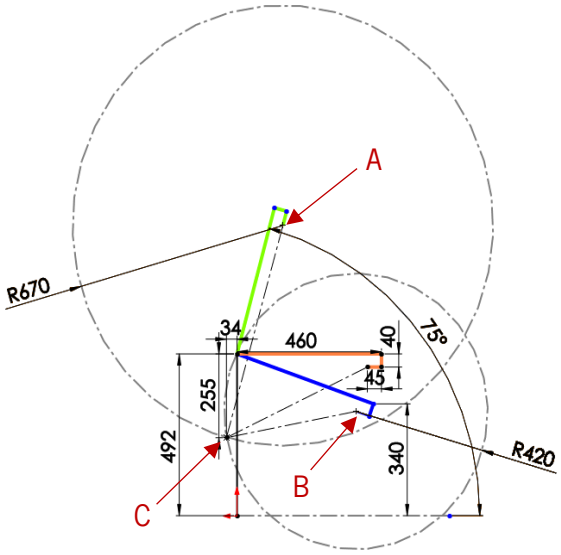


Figure 27 – *2D sketch for the seat actuator positioning.*

Finally, with all the information put together, the stroke and joint position, that stays below the seat, were adjusted until the two circumferences intersected in a point that could be placed in the device. Thus, the actuator dimensions that would solve the sketch presented in **Figure 27** are as follows: maximum length of 670 mm, minimum length of 420 mm, which relate to a stroke of 250 mm. Regarding the second point of attachment of the actuator, in the intersection of the two circumferences, it is signalled with a C in **Figure 27**.

Furthermore, in addition to the necessary stroke and correct positioning for the actuators, it is also important to understand the load they will have to support, in this instance, besides the user's weight, the pair of actuators will also have to support the upper structure of the wheelchair which, although lower than the former, cannot be ignored. Therefore, **Annex VI** shows the free body diagram of forces and distances involved in the operation of this pair of actuators, through which, it was concluded that, with a safety coefficient of 2, each actuator should be able to withstand at least a load of 1436 N.

Afterwards, followed the search for a solution for the pair of backrest actuators. The method used was the same as described above, with the restrictions being the reclining angle (140° to 170°) and the fact that the backrest joint had to be as close as possible to the user's hip. Then, same as before, two circles were added: the first one, whose centre is marked with an A in **Figure 28**, relates to the maximum actuator length (circumference radius), which occurs when the backrest is nearly perpendicular to the seat (blue line); and the second one, whose centre is marked with a B in **Figure 28**, pertains to the minimum actuator length (circumference radius), when the backrest is reclined (green line). Thus, the reclining angle was adjusted in the established range, as well as the first actuator joint, and the stroke,

until the two circumferences intersect in a convenient point, and with a radius that could be translated in a stroke available with the supplier.

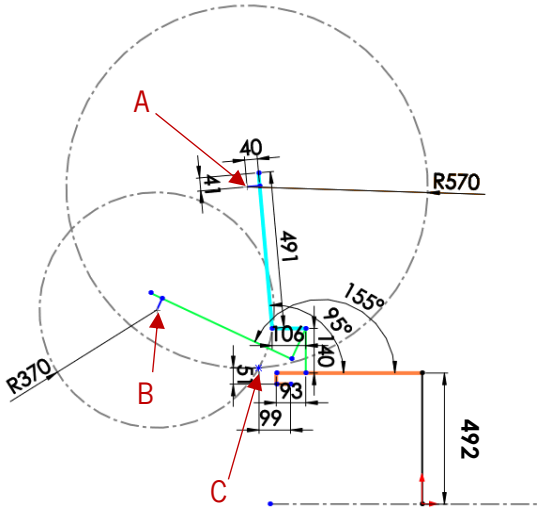


Figure 28 – 2D sketch for the backrest actuator positioning.

As shown in **Figure 28**, the maximum actuator length should be 570 mm, and the minimum length should be 370 mm, which translates to a stroke of 200 mm. The intersection of the two circumferences, which concerns the other actuator joint, is marked with a C in **Figure 28**.

Concerning the minimum load each actuator of the pair must be able to uphold, in **Annex VI** are the free body diagram and data that allowed the conclusion that each actuator should be able to withstand a force of 1032 N, with a safety coefficient of 2.

With all the information aforementioned, both pairs of actuators were dimensioned and positioned. Below, in **Table 14**, is an overview of the components selected, with the most relevant information about each one.

Table 14 – Detailed actuator information.

Component	Max diameter (mm)	Min diameter (mm)	Length closed (mm)	Stroke (mm)	Force (N)	Voltage (V)	Mass (kg)
Seat actuator	35	20	430	250	1600	24	1.2
Back actuator	35	20	370	200	1600	24	1.1

6.3.2. Gas spring

The analysis and selection of gas springs were also tackled taking into account the company's current supplier and the catalogue provided by the same. The use of gas springs for lifting the arch and

subsequently lifting the user, emerged as a more economical and compact alternative to actuators since the spring diameter is smaller than those available for actuators.

Same as with the actuators, there will be two identical gas springs working simultaneously, one on each side of the backrest structure. Since the gas springs will only have to support the weight of the user and the arch, the latter being so low that it can be disregarded, and will be placed inside the lateral upper structure, the characteristics that were taken into account for the selection of the most fitting gas spring were the load it would have to support, its diameter and stroke, and the locking mechanism.

As for the load, since the gas springs will work perpendicular to the arch, onto which the weight of the user is applied, and that same weight will be distributed between the two, one on each side of the structure, the torque of the system was calculated. The calculations can be found in **Annex VI**, and the result obtained was that each gas spring should be able to bear a load of at least 314 N.

With regards to the locking mechanism, the supplier offers various solutions. For application in this project, since it's essential that, after lifting, the arch does not descend without it being intended, the gas spring must lock the movement in the downward direction, since the weight of the user forces this movement. On the other hand, in the upward direction, since no force applied in this system drives it towards this movement, the locking mechanism is not rigid, meaning that, although it is also blocked if a certain threshold is exceeded, which surpasses the maximum load of the gas spring, it is unlocked and allows movement. **Table 15** is an overview of the technical information of the gas springs.

Table 15 – *Detailed gas spring information.*

	Max diameter (mm)	Min diameter (mm)	Length closed (mm)	Stroke (mm)	Force (N)	Mass (kg)
Gas spring	22	10	536	200	320	0.4

6.3.3. Batteries

The selection of the lithium batteries was mainly because of their shape since they could fit on the sides of the structure, freeing the space in the interior of the device, and their weight, which is 1.2 kg each. Nonetheless, it is important to understand if the batteries selected will be sufficient to provide energy to the electric components of the device. In **Annex VII** are the calculations carried out, to understand if the two batteries, each with a 12 V voltage, 12 Ah of capacity, and electric energy of 34.8 Wh which, connected in series, translates in 24 V voltage, 12 Ah, and 34.8 Wh, would be able to power the 10 daily transfers and 1 km autonomy predicted. Through the calculations, it was possible to realize that the number of transfers expected would be too excessive to obtain a relevant safety coefficient, so that the friction of the mechanism is accounted for. Therefore, the maximum number of transfers that

the device should allow for these batteries, is 6 full transfers, which translates in a safety coefficient of 1.5. Thus, 6 transfers, which use both pairs of actuators, seat and backrest, plus the 1 km autonomy, reflect on a 23.17 Wh daily consumption, meaning that it is enough for the device to be charged overnight, to provide a complete use the next day.

6.4. Materials

When it came to the selection of materials, weight and durability were the main concerns, as well as a reasonable production cost. Since there are components that need to perform in different ways, the material selected for their production would heavily impact their outcome.

Therefore, for the metallic components, which represent a large portion of the overall mass of the device, initially, to design a lightweight device, the idea was to use an aluminium alloy, since it would provide the necessary mechanical resistance, without compromising the final mass of the device. Nevertheless, through the calculations mentioned in the previous subchapter, in which the necessary actuator force is determined, and the use of *SolidWorks,* that allows identifying the mass of the designed components, when a certain material is applied to it, it was realised that even if all metallic components were made of steel, both the individual component mass and the overall device mass would meet the desired requirements. With this material change, not only is the production cost more economic, but the fact that the wheelchair structure is heavier may help stabilize the device during patient transfers.

Thus, the metal used for the production of the metal plates was the S235JR steel, as per the EN 10025-4 standard, and for the metal tubes was the S235JR steel, as per the EN 10025-2 standard, and both follow the EN 10051 standard for dimensions and tolerance. In **Annex VIII** is a table with the most relevant mechanical properties for the S235JR steel [64].

The most crucial example of a metallic component in which the mass should be as low as possible, without in any way compromising the mechanical resistance, is the arch used for user transfer. As this component undergoes assembly before use, its mass should be low enough, so that the caregiver can assemble and disassemble it, without being burdened. Thus, the total mass for this metallic component is 2.1 kg, which is a reasonable weight for the caregiver to carry.

Two other components where the chosen material will have a great impact on its mass, and thus on its functionality, are the backrest and the seat. As these two components are manually removable, the weight should be kept to a minimum, so as not to burden the caregiver during the task. Thus, to ensure the minimum possible mass for these components, the solution found was to define the structure of the components with a bent round tube, and use fabric to make the base, as can be seen in **Figure 29**, nailed

to the tube structure. This fabric is made of nylon, waterproof and washable, and is already used in other devices of the company, such as seats. With this solution, the final mass obtained for the backrest and seat was 1.6 kg and 2.1 kg, respectively, which once again, is a reasonable mass for the caregiver to work with.

Figure 29 – *Backrest design, fabric nailed to the tube structure.*

Regarding the non-metallic components, as is the case of the cushions of the headrest, armrest, knee support, and calf support, the material for these components is polyurethane foam, whose mass is relatively low when compared to the other components of the device. However, besides the foam element of these components, there is also an MDF (medium-density fibreboard) base, a material derived from wood, onto which the foam is glued, to provide more resistance, and to allow a suitable base on which to screw the rest of structure of these components. That being said, the mass of the combination of foam and MDF for the headrest is 503 g, for the armrest is 192 g, for the knee support is 574 g, and for the calf, support is 126 g. And finally, for the footrest's base, the material defined is PA+GF (polyamide powder filled with glass particles), because of its stiffness and wear resistance since, during verticalization, it will support most of the user's weight, resulting in a mass of 855 g each.

7. CHAPTER VII – Final concept

This chapter is the culmination of the information presented up to this point, since it is in this chapter that the 3D model, corresponding to the device developed within the scope of this dissertation, is presented, both in terms of individual components and functioning. Moreover, a configuration for the electrical system will also be briefly presented, as well as the simulation of two components of the device, which were considered the most vulnerable.

One aspect that should be clarified beforehand, is that the device was designed considering the use of back and seat cushions since wheelchairs are commonly complemented with these two. Therefore, given that the company has much experience in this type of accessories, the products that are already marketed by the company were used as guidelines. The seat cushion considered has 70 mm in height, and the back cushion has 40 mm in thickness. Different users may have different needs and, even though the width and depth are limited by the device's structure, there is still enough room for different cushion sizes and heights that better fit the user of the wheelchair.

7.1. Concept design

From the selected concept in the morphological diagram, and with the integration of the structural sizing constraints, component positioning, and the addition of new features, mentioned in the previous chapter, it was possible to create a 3D model, using the *SolidWorks* software, which relates to the final device developed in the course of this dissertation, which is illustrated in **Figure 30**.

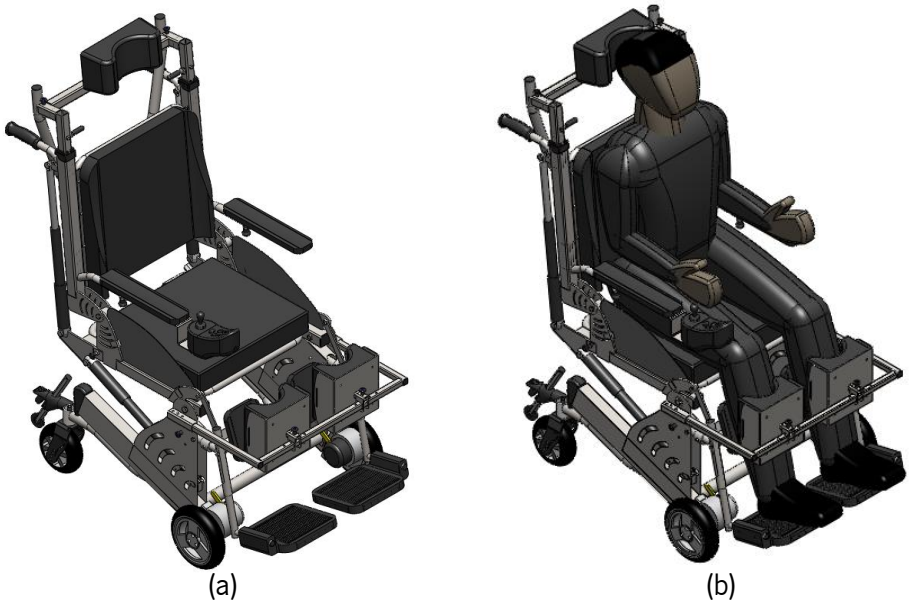


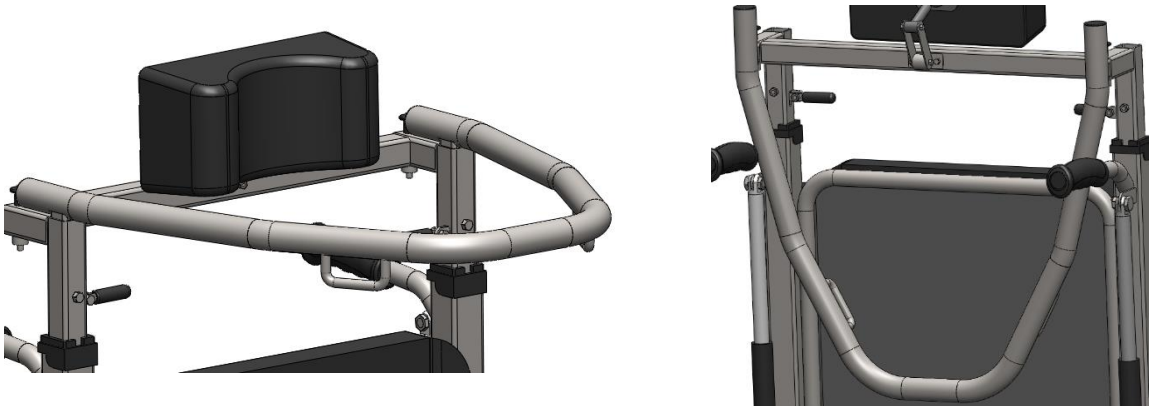
Figure 30 – *3D model of the final concept: (a) without dummy, (b) with the dummy positioned.*

To develop the device depicted in **Figure 30**, the previously mentioned restrictions were taken into account, however, some aspects initially outlined had to be compromised to obtain a functional and safe device, whose production was easily industrialised. In order to provide an adequate understanding of the functioning of the device, as well as of the various parts that comprise it, a detailed individual analysis of each one of them will be carried out.

7.1.1. Arch

Perhaps the main component of this device is the arch, which is responsible for holding the patient while performing transfers. Although the initial aim was to deviate from this concept, with the morphologic diagram it became clear that it is the safest option to perform this task. Hence, to implement this solution in the device that was being developed, alterations were made relative to the original project, with the purpose of obtaining a solution that met the project's expectations.

The most relevant change is the fact that the arch is now removable. As shown in **Figure 31 a)** and **Figure 31 b)**, respectively, it is possible to see the assembled arch, ready for use, and the arch stored behind the back. This is an improvement because the arch being stored way when not in use gives a cleaner look to the design of the device.

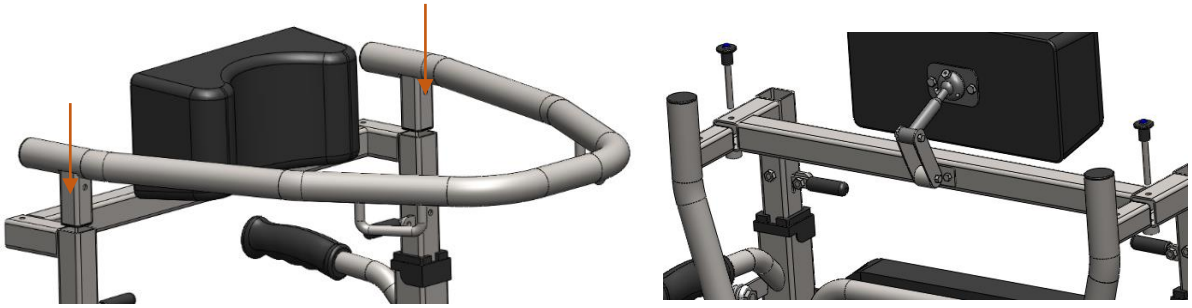


(a) (b)

Figure 31 – *Arch design: (a) ready to use, (b) stored away*

The arch features two welded square tubes, which fit into two laser cuts made on the arch, for the weldment to be more resistant and more precise. To assemble the arch on the wheelchair, for it to be used, as is displayed in **Figure 32 a)**, these 25 mm wide tubes fit inside the tubes of the upper structure, thus increasing the contact area and strengthening the attachment. Regarding the stored position, the welded square tubes also enter the upper frame, however, from the back, as is illustrated in **Figure 32 b)**. To ensure that the arch does not slide out of place, which isn't a concern in the previously

described configuration, two pins have been applied, one on each side, to prevent the arch from moving out of place.



(a) (b)

Figure 32 – *Arch positioning: (a) assembled, (b) stored*

Finally, the arch has hoops at the front, which can be seen throughout the figures presented above, onto which two carabiners will be placed, which in turn will attach to the sling, following the same concept described in Chapter IV. Since it was not possible to avoid the solution of the arch as an essential component for patient transfer, there is still a risk of the patient hurting the head on the arch. However, this problem can be decreased by placing foam around the arch so that, even if the patient bumps with the head, the risk of a significant injury is reduced. For the placement of the hoops, the positioning in the original HomeHoist device was taken as a reference, as well as the hoisting mechanism available at the company. However, to ensure the arch size and hoop positioning are adequate, practical tests must be carried out with the resulting prototype of this dissertation.

7.1.2. Removable seat and backrest

As mentioned before, a feature incorporated in this device, that distinguishes it from its predecessor, is the fact that the backrest and seat can be removed individually. According to the morphological diagram, the solution chosen for this purpose was the sliding slots and, although it was the baseline, because the gas springs are placed inside the upper structure tubes, problems of obstruction emerged, and the solution had to be rethought. Besides, it was realized that it would be fundamental to have some method to stop the seat and backrest from sliding, since, otherwise, they could be displaced at any moment. To avoid this situation, two index plungers were applied, one in each component. The reasoning behind this choice was because these index plungers are easy to apply and to use, and don't need to be removed from the chair, that is, they are not a removable component that can be lost.

Figure 33 shows the seat removal mechanism, in the removing situation, with a blue arrow marking the direction of movement. Two metal plates, welded on the sides of the seat, slide in the slots

cut in the tubes of the seat structure. Two plastic pieces were also applied, marked on **Figure 33** with *A*, to reduce friction, which not only makes the sliding smoother but also preserves the paint of the components, for longer-lasting life. Marked with *B* is the index plunger, which is fixed on the lateral structure and, by pulling the head, the piece that prevents seat movement retracts, releasing the seat. Additionally, the back of the structure has two handles, marked with *C*, for the caregiver to grab on and pull, to facilitate sliding, which occurs from the back of the device. It is important to state that this addition to the design doesn't allow for the backrest to be removed before the seat since the grips stand in the way of the backrest sliding. This feature can be removed in the future if it is realized that it negatively impacts the use of the device.

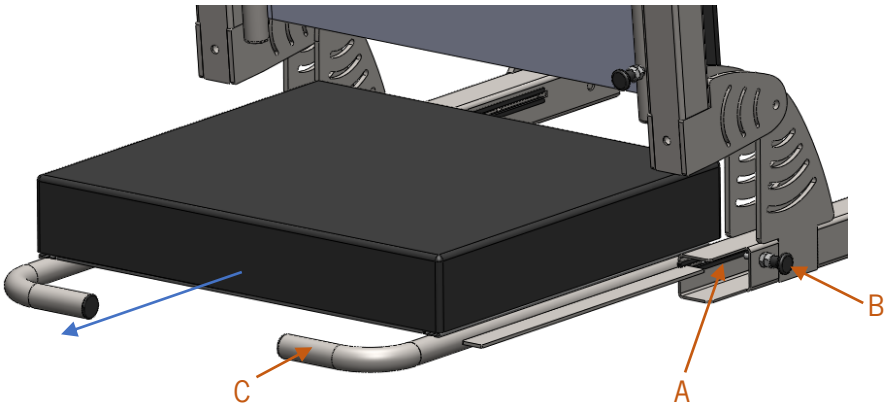


Figure 33 – *Seat removal mechanism.*

Regarding the mechanism of the backrest, represented in **Figure 34** in the removing situation, with the direction of movement marked with a blue arrow, it is in theory similar to the seat, although, in this case, the backrest has the slots where the metal plates, that are welded to the upper structure, slide. A plastic cover was also designed, marked with *A*, that is fitted to the metal plates, for the same reasons as in the seat. However, the reason why this plastic protection was made in two different ways, was because it was more troublesome to apply the protection to the slots cut in the round tubes. Therefore, the protections were applied to the metal plates. The index plunger, marked with *B*, works in the same way as the seat. For this component, the grip was not applied since the sliding to remove the backrest occurs in the direction of gravity, so it can be easily pulled.

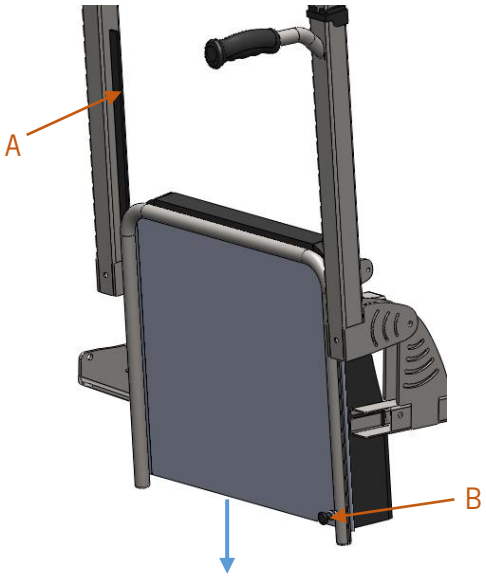


Figure 34 – *Backrest removal mechanism.*

7.1.3. Footrests

In order to achieve the complementary footrest displacement, which would compensate for the verticalization of the user, as described in Chapter VI, the footrest was designed as depicted in **Figure 35**. This mechanism works because the external tube is fixed and secured to the chassis, and the inside tube is connected to the metal plate signalled with *A*, which in turn is pivoted in the metal plate next to the user's knee, marked with *B*, both in **Figure 35 a)**. The internal tube has three holes that serve as a size adjustment, enabling the device to be better catered for users of different sizes. Additionally, the calf support can be rotated, as shown in **Figure 35 b)**, to free the inside of the wheelchair during transfer. The calf support is connected to the footrest tube through a metal bush, that is fixed with a pin, which, by removing it, frees the metal bush to rotate and, consequently, rotating the calf support.

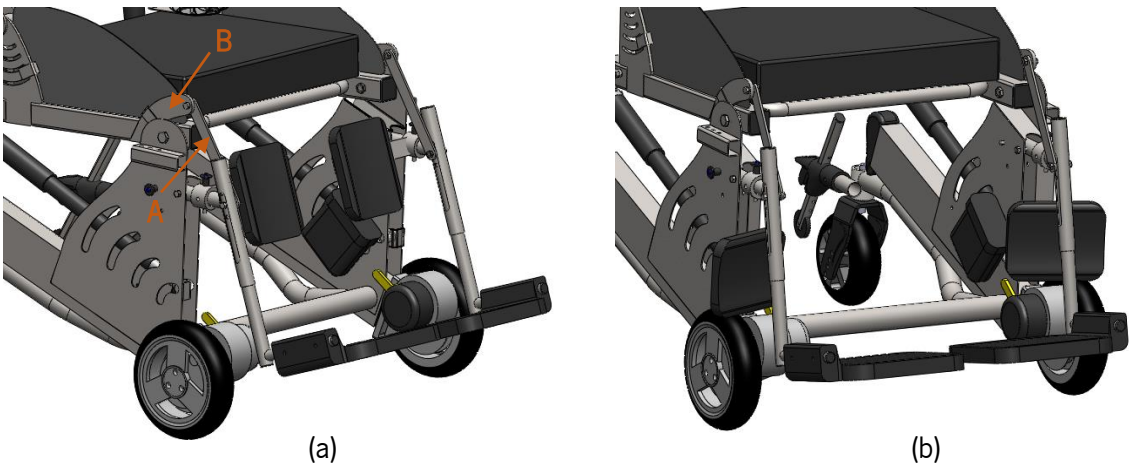


Figure 35 – *Footrest mechanism: (a) standard configuration, (b) calf support rotated.*

When the user is being verticalized, the knee metal plate follows the structure movement and forces the internal footrest tube down. As can be seen in **Figure 36 a)**, when the user is seated the footrest distance from the ground is around 101 mm, however, when the user is verticalized, **Figure 36 b)**, the footrest distance to the ground is around 28 mm.

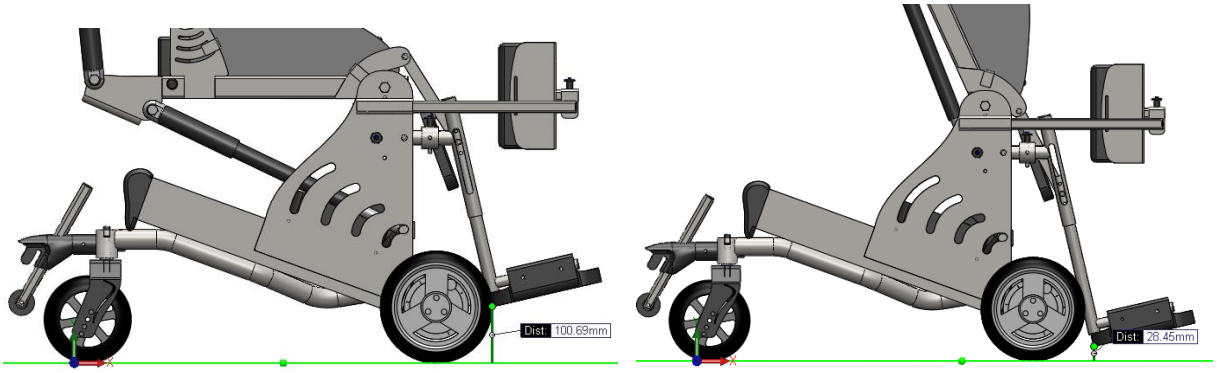


Figure 36 – *Footrest mechanism: (a) seated, (b) verticalized.*

Another addition that this footrest design brings to the table is the raise legs mechanism, depicted in **Figure 37**. The connector part to the structure of the wheelchair rotates in one point, signalled with *A* in **Figure 37**, and can be moved between the positions marked with *B* in **Figure 37**. In this way the footrest can be raised, and, with the help of the calf support, the legs are raised. Besides supporting the legs while raising the footrest, the calf support also plays a part in securing the patient in place when the seat is removed. However, this feature poses a problem which is that the footrest doesn't elongate enough for the user's legs to be stretched. This issue will be made clearer further in this chapter.

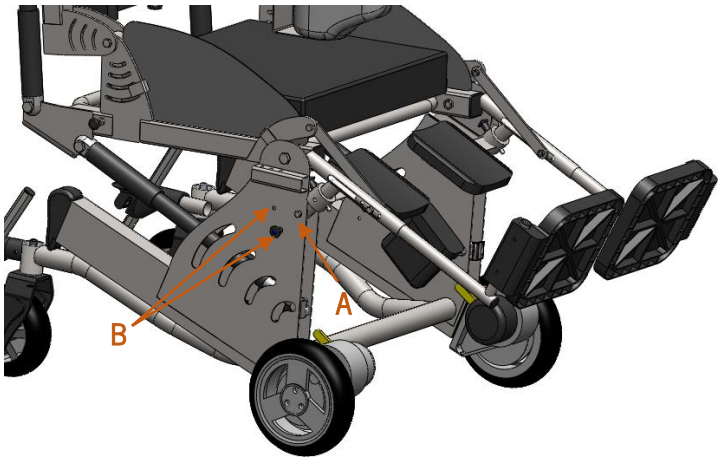
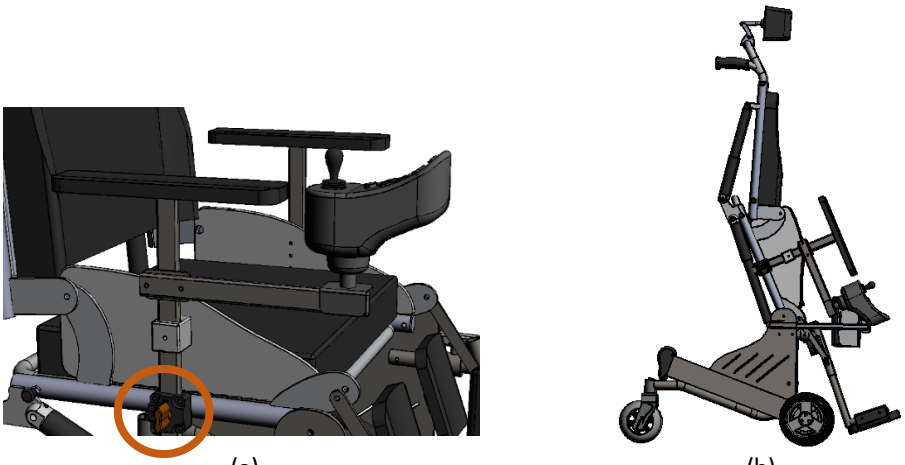


Figure 37 – *Raise legs mechanism.*

7.1.4. Armrest

For the development of this component, it was initially thought of a system in which the armrest would be connected to the seat structure, utilizing a component, signalled in **Figure 38 a)**, that allowed adjustment of height, for the armrest height to be as customizable as possible. This piece functioned in two positions: ON and OFF. When the orange handle was rotated to the OFF position, the armrest's tube would be fixed, however, if the orange handle was in the ON position, the tube could slide upwards and downwards, allowing for a very precise height adjustment. In addition, the tube could slide completely out of the piece, and be removed, completely freeing the patient's side, which was one of the features to be incorporated. However, during verticalization, since this armrest was connected to the seat structure, it would not support the arms, as is clear in **Figure 38 b)**.



(a) (b)

Figure 38 – *First armrest design: (a) seated, (b) verticalized.*

To overcome this problem, the solution found, depicted in **Figure 39**, was to weld the armrest to the upper structure of the wheelchair, which relates to the backrest, for in this way, regardless of the movement of the wheelchair, the armrest always follows the natural movement of the arms.

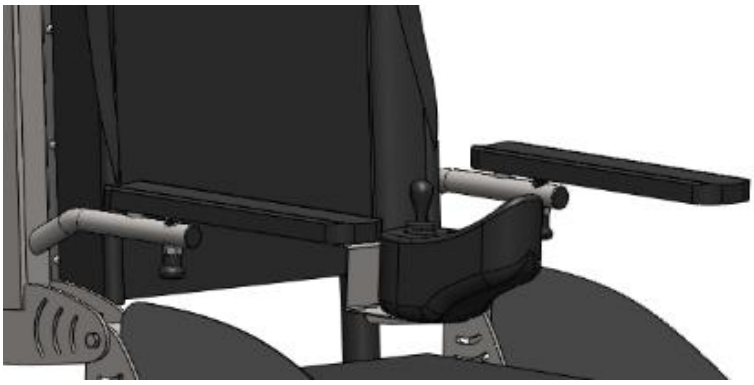
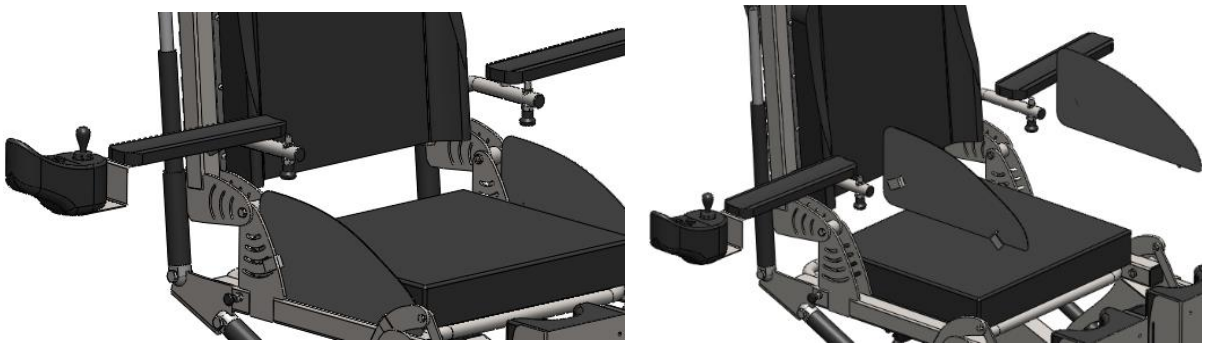


Figure 39 – *Final armrest design.*

However, the welded armrest brings back the lack of lateral clearance and is not adjustable for different user sizes. To mitigate this situation, index plungers, which are positioned underneath the armrest tube, were used to hold the armrest in place, and when activated, the armrest is released and can rotate outwards, as depicted in **Figure 40 a)**, freeing up lateral space. The index plungers fit inside a metal bush that is placed perpendicularly in the armrest tube. Although not completely free, this configuration allows some handling. The safeguards, which are metal components placed on the sides of the seat, that serve to protect of the patient's body, can also be removed, as is shown in **Figure 40 b)**.



(a) (b)

Figure 40 – *Armrest mechanism: (a) rotating armrest, (b) removing safeguards.*

To one of the armrests is also attached the joystick, with which the wheelchair's electric components are controlled. It can be positioned on either the right or left side, according to the user's preference.

7.1.5. Headrest

For the headrest, which is depicted in **Figure 41**, since the standard headrests at Orthos XXI didn't quite fit the structure of this device, a new and simple concept was developed, one that would be easy to manufacture but still provided adjustability and comfort for the user.

Therefore, the U-shaped foam in which the head lays relates to one of the company's standard components, but the mechanism that allows the headrest adjustability is different. It is comprised of 3 parts, that are signalled with *A*, *B,* and *C* in **Figure 41 b)**, and to better describe the capabilities of adjustment of these parts, each movement is identified. These movements can be accomplished by loosening the screws that keep each part in place, and by tightening them back up, the headrest will remain in the desired configuration.

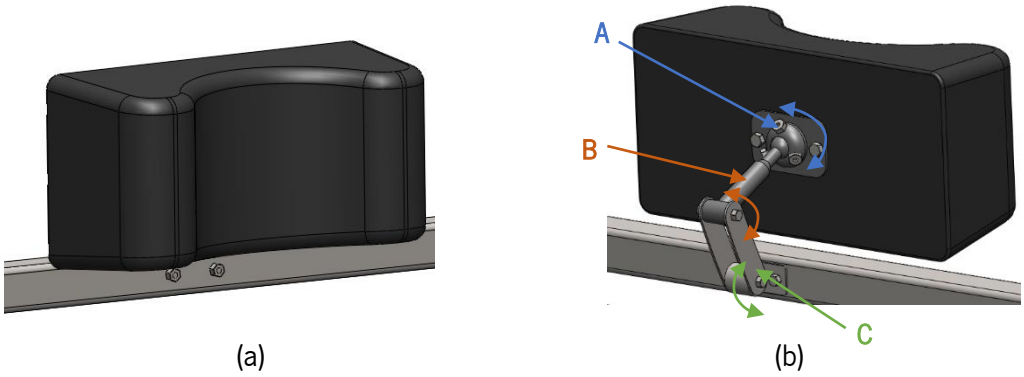


Figure 41 – *Headrest: (a) front view, (b) adjusting mechanism.*

7.1.6. Structural aspects

Besides the mechanisms and components aforementioned, there were still various structural aspects that were thought and designed in order to accomplish the functions and goals described in Chapter V.

Firstly, the use of square tubes and double metal plates for the seat and back structure was incorporated to provide strengthen and facilitate welding. The shape of the metal plates is laser cut in the surface of the square tubes, so the metal plate can be fitted in place, which accelerates and reduces variability in the welding process, since each part is placed in the exact spot of the cut and, since a bigger surface of the metal plate is welded to the tube, the bond becomes stronger. To better illustrate the difference between using round tubes and squares tubes, **Figure 42 a)** and **Figure 42 b)** pertain to each situation, respectively.

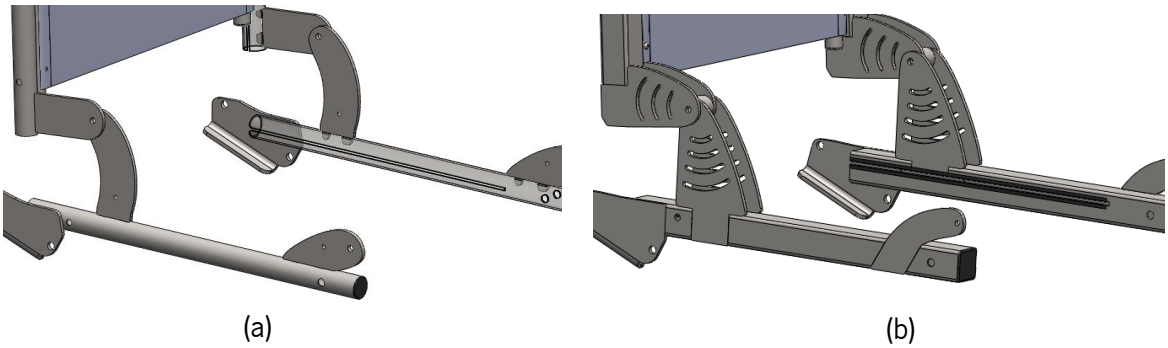


Figure 42 – *Seat and backrest metal plates: (a) first design on rounds tubes (b) second design on square tubes.*

Relating to the use of double metal plates, in both the back and the seat, to form the pivot nearest to the user's hip, even though the metal plates are relatively thick (5 mm), there still could be long-term problems of bending, that could prevent the system from working at its full potential. To this joint, a metal

bush was applied, to compensate for the distance between the metal plates, which is pointed out in **Figure 43**. The sloths cut in these metal plates serve to reduce weight, and for aesthetic purposes.

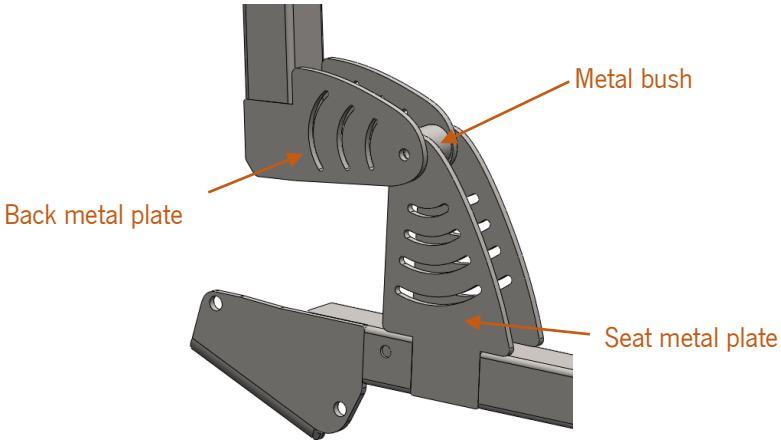
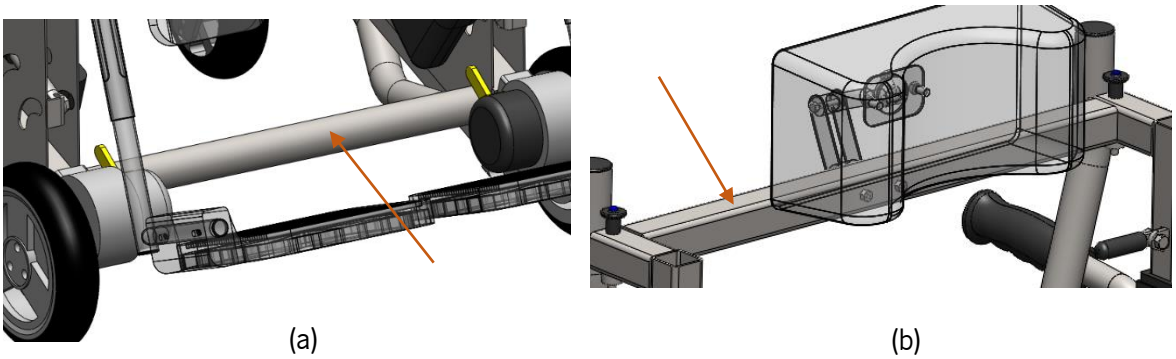


Figure 43 – *Hip joint metal plates.*

Still concerning the use of double metal plates, as can be seen in **Figure 44**, the chassis of the wheelchair also comprises this feature, once again to strengthen the device, especially since the verticalization and lowering movements rely on this structure, as it is one of the main support points of the upper structure, and even contains one rotation point. To secure the two metal plates there is a horizontal metal plate welded to them both. The sloths cut in these metal plates were essential to allow the attachment of the seat actuators, placed between them, with the aesthetic of the design in mind.

Figure 44 – *Chassis double metal plates.*

One other way in which the overall device was strengthened, and torsion forces avoided, was through the use of the tubes shown in **Figure 45**. These tubes were added to prevent torsion in the overall device, mainly because the use of actuators, if not completely in sync, or if one of them is defective, may force one of the sides of the wheelchair and cause torsion. **Figure 45 a)** pertains to the tube added on the bottom of the device, and **Figure 45 b)** to the tube added on top.



(a) (b)

Figure 45 – *Structural tubes.*

Later in the project, an extra safety measure was incorporated, the use of anti-tippers, which can be seen in **Figure 46**. This is a standard procedure in wheelchairs, especially if intended for use outside since climbing ramps with bigger slopes can cause the wheelchair to tip backwards.

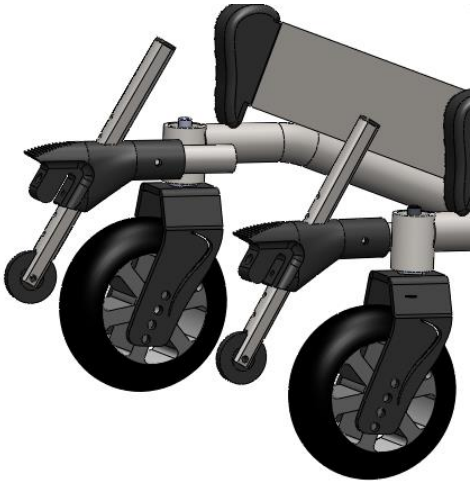


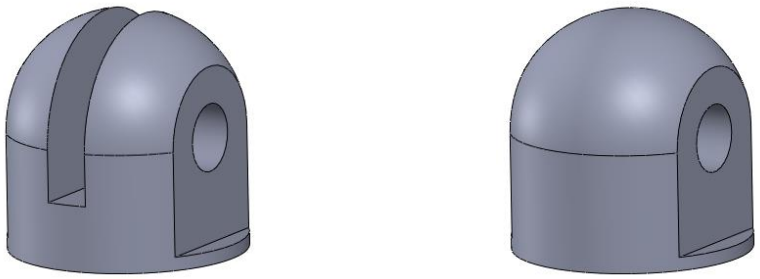
Figure 46 – *Anti-tipper wheels.*

As a final detail, metal bushes and washers were used throughout the development of the device to mitigate unwanted spacing or to reinforce connections. For aesthetical purposes, the battery angle is the same as the actuators, for the two components to be parallel in the sitting position, and finally, from an aesthetical point of view, and for mass purposes, some designs were cut into the more significant metal plates.

7.1.7. Actuator connections

Another essential aspect for the operation of this device is the positioning of the actuators. The connections between actuators and the rest of the structure should be as safe and resistant as possible because the failure of these components can cause serious structural damage and, in the worst-case scenario, injure the user. The structural damage that can occur may be due, for example, to the actuators not being properly aligned and one of them overworking to compensate. This can not only damage the

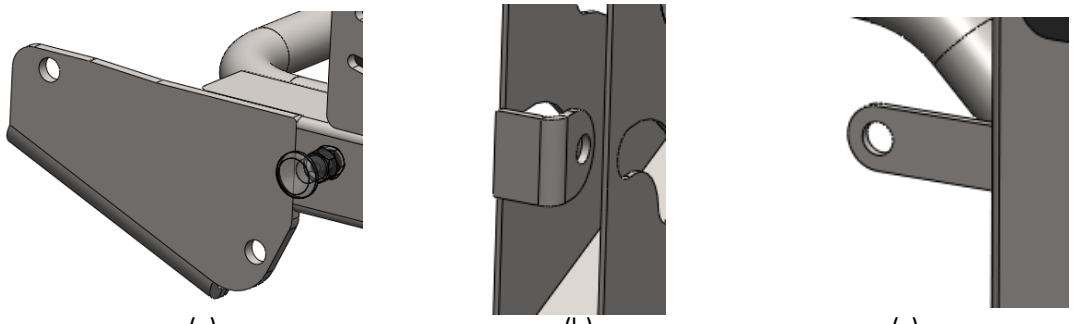
structure, as uneven stresses are applied the structure starts to lose its symmetry, but furthermore, the fact that one of the actuators is overworking can lead to its failure and jeopardize the functioning of the device. The type of actuator connection chosen between the two provided by the supplier, illustrated in **Figure 47**, also took into account their assembly recommendations, and the one that best fitted the structure was the connection depicted in **Figure 47 a)**.



(a) (b)

Figure 47 – *Actuator connections: (a) middle opening, (b) whole piece.*

Thus, the connection points of the actuators to the structure, as illustrated in **Figure 48**, correspond to the connection points determined in the previous chapter, and were designed through metal plates welded to the structure. The first metal plate, **Figure 48 a)**, is 5 mm thick and is welded to the back of the seat structure tube, as previously described. In addition, this metal plate presents a bend, to enhance its resistance against warping. The metal plate, shown in **Figure 48 b)**, refers to the second connection point of the seat actuator, place between the two front metal plates, and the metal plate present in **Figure 48 c)**, refers to the second connection point of the back actuator, placed near the wheelchair handles, both with 3 mm thickness. Particular attention was given to the development of the metal plate (a), in terms of increasing its strength, since it is a shared connection point for the backrest and seat actuator, and due to the desired position for their connection, further away from the main structure, it could present a higher risk of instability. The thickness of the metal plate also took into account the hindrance of the positioning of the actuators, since, if they were positioned a little further out, they would collide with the battery. The three connections mentioned have a symmetrical one on the other side of the wheelchair.



(a) (b) (c)

Figure 48 – *Actuator connection points: (a) seat and backrest actuator, (b) seat actuator, (c) backrest actuator.*

7.1.8. Overall device dimensions

Lastly, taking into account the structural sizing specifications established in Chapter VI, and the different components that were described in this chapter, it remains to be ascertained whether the design presented above, with the compromises that it implied, fulfilled the size specifications mentioned in the previous chapter.

In **Table 16** it can be found the same measures established as critical in Chapter VI (refer to **Table 13**), but with the values obtained in the final design.

Table 16 – *Overall device dimensions.*

Dimension	Value (mm)
Minimum seat height (from ground to underneath the seat)	374
Interior depth (clearance underneath the seat)	497
Interior width (clearance underneath the seat)	407
Maximum rear components height (wheels and batteries)	340
Overall width	701

Comparing this table with **Table 13**, it is possible to see that some restrictions were fulfilled, except the interior depth and width, and the maximum rear components height. Nevertheless, it was expected that some values would be difficult to achieve, during the design of the device, as was stated before, yet the final dimensions obtained still fall in line with the functions of the device, even if not in extreme situations, as the difference between the values obtained and those intended is around to 1 cm. For reference, in **Annex IX** it is possible to observe how the measurements were performed.

Finally, the overall device weight, obtain through *SolidWorks*, is 61.6 kg, without batteries.

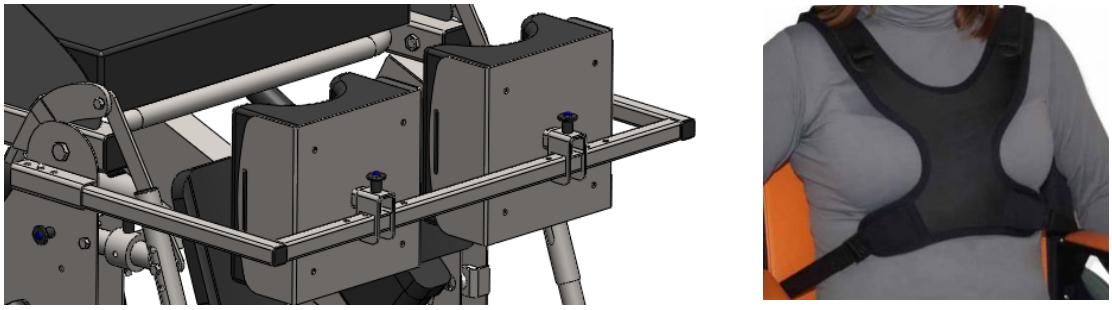
7.2. Functionality

Once the components that comprise the developed device have been clarified, follows a presentation and explanation of the functionalities that it features, as well as the degree of operation of each one of them.

7.2.1. Verticalization

The verticalization of the device is achieved by increasing the size of the seat actuators and reducing the size of the back actuators, which gradually follow the movement of the former. In addition,

the footrests, as already mentioned, slide downwards to attenuate the force exerted on the patient's joints, as well as to reduce the displacement inherent to the verticalization process. Finally, for the patient's safety, to prevent unbalancing and falling forward, a knee support was added, which may be supplemented with a chest support, to further secure the patient while verticalizing. The knee support designed in the scope of this project, and an example of chest support, marketed by Orthos XXI, can be found in **Figure 49 a)** and **Figure 49 b)**, respectively.



(a) (b)

Figure 49 – *Verticalization support systems: (a) knee support, (b) chest strap (adapted from [65]).*

Figure 50 pertains to the wheelchair verticalized to its maximum, which takes around 42 seconds (refer to **Annex VII**) and happens when the angle between the seat and the horizontal plane (parallel to the floor) is 65°. At this point, the footrest is also at its maximum length, and its distance to the ground is 28 mm. The positioning of the seat actuators allows the device to reach a 75° angle, however, the backrest reclination is the limiting factor for this feature. Since the backrest can't recline more than 155°, if the seat continued raising, the user's chest would be propelled to the front, in an uncomfortable position.

(a) (b)

Figure 50 – *Verticalization function: (a) fully verticalized device, (b) fully verticalized device with dummy positioned.*

To achieve the verticalization, and for posterior implementation of the electric system, it is relevant to comprehend the relative size between the two pairs of actuators during the verticalization process. For this matter, **Table 26**, depicted in **Annex X**, was elaborated, to present a possibility for the simultaneous size of the backrest and seat actuators, for increments of 10° of the angle between the seat and the horizontal plane, until the maximum 65°.

These values may be adjusted for different patients, since, as previously stated, each case is unique, and different patients may have different needs. Thus, the values presented in **Table 26** should serve as a guideline and may be adjusted if needed, during the programming of the electric system.

7.2.2. Recline

To perform the recline function, only the actuators on the backrest are engaged. The position of the actuators allows for a reclining angle of 155° (between the backrest and the seat), which takes around 33 seconds to be achieved (refer to **Annex VII**). This movement is ensured by the shortening of the backrest actuators from 567 mm to 370 mm and can also be complemented with the raise legs functionality of the footrest. In **Figure 51** it is possible to see the device in the maximum recline position.

Figure 51 – *Fully reclined device.*

Although the raise leg function has been added, through **Figure 52**, in which the dummy is placed on the device to simulate the patient's position, it is possible to see that the footrest is too short for the legs to be raised and stretched. This is due to the fact that the mechanism which originates the elevation of the footrest has a maximum length, which in turn, as illustrated in Chapter VI, depends on the verticalization movement and on the fact that the footrest cannot elongate more, otherwise, it hits the ground when the patient is fully verticalized.

Figure 52 – *Fully reclined device with dummy positioned.*

7.2.3. Lower

Regarding the lower patient function, it is obtained by decreasing the size of the seat actuators. When the patient is sitting with the seat parallel to the floor, the seat height, including the seat cushion, is 583 mm from the floor. However, this operation has been designed for when the patient is being transferred to a surface lower than the height of the wheelchair seat. Therefore, since during the transfer the seat is removed, the reference point for the height of the patient was the middle of the tube of the seat structure. The reason behind this is because, if the seat is removed, and the arch placed in the lowest position, the patient's body will lower below the seat surface. However, since it is not possible to determine exactly how low the patient's body will go, the middle of the seat structure, as marked in **Figure 53**, was considered a reasonable point for reference. In these circumstances, with the wheelchair in the sitting position, the reference point, is at 492 mm from the floor. Thus, as can be seen in **Figure 53**, the minimum seat height that is obtained through this device is 374 mm. The actuator goes from 498 mm in length to 430 mm to achieve this height.

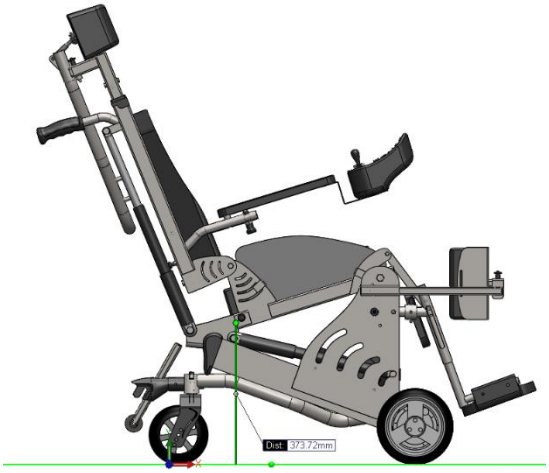


Figure 53 – *Device's lowest height.*

7.2.4. Transfer

The transfer function is perhaps the most relevant of the device, as it is what distinguishes from others, enabling the patient to be transferred to and from various surfaces, such as beds, toilets, shower seats, and chairs. This function is achieved using the verticalization and lower mechanisms, along with the gas springs, found in the upper structure. The latter is activated by the caregiver, through the handles marked in **Figure 54**, and allows adjusting the height of the arch, which is attached to the structure as previously described. To both the tube that slides upwards and downwards and the fixed tube, plastic glides were applied to reduce friction between these components, providing a smoother slide.

Figure 54 – *Adjusting arch height through gas springs.*

Moreover, the purpose of using gas springs to lift the arch is so that the weight of the patient is relieved from the seat, for the caregiver to remove it, while the patient is secured through the sling attached to the arch. The gas springs can lengthen 200 mm, however, to understand the impact that increasing the height of the arch has in lifting the patient, practical tests would have to be performed, as different factors will have an impact on this feature. One of them, for example, is the patient's mass. Although the wheelchair is designed for a maximum user mass of 95 kg, the lighter the patient using the device, the higher the elevation will be. Another factor is the adjustment of the sling straps since the looser they are, the less impact the increase in arch height will have on the patient. In **Figure 55** it is possible to see the difference in height of the arch when it is at its lowest and highest position, respectively.

(a) (b)

Figure 55 – *Arch different heights with seat and backrest removed: (a) lowest height, (b) highest height.*

Furthermore, the backrest can only be removed after the seat, otherwise, there isn't enough clearance for it to slide under the structure. With the patient secured by the sling and arch, and the backrest and seat removed, the caregiver can then raise the wheelchair structure using the verticalization mechanism to position the patient over the desired surface for transfer, and use the lower patient function to gradually lower the patient onto the surface, or the other way around.

As can be ascertained by **Figure 56**, the interior space of the wheelchair is mostly free, besides the electric modules and the round tube that attaches to the back wheels, which are positioned as much as possible to the front of the device, to make the most of the free space on the back. This allows for the device to be fitted into different surfaces, which was one fundamental aspect of the device. With the calf supports rotated to the bottom, the patient can pass through the free space inside the wheelchair and be fully transferred to another surface.

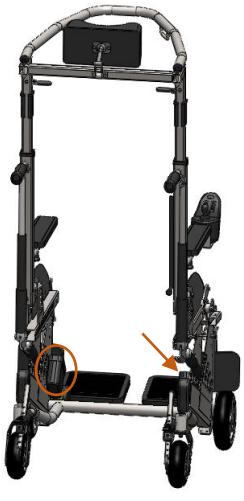


Figure 56 – *Free interior space.*

The development of the sling to be used in combination with this device was not part of this dissertation, and because of that, the slings used as a reference for future application in this device were the ones produced by the company, which provides a various range of options.

7.3. Electric components

Once the design and functioning of the device had been defined, as well as the selection of the mechanical components that would best suit the project, followed an understanding of how the electrical installation of the system would be done. For this, the systems already used in the company were taken as a reference, in order to develop a system that could be put into practice.

Thus, the control system used will be the R-Net system, which is already used by the company. It is a modular system since it allows for the installation of different modules, which enables adding functionality over time and easily replacing components if there is any malfunction [66].

The first component to be applied, shown in **Figure 57**, is the Power Module. To this module are connected the batteries, in series, so that the voltage is 24 V, and also the two motor wheels, each with dedicated input. This power module can provide 90A per channel, which is enough for the purposes of the device, and allows gradient control, curb climbing, and high-speed front-wheel driving. Finally, this module connects to a can-bus, which allows the other modules to connect, so that the system works as a whole.

Figure 57 – *Power module (adapted from [66]).*

Afterwards, comes the connection of the Intelligent Seating/Lighting Module, depicted in **Figure 58**, onto which the actuators are connected, as well as turn signal indicators, and brake lights or a high volume horn, which are relevant features if the device is to be used in the exterior environment. The maximum actuator current this module allows is 12 A, and it is also programmable to independently adjust speeds, acceleration, and deceleration, which are relevant aspects for the safe operation of the device.

Figure 58 – Intelligent Seating/Lighting Module (adapted from [66]).

Each pair of actuators can be controlled individually or can be driven simultaneously, namely, for verticalization, however, to achieve the latter, in addition to the intelligent seating module, it will be necessary to add rotary encoders to the actuators, to identify their length in each instance. With this information, coupled with **Table 26** (refer to **Annex X**) proposed in the previous subchapter, which establishes the relative length of the backrest and seat actuators, during various angles between seated and verticalized, it's then possible to program the verticalization function into the R-Net system, as well as end-stop points for both pairs of actuators, to prevent them to work out of the range intended, which may compromise the integrity of the structure. These end-stop points would relate to the maximum and minimum lengths, for each pair of actuators, registered in **Table 26**.

Both the power module and the intelligent seating module can be placed in the interior of the wheelchair, without compromising the clearance already foreseen, as signalled in **Figure 56**.

With all this, comes the need to have a component that controls the electrical system of the device, which is the Joystick. The selected joystick has a large LCD screen, which allows an intuitive use, with buttons to control the speed, lights, horn, and other features, however, most of the control is done with the knob that allows the selection of each set of actuators, namely, the pair of seat or backrest actuators, for individual adjustments, or the verticalization feature, which engages both pairs of actuators. In addition, the batteries are charged through a cable that connects to the joystick.

Additionally, since this device requires the assistance of a caregiver, it is important that the caregiver has the ability to handle the wheelchair and control the processes of transfer, reclining, and verticalizing when necessary. Therefore, the Attendant Module has been added, which is a joystick-style controller that can be programmed to have superior control over the wheelchair if the need exists.

The joystick is attached to one of the armrests and the attendant module is remote, both depicted, respectively, in **Figure 59 a)** and in **Figure 59 b)**.

(a) (b)

Figure 59 – *Controls: (a) joystick, (b) attendant module (adapted from [66]).*

After assembling the system, it's necessary to program it, to accomplish the features previously mentioned. Thus, the programming of the system can be done through the joystick, using a hardware dongle or a keycode, which unlocks the programming mode. These programable adjustments may differ from user to user since each patient is a specific case and should be treated as such. Therefore, all features of this electrical system must be individually adjusted in each specific case according to the needs of the patient and caregiver, to ensure a safe and convenient use of the device.

Along with the components that guarantee the functioning of the device, it is also important to add safety mechanisms to ensure that it operates in safe conditions. The main safety concerns at this early stage of development are that the device must be stable before any operation is performed and that the maximum user weight, 95 kg, cannot be exceeded. Thus, for the first condition, an accelerometer will be applied to the device, and for the second, a load cell. For prototype testing, which is the current phase of development, the use of an Arduino to manage these sensors is the ideal choice, not only because it is user-friendly, but because it is also cost-effective and open source. On a more advanced stage of development of the electric system of the device, a printed circuit board (PCB) could be used instead.

Relating to the accelerometer, this component will monitor the stability of the device. By being placed in the base of the wheelchair, namely, the tube that connects the two battery cases, the accelerometer will report the device's inclination relative to the horizontal axis to the Arduino, and if the device is out of the range of inclination considered safe to perform, the programmed safety logic will prevent the actuators from working and, if an operation was already undergoing when the system detected an unsafe environment, the only option available for the user will be to return to the initial position. To determine the safe inclination range, tests would have to be carried out. When the device is back in a stable condition, the safety logic will reset.

Concerning the load cell, which should be placed, for example, under the seat, if the system detects that the user is over 95 kg, the programmed safety logic must prevent the actuators from working,

to avoid damage to the device because of overloading, but most importantly, to avoid any injuries to the user. Since the raise patient function is manual, due to the use of gas springs, a warning must be emitted so that, since the manual functions can't be disabled through the electric system, the user will be aware that the device is not safe to be used in the current condition. This warning may be audible or appear on the joystick display.

Thereby, with all this information in mind, a diagram of the connections for the components aforementioned is presented in **Figure 60**, to better illustrate how this system should be assembled.

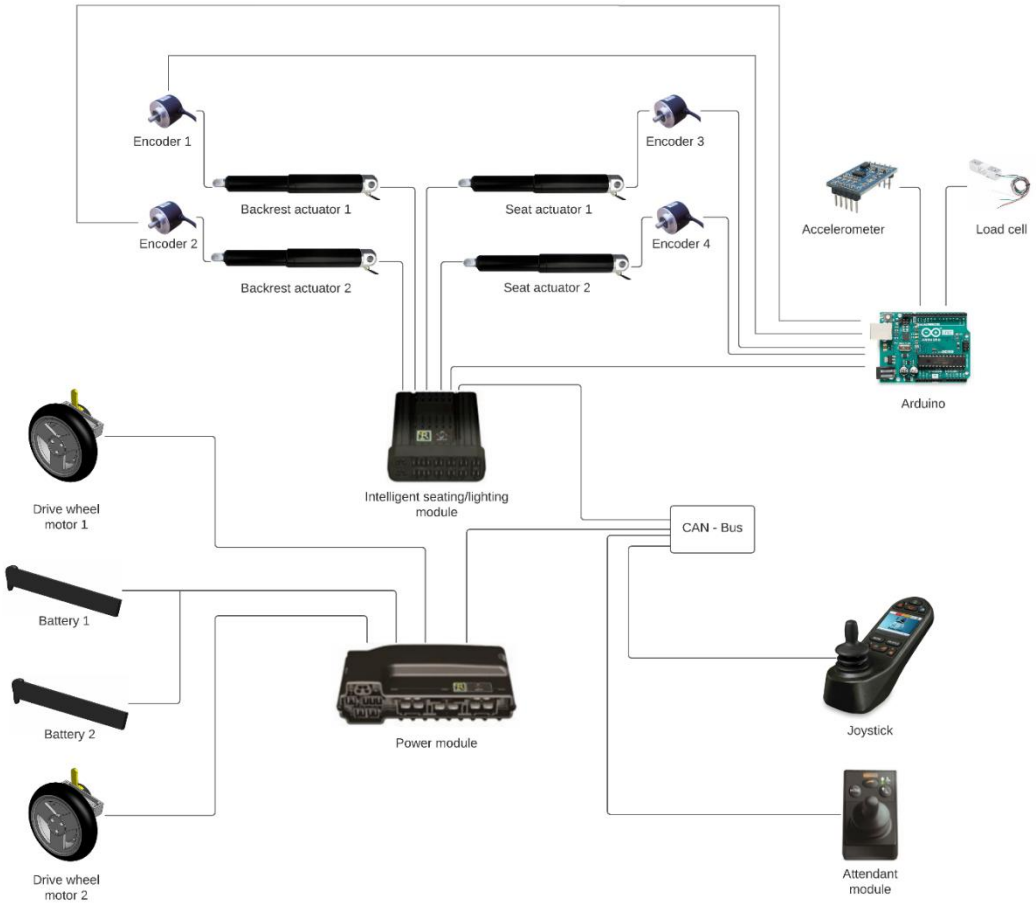


Figure 60 – *Diagram of the electrical component's connections.*

7.4. Simulation

After introducing the developed device, which was the result of the various factors that were analysed throughout the previous chapters, it is pertinent to understand if the device, besides fulfilling the intended requirements and functionalities, has the necessary mechanical resistance to work safely in the established conditions. Although in the development of the device it was always taken into account that the different components should be as resistant as possible so that, when they were put together,

the outcome would also be, the mass and size limitations were in several cases limiting factors for the design, and in some cases, went against the former.

Therefore, to ensure that the device can operate safely even under the foreseen extreme conditions, two critical components were studied through the simulation tools of the *SolidWorks* software. The FEM simulations were carried out for the component's most mechanically demanding situation and the maximum user weight of 95 kg. Ideally, the safety coefficient for the stress analysis should be at least 2, and the deformation of the components should be below 1 mm. These were arbitrary values that were established as what was considered enough for the purposes of this project.

The first simulation was for the arch. As previously described in this chapter, the arch is the patient's support during transfers, utilizing a sling. Therefore, this component must be able to support the maximum user weight without yielding or deforming. The simulation served to understand if the diameter of the tube, the positioning of the hoops where the sling is attached, and the attachment points of the arch to the wheelchair structure, would be sufficient to perform its function safely.

The initial design for this component consisted of a round tube with 30 mm in diameter and 2 mm in thickness, and the bends and widths of the different sections were determined by the space required for the patient and storage in the back of the wheelchair. Concerning the placement of the hoops, it is shown in **Figure 61** the sketch of the holes made in the arch for the hoops to be placed and welded.

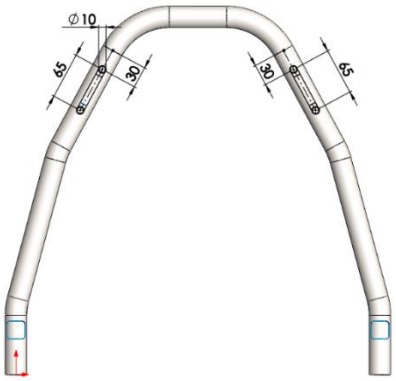


Figure 61 – *Hoop positioning sketch – arch initial design.*

To simulate this component, the connections between the square tubes, that are attached in the back, and the hoops, that are attached at the front, were established as weldments, for the simulation to mimic the component's behaviour as similar as possible to the real conditions. Then, the component's fixation points were established, in this case, the faces of the square tubes were considered immovable, since they fit into a square tube with a reduced gap, and it was also considered that the ends of the arch, which are supported on the wheelchair structure, were immovable, to simplify this feature since the real conditions are much more complex. Concerning the load applied, it was defined that each hoop would

be supporting 465.5 N, which corresponds to half the weight of a user with the maximum mass expected, 95 kg, since the weight is distributed between the two hoops, one on each side of the arch. As for the mesh, the curvature-based option was selected, since the tube is round, and two refinements were tested: one had 7.33 mm element size, which resulted in 17194 total nodes and 8530 total elements, and it took less than a minute to solve, both the mesh and the results; the other mesh had a 1.5 mm element size, which resulted in 272523 nodes and 135909 elements, and took five minutes to solve and present results. Since the results obtained in both instances were virtually the same, with the differences being in the tenths order, it was concluded that the first mesh, which wasn't so refined, was fit for the study at hand. With this, the results presented in **Figure 62** and **Figure 63** were obtained.

In **Figure 62** it is possible to observe the Von Mises analysis, where the stress along the component is studied. Overall, the stress does not exceed 72 MPa, however, in the area just after the arch support to the structure, the appearance of yellow and red colours is clear, the latter translating into a stress of 122.4 MPa. Taking into account that the yield stress of the material used is 235 MPa, the safety coefficient obtained is 1.92, which, even though close, is still below the established value.

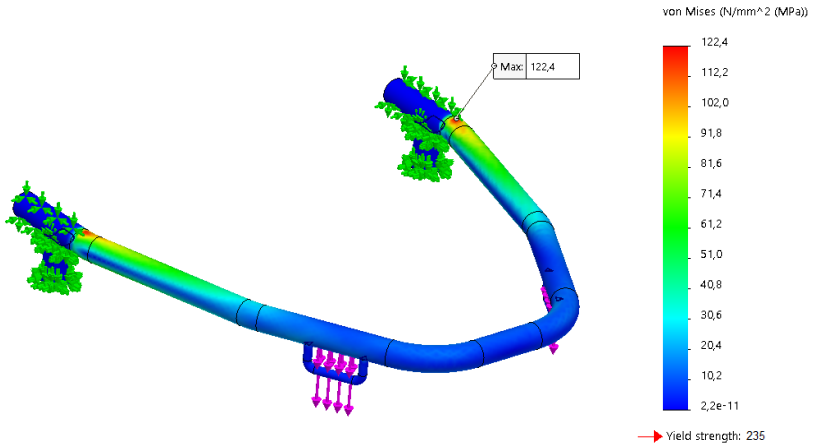


Figure 62 – *Von Mises analysis – arch initial design.*

Thus, through the deformation analysis of the component, illustrated in **Figure 63**, it can be seen that the front of the arch, coloured with red, is subject to a deformation of 2.5 mm. This value is more than double what was established as acceptable.

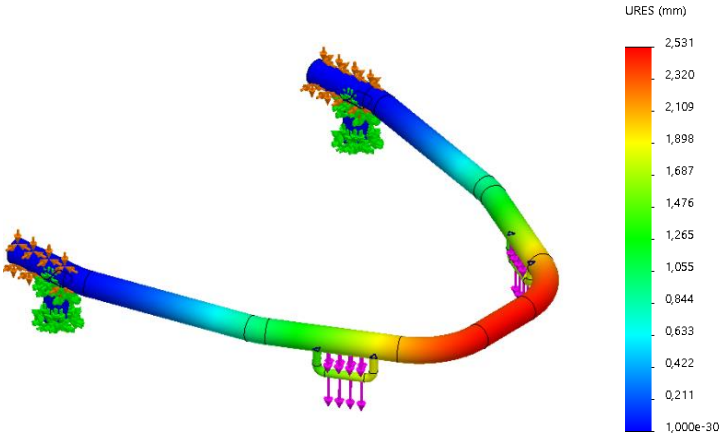


Figure 63 – *Deformation analysis – arch initial design.*

Thereby, with these two studies, stress, and deformation, it was perceived that it would be necessary to change some characteristics of the component, to decrease the deformation and, preferably, increase the safety coefficient. Furthermore, after realizing that the possible alterations for the fixation points did not impact the deformation and stresses applied to the component, the hypotheses studied were to change the positioning of the hoops and to increase the diameter of the tube. The shape of the arch could not be changed as it was made precisely to fit in the back of the wheelchair. A tube diameter of 35 mm was tested, but it was concluded that this would not be sufficient, and therefore the tube diameter selected was 38 mm, maintaining the 2 mm thickness. This change would influence the mass of the component, which should be as small as possible, as it will be assembled and disassembled by the caregiver, and results in a mass of 2.5 kg. As for the placement of the hoops, since it's where the user's weight is placed, it was perceived that the further forward they were, the more pronounced would be the deformation verified in the previous simulation. Thus, as illustrated in **Figure 64**, the hoops were displaced towards the inside of the arch.

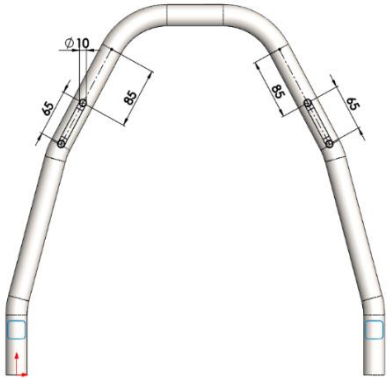


Figure 64 – *Hoop positioning sketch – arch redesign.*

With these changes, a new simulation was carried out, with the same specifications mentioned above, except for the mesh. The curvature-based option was still selected, however, the first mesh defined

had 8.13 m in element size, resulting in 17007 total nodes and 8381 total elements, and took less than one minute to apply and solve; on the other hand, the second mesh, which was more refined, had 1.5 mm element size, resulting in 341899 nodes and 170751 elements, and took around five minutes to apply and solve. Once again, since the difference in results was minimal, in the tenths order, the first mesh was selected, and the results obtained are illustrated in **Figure 65** and **Figure 66**.

Regarding the Von Mises analysis, depicted in **Figure 65**, the maximum stress value was obtained at the same location, which was expected, however, the maximum stress recorded was 65.5 MPa, in contrast to the yield strength of the material, a safety coefficient of 3.58 was obtained, a considerably higher value, with which is more comfortable to admit the safe operation of the device.

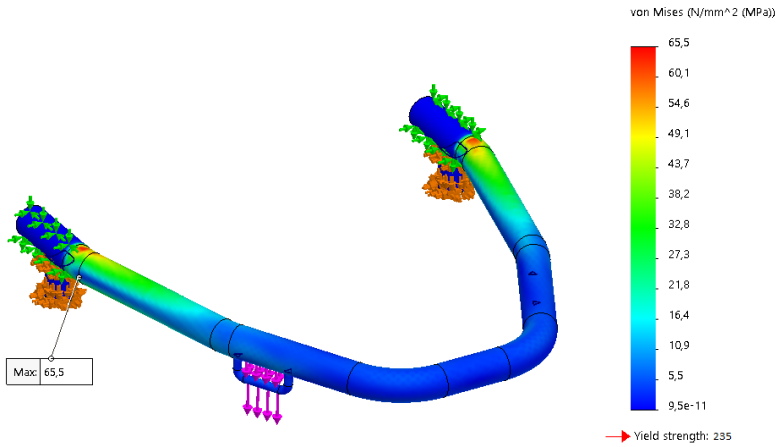


Figure 65 – *Von Mises analysis – arch redesign.*

Regarding the deformation analysis of the component, which can be visualised in **Figure 66**, the location of the greatest deformation maintains, coloured in red, however, the maximum deformation does not exceed 1 mm, which is in line with the intended.

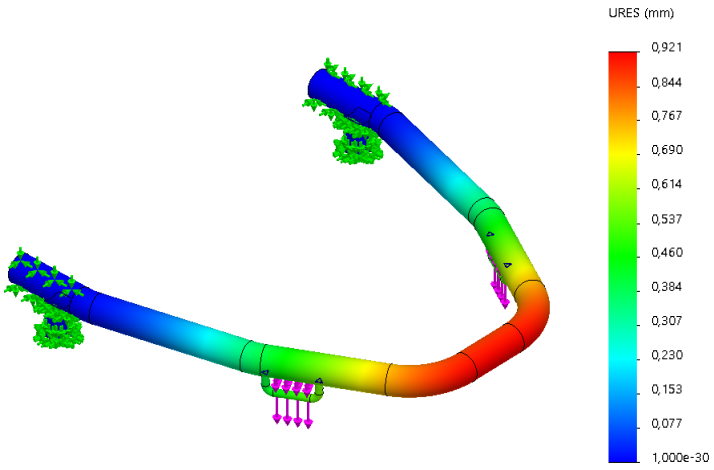


Figure 66 – *Deformation analysis – arch redesign.*

Thus, the changes applied to this component were sufficient to resolve the shortcomings that the simulation of the first configuration of this component brought to light. Even though the mass of the component was compromised, from 2.1 to 2.5 kg, it is still an acceptable value for the caregiver to carry. Regarding the gas spring selection, which depends on the position of the hoops, since it is where the user's weight is applied, moving the hoops closer to the gas springs, which is the case, would reduce the gas spring force need, which means that the selection previously established, remains valid for this design alteration.

Then, followed the analysis of another critical component, the connector between the footrest and the knee metal plate, which can be seen in **Figure 67**. The selection of this component was due to the fact that, when the user is verticalized, almost their complete weight is being supported by the footrest and this connector, which will be referred to as footrest metal plate, is what secures the interior tube of the footrest to the rest of the wheelchair structure.

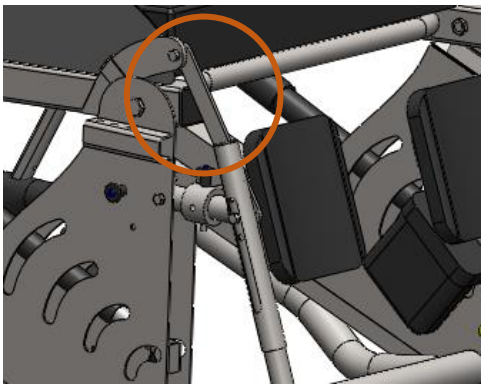


Figure 67 – *Footrest metal plate.*

To understand the dimensions of the footrest metal plate, **Figure 68** pertains to the sketch of the component, which translates to a 5 mm thick metal plate. The thickness and width of this component might be the key factors for it to be able to support the user's weight.

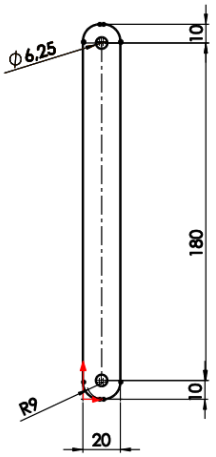


Figure 68 – *2D sketch of the footrest metal plate.*

To proceed with the simulation of this component, it was first important to understand how the force of the user's weight was being applied to it. After analysing the 3D model of the device, for the maximum verticalization angle, it was possible to understand the angle between the footrest metal plate, and the direction of the force applied to it. Thus, both the central line of the component and the horizontal line (parallel to the ground) were marked, as well as the direction of the force. In terms of fixtures, to simplify the simulation, the first hole of the metal plate, which is attached to the wheelchair structure, was marked as immovable, with no translation. Relating to the loads applied, half of the user's maximum weight, namely, 465.5 N, was applied in the other hole of the component, with the direction previously determined. Once again, it was used half of the user's weight since there is an equal, parallel component on the other side of the wheelchair, with which it shares the total load. Finally, two meshes were tested; the first mesh defined had 1.38 mm as maximum element size, with a total of 8195 nodes and 3928 elements, and took less than one minute to apply and solve; the second mesh, add 0.5 mm element size, resulting in 62695 nodes and 30884 elements, also taking less than one minute to solve. Since the results were significantly different, a finer mesh was applied, with 0.25 mm in element size, resulting in a total of 248605 nodes and 123378 elements, taking five minutes to complete. Since the difference in results was still significant, in the unit order, the finer mesh was the one used to determine both the stress and deformation analysis.

Figure 69 pertains to the Von Mises analysis, in which the direction of the force determined and used for the simulation is marked with an orange arrow. The maximum stress found was 115.6 MPa, in a small portion of the component, signalled in the figure. This stress translates into a safety coefficient of 2. Yet, since this peak tension only occurs in a very small fraction of the component and, overall, the tension doesn't surpass 67.4 MPa, it was considered that the footrest metal plate will be able to safely perform its function, in terms of applied stress.

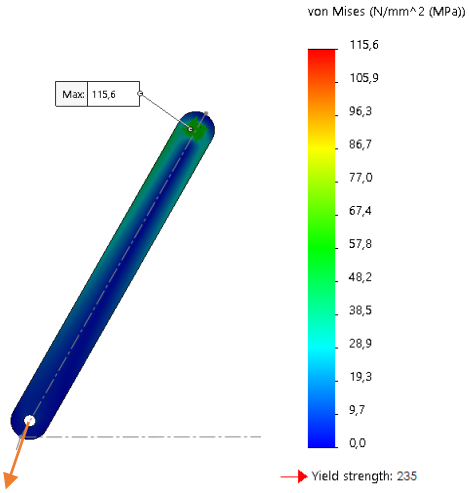


Figure 69 – *Von Mises analysis – footrest metal plate.*

For the deformation analysis, which is illustrated in **Figure 70**, the deformation tends to increase closer to the force's application point. Furthermore, the maximum deformation registered was 0.35 mm, which is within the values established as safe for the purposes of this project (below 1 mm).

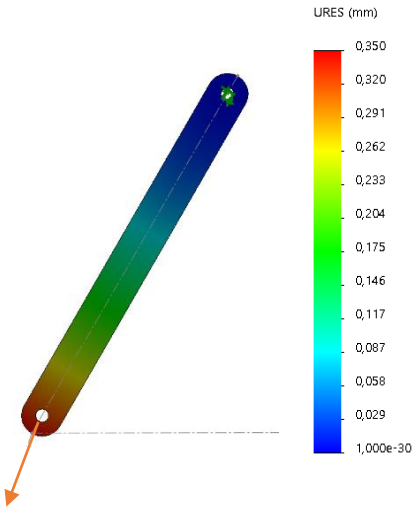


Figure 70 – *Deformation analysis – footrest metal plate.*

These simulations were important to understand how the loads applied to different components affect their mechanical resistance and, by understanding if some components will be able to withstand the load applied to them, it is possible to redesign them in the early stages of development. Thus, by changing some of the arch characteristics, it was possible to design a more robust component that will ensure the safety of the patient during transfers, without greatly affecting the initially outlined characteristics.

It should be noted that, for the production of the prototype, which will be detailed in the next chapter, these arch changes were not applied, since, because of time constraints, when these simulations were carried out, the prototype production was already underway.

8. CHAPTER VIII – Prototype manufacturing

In this chapter, the manufacturing processes relevant to this project, which are currently available at Orthos XXI, will be laid out, to introduce the production of the prototype built in the scope of this dissertation. For this matter, a detailed explanation of the different processes carried out will be given, followed by an analysis of its functioning.

8.1. Manufacturing

Considering that one of the main goals the device designed must meet is for it to be manufactured and assembled at Orthos XXI, it's important to understand the different manufacturing methods available in the facilities, as well as the company's established process of fabrication for a new device. The first step is to produce the components that comprise the device. Some are off-the-shelf and are available in stock to be used, such as screws, washers, and electrical parts, in particular, batteries, actuators, and so on. After each component is completed individually, the next step is to weld the ones that require so and then paint them. The final step is to assemble all components to achieve the finished device. Below, the available manufacturing processes available at Orthos XXI are presented, and a summary of the complete process of assembling a device is displayed.

8.1.1. Laser cutting

Laser cutting metal plates is one of the available resources at Orthos XXI. With this process, sheets of metal of different thicknesses and material can be cut with high precision and in large quantities, which is essential in large-scale productions, where production time must be reduced and variations minimised. Components are designed through the *SolidWorks* software and sent to the laser cutting department, in .dxf format, and then the machine operator only has to have an idea of the overall size of the component, as well as the material and thickness, to optimise the production process and reduce waste. The laser cutting machine will proceed to cut the metal plate desired, according to the paths established in the .dxf file.

When necessary, after the component is cut and separated from the original metal sheet, follows its bending. To perform this feature, a bending machine is used. For the bend to be well-executed, two aspects must be taken into account, namely, the bend's internal radius and the size of the flap that is to be bent. The greater the thickness of the metal plate, the greater the internal radius must be. Thus, there's a chart available at Orthos XXI in which the optimal internal radius for each metal plate thickness

is stated. The size of the flap is important because there is a minimum length so that the machine is able to bend the part, and it also depends on the plate's thickness.

8.1.2. Turnery

Another process available is the production of metal turnery parts. To produce this type of component, the CNC machine operator receives the *SolidWorks* drawing, in .x_t format, and the additional information to be provided is the material and overall dimensions, namely, length and diameter. By milling the material, it's possible to create features such as holes, undercuts, among others, according to the shape provided in the drawing, resulting in a component equal to the one drawn.

8.1.3. Tube manufacturing

At Orthos XXI, it's possible to manufacture tubes and rods of different sizes and materials. The tubes can be round, square, or rectangular, and the profile dimensions of the tube are standardised, in terms of diameter and thickness of the tube. Large beams are cut to obtain the desired length and then, two steps can be carried out when required: bending and or drilling the tube. To drill the tube, the operator must follow the measures provided in the 2D drawing but, when the tube is also bent, drilling must be the last step, to ensure the holes are positioned correctly. There are three machines available at Orthos XXI to bend the tubes, each one as a specific bending radius for each tube profile dimension. For this purpose, there's a chart that relates each machine to the appropriate bending radius, according to the profile dimension. Furthermore, so that the machine can bend the tube as expected, the following details must be provided as input to the machine: straight section length, angle of the bend, rotation of plane, and the internal radius of the bend.

Orthos XXI also uses an external company to laser cut tubes, which is used for tubes that have complex cuts that would be too difficult to make manually.

8.1.4. Plastic Injection Moulding

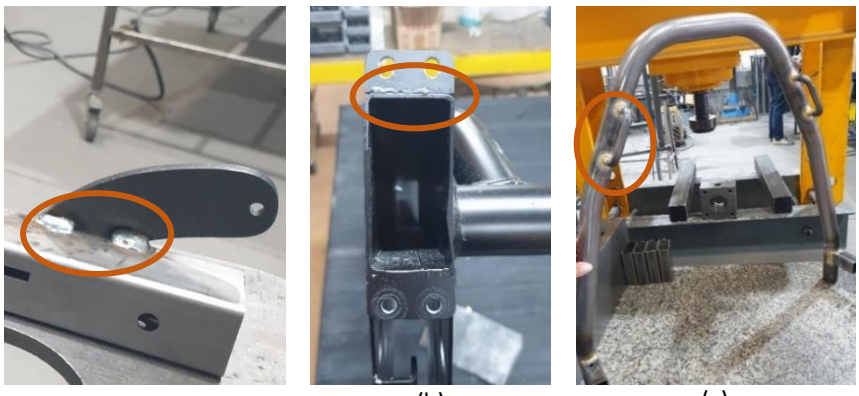
Another process available at Orthos XXI is plastic injection moulding. For this process to take place, a mould of the desired component is required. The mould is the negative of the component to be obtained, therefore, the first step is to design the component and then manufacture the matching mould. These moulds are usually metal, such as steel or aluminium.

In the plastic injection process, molten plastic material is injected into the mould with the shape desired and after the material cools and hardens, the result is a plastic component that is then incorporated into the final device.

8.1.5. Welding

Another relevant manufacturing process is welding. This process consists of joining parts by melting material, using a flame and additional material, to fill the gaps between the surfaces to be joined. For the operator to manually weld the components, it's necessary a 2D drawing that contains all the components to be weld, where to weld them, and the corresponding measurements to ensure that the final structure matches the intended. There are three types of welding available, MIG, most common for steel components, which is depicted in **Figure 71 a)**; TIG, for more detailed welding, usually used in stainless steel and aluminium, which is illustrated in **Figure 71 b)**; and oxyacetylene, for smaller components, which can be seen in the components welded in **Figure 71 c)**. Furthermore, at Orthos XXI it's possible to perform welding manually, more relevant for the case in question, as it is a prototype, and welding with a robot, which is used to weld components that are produced in large quantities. In the case of robot welding, welding templates are used to ensure low variability between components.

After cooling down the area that has been welded, the components joined behave as one. Then, spatters and other imperfections are removed, and the component is straightened to match the desired measurements, since, during manufacture and welding, the component can distort.



(a) (b) (c)

Figure 71 – *Different types of welding: (a) MIG; (b) TIG; (c) oxyacetylene.*

8.1.6. Painting

The final step before assembling the components is painting them. The painting should only be done when all the previous processes are completed, to prevent the paint from being damaged with further processing.

Following the manufacture of each component, there are always residues that latch to the said component, whether these are lubricants, metal shavings, among others, so each component must be cleaned before being painted, to avoid unwanted textures in the final product. Hence, the components are hung on a structure that guides them through different stations. Firstly, they go through a chemical cleaning phase, to remove oils and grease. Then, they're cleaned with water and undergo an antioxidant treatment. Only after the components are well dried does the actual painting process begin. Painting is done with a powder of the desired colour, which is sprayed over the components. They then undergo a cooking process, thus finishing the painting process.

8.2. Prototype production

First, it is important to understand that in a production setting, where components and devices are constantly being manufactured, either for stock or immediate sale, special attention should be paid to the internal organization of production. In this case, where only one device was being built, the production of components followed the schedule that was already defined by the company at the time, for better work efficiency. For example, for laser cutting, the components were incorporated in metal plates, of the same material and thickness, that were already scheduled to be cut. On the other hand, to paint the components, there is a rotating schedule for each colour that is used, to maximize the number of components painted, without having to constantly change the paint colour settings. In this way, the different processes that led to the final prototype are described below.

8.2.1. Component manufacture

The 2D technical drawings for every component were elaborated, which can be found in **Annex XI**, organized in laser-cut metal plates, tubes, turnery parts, and welding and assembly drawings, and sent to the sector responsible for their production.

Through the manufacturing process, it was realized that there was a component that, even though possible to produce, required significantly more production time than the rest due to its complexity, namely, the chassis tube that connects the front and rear wheels. Due to the angles of the curvatures, this component took more attempts and time to produce, which means that, in a future stage, it should be rethought to simplify its production.

Another component that raised a problem was the backrest structure tube, as illustrated in **Figure 29**, which, having sloths on the sides that overlap with the bends of the tube, since the tubes were laser cut and then bent, the sloths were deformed during the bending process, which disturbed its intended

purpose, which is for the backrest to be removed through these sloths. This problem had to be solved on the spot, and a new tube was made, where the sloths were cut manually after the tube was bent. Thus, this process implied a longer labour time which, ideally, should be avoided.

Lastly, for time-saving purposes, some of the tubes used for the footrest were standard tubes already used in another device of the company. This change resulted in the sliding tube being a few centimetres shorter than anticipated. The impact of this change will be addressed later on.

8.2.2. Welding

After all components were ready, the welding process took place, which took about 16 hours to be completed, since all the work had to be done by hand. Since this is the first prototype built for the device developed within the scope of this dissertation, it is expected that some details that were not detected in the 3D model would be detected in the construction of the prototype. Thus, during the welding process, before proceeding with this process, which is permanent, holes and measurements were confirmed so that the necessary adjustments could be made. If no problem was detected, the welding proceeded. In this process, the parts were positioned using clamps and spacers, and by dripping welding material, the parts were temporarily joined in the final position. After checking the dimensions and positioning, the final weld was made. **Figure 72** pertains to the positioning of the components, using clamps, for the chassis weldments.

Figure 72 – *Example of the positioning of components for welding.*

After permanent welding, any spatters resulting from welding were cleaned and, when necessary, the weld was deburred so as to present a smoother surface. This last situation became relevant, for example, in the seat structure, shown in **Figure 73**, where it was necessary to deburr the welds to prevent interference with other components.

Figure 73 – *Example of components after cleaning and deburring the weldment.*

Finally, it was necessary to ensure that the parts maintained the intended dimensions and alignment, **Figure 74 a)**, and if the components fitted where they were supposed to, **Figure 74 b)**, being necessary in some cases to straighten the components. After all the welding was complete, the components were sent for painting, where they were painted black.

(a) (b)

Figure 74 – *Example of dimension, alignment, and fitting verification: (a) dimension and alignment verification, (b) fitting verification.*

8.2.3. Prototype assembly

Subsequently, the prototype was assembled, which took about 12 hours. For the production of this prototype, some components were simplified or removed, to speed up the manufacturing process, since there were time constraints. Thus, both the headrest and the armrest were simplified, the first does not allow the adjustments described in Chapter VII, and the second does not have the built-in bushing to fit the index plunger. These components were selected for simplification as they do not have a significant impact on the operation of the device. On the other hand, it was not possible to build the knee support, which serves as support during the verticalization, since, although relevant to support the user, its absence did not prevent the operation of the device. Finally, both the actuators and the gas springs had to be replaced by existing models in stock at the company, since it was not possible to place an order

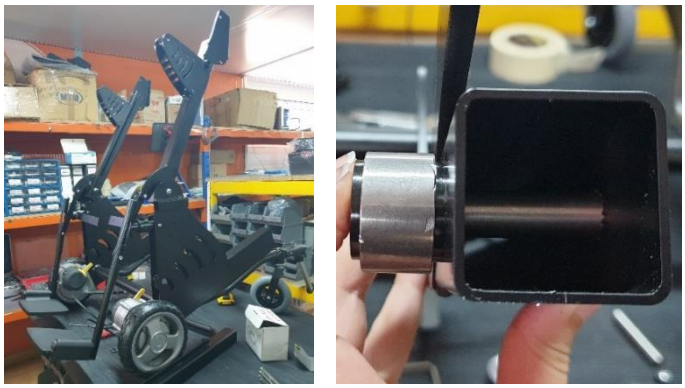
with the supplier, for the required components. This change had the greatest impact on the final model, as will be mentioned later.

Firstly, the chassis was assembled. Both the front-drive wheels and the rear wheels were placed in the respective place, as can be seen in **Figure 75 a)**. In the rear wheels' bushes, two bearings were applied, for the wheels to rotate 360°. Afterwards, the anti-tipper wheels were assembled. In this instance, during welding, it was concluded that their positioning could be changed, without great impact on production time, so that it would be in a more adequate and aesthetically pleasing position, relative to **Figure 46**. This change can be seen in **Figure 75 b)**, where the metal tube connecting the anti-tipper wheels to the structure is welded in the centre of the bushing instead of on the inside.

(a) (b)

Figure 75 – *Chassis assembly: (a) front drive wheels and rear wheels, (b) anti-tippers placement.*

Thereafter, the footrest mechanism was assembled, as well as the lateral seat structure, both depicted in **Figure 76 a)**. For the lateral seat structure, plastic washers should have been applied, as shown in **Figure 76 b)**, however, it was realized that the resulting free interior space would not allow the seat to slide smoothly. To solve this situation, the bushing that can be seen in the same figure should be narrower, yet, since it was no possible to change its size, this prototype did not encompass these washers



(a) (b)

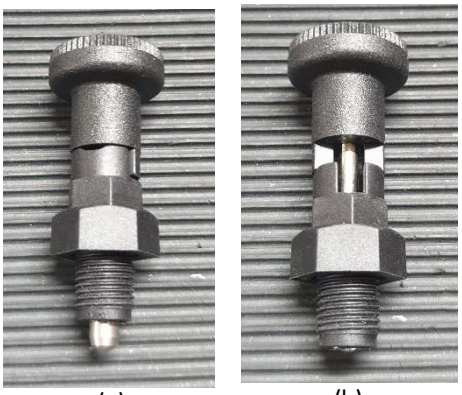
Figure 76 – *Lateral seat structure and footrests assembly: (a) assembly stage overview, (b) placement of plastic washers for smoother rotation.*

The following step was to assemble the upper components of the device, namely the upper structure, the armrest, headrest seat, and backrest, resulting in the stage presented in **Figure 77 a)**. The gas springs were attached at this point, and, as mentioned before, the gas springs used were different from the ones selected for this device. Even though the diameters were similar, the length while closed was 50 mm longer, which, in the end, affected the headrest positioning, since it was 50 mm higher than it was supposed to be, and the stroke was 260 mm, instead of the 200 mm intended. Additionally, the gas spring model available did not have the locking system, meaning that, it would not be able to raise the user since the user's weight would force the gas spring downwards, and it did not stay lowered, for the seating position, as can be seen in **Figure 77 a)**. To keep the upper structure down for the seating position, **Figure 77 b)**, cable ties were used.

(a) (b)

Figure 77 – *Difference in height of the upper structure: (a) with the gas springs released, (b) with the gas springs secured with cable ties.*

For the index plungers used in components such as the seat, backrest, and armrest, the ideal system is depicted in **Figure 78**, which is an index plunger, available at the company, that locks in the open position, **Figure 78 b)**, facilitating the removal of the seat and backrest, since the caregiver would have both hands free to pull them. Nonetheless, the index plunger presented wasn't long enough to be used in this device, and for that reason, another type of index plunger was used, which doesn't include this locking feature. In the concept design, only one index plunger was intended to be used with the seat, and another other with the backrest, however, during assembly, it was realized that one index plunger on each side, would keep the seat and the backrest more secure. This, however, causes greater difficulty to activate the index plungers without the locking feature.



(a) (b)

Figure 78 – *Index plunger: (a) released, (b) locked in the open position.*

Finally, the assembly of the actuators took place. As previously stated, the actuators used were different from those selected in Chapter VI, mainly because they weren't compact actuators. Nevertheless, it was possible to use actuators with similar stroke and length, which didn't gravely impact the prototype's functioning, with the biggest issue being the fact that the top of the actuators, as signalled in **Figure 79 a)**, took up some lateral space, as well as some of the interior space, which cannot be compromised, since the patient is to be transferred from the back. The tops of the actuators are in opposite directions as a result of obstruction that occurred because the device was not designed for this type of actuator, thus, the actuators had to be positioned in different ways. The fastening of the actuators to the device complied with what was established in the 3D model, except for the bottom connection of the seat actuators. As depicted in **Figure 79 b)**, the head of the bolt did not fit in the cuts of the metal plate, and because of that, the fastening was made through the outside of the metal plates.

(a) (b)

Figure 79 – *Actuator positioning: (a) actuator's top hindrance, (b) seat actuators bottom connection.*

As a finishing touch, tube covers were applied, and the final result of the assembly process described above is shown in **Figure 80**, with both positions for the arch represented, namely, stored, and ready to transfer, **Figure 80 a)** and **Figure 80 b)**, respectively.

(a) (b)

Figure 80 – *Final prototype: (a) with the arch stored, (b) with the arch mounted.*

8.3. Prototype and performance analysis

With the prototype completed, followed the analysis and comprehension of its functioning, to determine if the device followed the expected requirements, and to unravel any structural details that may have gone unnoticed in the 3D model. Additionally, some relevant measurements were verified, to determine if the information gathered from the 3D model did not suffer any alterations during the production process.

8.3.1. Structural sizing verification

The first dimensions to be assessed were the critical dimensions described in Chapter VI. Since the 3D model provided the information needed to verify these measurements, as described in **Table 16**, this step aimed to confirm whether the manufacturing process caused any significant change in these measures. Below is **Table 17** which pertains to the dimensions obtained from the prototype previously described.

Table 17 – *Overall prototype dimensions.*

Dimension	Value (mm)
Minimum seat height (from ground to underneath the seat)	430
Interior depth (clearance underneath the seat)	500
Interior width (clearance underneath the seat)	400
Maximum rear components height (wheels and batteries)	345
Overall width	700

As can be verified through **Table 17**, generally, the collected measurements, fall in line with those obtained through the 3D model, except for the minimum seat height, which is 56 mm above the expected. Through visual analysis of the device, it was noticed that the seat was colliding with a component of the chassis, marked in **Figure 81**. This detail was not detected in the 3D design, which led to this problem arising in the prototype production. However, this situation can be solved by cutting the metal plate where the seat collides, allowing it to go lower.

Figure 81 – *Seat minimum height.*

Thereafter, another feature was analysed, namely, the displacement of the footrest, from seated to verticalized. As can be seen in **Figure 82**, the height was measured at the lowest point of the footrest. In the seated position, **Figure 82 a)**, the height was 140 mm, and in the verticalized position**, Figure 82 b)**, the height was 65 mm. This difference translates into a 75 mm displacement. As previously mentioned, since the sliding tube used for the footrest was shorter than intended, the measurements taken do not coincide with that of the 3D model, nonetheless, the displacement obtained is practically the same, which means that the mechanism works as foreseen in the 3D model.

(a) (b)

Figure 82 – *Footrest height: (a) seated, (b) verticalized.*

Finally, the total length of the device was confirmed, which resulted in 1040 mm and 900 mm, with and without the anti-tippers, respectively, as these may prove unnecessary in a domestic environment and, therefore, removed; as well as the seat height, in the seated position, which was 505 mm.

8.3.2. Structural analysis

One of the most significant aspects of the construction of a prototype is that, during its assembly, details emerge that are often undetectable in the 3D computer model, or that are more easily verified in practical terms. Thus, some structural aspects were noted during the device assembly, which can, at a later stage, be reconsidered and improved, to achieve the final model.

The first matter that surfaced was the chassis structure. As can be seen in **Figure 83 a)**, the lateral metal plate has equal thickness throughout, namely, 2mm. However, since the weight is applied at the point marked in **Figure 83 a)**, and the metal plate is relatively thin, the idea arose to increase its thickness at the top (above the horizontal weld), by welding a thicker metal plate, namely, 4 mm thick, to make it more resistant, preventing bending. As it is possible to verify in **Figure 83 b)**, there is enough space for this alteration, being only necessary to reduce the thickness of the bushing so that this alteration does not impact the rest of the structure.

(a) (b)

Figure 83 – *Chassis' lateral metal plate: (a) side view, (b) front view.*

Concerning the removable backrest, it can be noted through the scratches shown in **Figure 84**, that the backrest needs more clearance to slide freely through the structure, without scratching the paint. Even though the 3D model took into account the leeway necessary for the backrest to slide, it should be increased, taking into account the thickness of the paint, which, although reduced, takes away some of the intended clearance.

Figure 84 – *Structure scratches due to backrest's lack of clearance.*

Regarding the removable seat, as can be seen through the displacement signalled in **Figure 85**, with **Figure 85 a)** pertaining to the seat without weight applied, and **Figure 85 b)** to the seat with some weight applied, when the user is seated, the seat gives way under the weight and moves inwards. This issue can be addressed in a future stage, however, after testing the chair with a 75 kg user, it was possible to realize that the weight applied on the seat will not be enough for this displacement to have negative repercussions. This is due to the fact that the side metal plates that support the seat are long enough so that, even with the displacement, they remain supported on the structure.

(a) (b)

Figure 85 – *Removable seat: (a) without weight applied, (b) with weight applied.*

Finally, about the arch mechanism, some aspects emerged that should be further improved, one of them being more relevant than the others, since it may compromise the user's safety.

The one aspect to consider is the storage of the arch. As can be seen in **Figure 86 a)**, there is no clearance between the handle for pushing the wheelchair and the arch, however, since the handle is slightly malleable, it allows the arch to be removed and fitted, even without clearance. This condition makes the process more time-consuming and exhaustive, and therefore it should be rethought, either by moving the handle to the sides, or by changing the angles of the curvatures of the arch.

Another factor to bear in mind is that the handle for activating the gas springs, depicted in **Figure 86 b)**, is not very comfortable, and therefore not easy to use. In practical terms, when activating the gas spring, the upper tube of the frame is always used as a support to reach the handle. A solution to this problem could be, for example, to use a foot pedal to activate the gas springs instead of the handles.

(a) (b)

Figure 86 – *Structural considerations: (a) lack of clearance for arch storage, (b) gas spring handle.*

8.3.3. Functioning analysis

After completing the assembly and structural analysis of the device, its performance was assessed, particularly, the different movements and mechanisms incorporated for it to function as a comfortable and complete wheelchair, as well as a device for user transfers.

First, the movements of the device were tested, specifically, user verticalization, user lowering, and user reclining. Although the actuators used were not the ones foreseen in the 3D model, their closed length and stroke were similar to the intended ones, thus, not constituting a limiting factor in this analysis. For the tests performed, a control box was used, with a controller that enabled the activation of each pair of actuators individually, namely, either the pair of seat actuators or the pair of back actuators was enabled at each instance. As for the drive wheel mechanism, it was not possible to connect batteries to the device, since they were not available, and, therefore, the movement of the wheelchair occurred manually.

Regarding verticalization, depicted in **Figure 87 a)**, it was possible to obtain an angle between the seat and the horizontal plane (floor) of 58°. Through visual analysis it was realized that the limitation of the angle, which should reach 65°, was due to the actuator bumping the perpendicular metal plate welded between the two lateral metal plates of the chassis. This situation also occurred when lowering the patient, **Figure 87 b)**, limiting the minimum seat height to 430 mm, instead of the intended 374 mm. Although this situation went unnoticed in the 3D model, the solution is pretty straightforward. In spite of the fact that it was no possible to fix this situation during the assembly of the device, by cutting a section of this metal plate, both the seat and the actuator can perform the expected movements, without bumping in

the metal plate. Lastly, for the recline feature, the maximum angle obtained between the seat and the backrest, represented in **Figure 87 c)**, was 152°, a very close value to the 155° obtain through the 3D model, proving this feature successful.

(a) (b) (c)

Figure 87 – *Movement analysis: (a) verticalize, (b) lower, (c) recline.*

For the user transfer feature of the device, since the gas springs used were significantly different from the ones used in the design of the device, not only in terms of size, being 50 mm longer and with a stroke about 10 mm longer, but also in terms of locking system, which in this case is non-existent, and load capacity, which was lower than required, the analysis of this function was undermined as it was not possible to establish the intended requirements for this operation.

Nonetheless, as much as possible of this feature was tested, namely the removal of the seat and backrest, as it is displayed in **Figure 88 a)**. As previously mentioned, the backrest needs more clearance for a smoother removal, regarding the seat, the index plungers used made the process a bit difficult, since, being positioned one on each side of the structure, it becomes difficult to activate them simultaneously and remove the seat. In **Figure 88 b)**, it is possible to verify the elevation of the arch, and the appearance of the device in this circumstance. The gas springs used allowed a height difference of 260 mm between the lowest and highest position of the arch. However, since the gas spring was not capable of supporting the weight of the user, so much so that when a user was placed, the arch came down, it was not possible to verify the impact that this increase in the arch's height would have on the patient.

(a) (b)

Figure 88 – *Device with seat and backrest removed: (a) with arch lowered, (b) with arch raised.*

Another aspect of the transfer feature is marked in **Figure 89 b)**, where a 75 kg user tested the device, to obtain an approximation of its functioning, even if not for the maximum mass considered, 95 kg. The arch should be completely supported on the upper structure, to ensure the safety of its operation, however, in the tests performed, it was noticed that the arch tended to lift at the back, as a result of the user's weight. Although the connecting tubes of the arch were long enough, so that, even lifting, they remained fitted to the structure, this situation is alarming, especially with the increase in the user's mass. Thus, several factors play into this situation, which can be altered. As shown in the simulations in Chapter VII, the hoops of the arch can be shifted backwards, for better weight distribution; a pin can be placed that fits through the structure and the arch's connecting tubes, locking the arch, and holding it in place; and increasing the length of the arch's connecting tubes, which, subsequently, will increase their support surface.

(a) (b)

Figure 89 – *Testing arch support with a user of 75 kg: (a) front view, (b) rear view.*

Finally, the armrests and footrests were analysed. As can be seen in **Figure 90 a)**, the armrest rotates outwards, as expected, however, since there is a substantial portion of the armrest at the rear of the pivot point, the armrest hits the wheelchair's structure, preventing it from rotating further. This armrest

was used for the prototype demonstration, however, a shorter armrest should be used, to allow more rotation. The safeguards are also easily removed, providing the free lateral space intended. Regarding the elevation of the footrest, demonstrated in **Figure 90 b)**, and the rotation of the calf support, demonstrated in **Figure 90 c)**, both features were executed as expected.

(a) (b) (c)

Figure 90 – *Other features: (a) armrest rotation, (b) footrest elevation, (c) calf support rotation.*

8.4. Discussion of results

With the prototype assembly, it was possible to detect several details that went unnoticed in the 3D model, however, due to time and component availability constraints, several aspects were not executed as intended, such as, for example, the knee support and the adjustable feature of the headrest.

Concerning the aspects that became apparent with the prototype production and testing, it can be highlighted the change in the position of the anti-tipper wheels, the need for reinforcement in the chassis' lateral metal plates, and the fact that the perpendicular metal plate that connects the double metal plates of the chassis, poses an obstacle for the actuator during verticalization, and the seat while lowering, preventing these two features to be performed to completion. The last two situations could be easily solved, the first, by welding a thicker metal plate where the seat is connected, and the second by changing the shape of the perpendicular metal plate. The method for activating the gas springs also proved to be inconvenient and changing to pedals should be considered.

The most relevant structural aspect that was detected in the testing stage is the fact that the arch moves out of its position when supporting the user. This issue is undoubtedly the most concerning since it puts the user at imminent risk, therefore, it should be the first aspect to be addressed. Some suggestions are the use of a pin to lock this component, and changing the position of the hoops, as mentioned during the simulation analysis. Still regarding the arch, the lack of clearance for storage should also be addressed, either by altering the arch structure, or the handles position.

Regarding the component limitations, the gas springs used had the most negative impact, not only in terms of structure, as the top of the wheelchair, including the headrest, was 50 mm higher than expected, due to the gas springs' length; but also, because they did not allow locking and could not withstand the user weight. These circumstances rendered it impossible to fully test the user transfer feature. As for the actuators used, the fact that they were not compact actuators, affected the device's overall width and jeopardized the free space on the back of the wheelchair, needed for transferring the user. Apart from that, the actuators used allowed to test the functionalities of the device, without great impact. It should be noted that the control system described in Chapter VII was not applied, since the components, such as the batteries, were not available. The control of the actuators was done through a control box, that allowed each pair of actuators to be moved one at a time.

Concerning the features that were performed manually, namely, the seat and backrest removable; the armrest rotation; the footrest raise; and the calf support rotation; all were accomplished, although there are still some adjustments to be made, to consider them finalized, such as, for example, giving more clearance for the backrest to slide smother, changing the index plungers used in the seat, and changing the armrest used.

All the considerations mentioned in this analysis should be applied to the device, in the next development stage, so that, with these improvements, it is possible to get closer to a final model.

Finally, taking into account that this concept should still be tested with CP patients and their caregivers, to understand if it meets their needs and expectations, it should also be noted that this device may prove useful for patients with other types of impairments, always considering the assistance of a caregiver, since there is no limiting factor for this device to be only used with CP patients. Further tests and research should be conducted to understand the suitability of this device for patients with different motor abilities.

9. Chapter IX - Conclusions and future prospects

In this chapter, the overall conclusions of this project will be presented, as well as the future prospects, which pertain to the aspects that weren't able to be achieved or could use further development in the future.

9.1. Conclusions

The focus of this dissertation was to improve and adapt the HomeHoist device, the outcome of a European project, in which Orthos XXI was a partner company. With the guidance of the company's professionals, some concerns were identified in the original prototype, which refers to the HomeHoist project, and from that, the purposes of this dissertation were defined. After several meetings with the company, it was established that, even though the result should be the same, transferring CP patients between surfaces, the design of the device should be significantly different, for the production of this device to meet the company's standard production, and that a verticalization feature should be added to differentiate the final product, making it more appealing to the market.

Then, followed the understanding of the needs of CP patients and caregivers. One chapter was dedicated to the research conducted on this disorder, in which the different types of CP were identified, as well as the requirements for transferring and handling patients with different degrees of severity. It was also ascertained the need for this kind of device, because of the physical and psychological burden of the caregivers, and the increasing number of CP patients that reach adulthood.

Afterwards, a deeper analysis of the HomeHoist device was undertaken. By means of the documentation available at Orthos XXI, it was possible to understand the process of development that led to the final device. Each function was analysed in more detail, in terms of which components were involved and how. Since there wasn't a 3D model available of the original prototype, one was built using the *SolidWorks* software, to substantiate the information gathered. The development of the 3D model helped to identify what were the most relevant aspects to be addressed, such as, the incorporation of the raise legs feature, which wasn't accomplished in the original project; change the actuator positioning to free the lateral space of the user; add the verticalization feature; alter the structure to metal plates and tubes, to better fit the company´s production; divide the seat and backrest; and avoid the use of the arch to lift the patient.

Thereafter, these aspects were translated into goals, which were established in a goal tree, and then the functions the new device should have to encompass to meet said goals were determined.

Different solutions were brainstormed with the company, to determine which was the best approach for the purposes of this dissertation. To organize these solutions, a morphological diagram was created, from which four concepts were established, one being the original HomeHoist prototype. With the weighted goals method, it was possible to choose the concept that better fulfilled the goals intended.

With the concept selected, followed its improvement. For this matter, a deeper examination of the structural sizing restrictions was pursued, regarding user anthropometric dimensions, and the dimensions of the transfer surfaces, namely beds and toilets. A study of the verticalization feature in wheelchairs was examined, to understand how to incorporate it in this device, from which the placement of the pivots and the footrest mechanism were established. The selection and positioning of mechanical components, in particular, the actuators, gas springs, and batteries, was a fundamental step to ensure the functioning of the device as intended. This process also brought to light some limitations, in terms of the time that the verticalization and reclination would take, which was determined by the type of actuator selected, however, with the possibilities offered by the supplier, the type of actuator selected was the best to achieve the dimensions and functions required; and the fact that the batteries used would limit the number of daily transfers permitted. The last step was to determine the materials in which the device should be manufacture, with most of the components being metallic, the material chosen was S235JR steel. The mass of the components that were to be carried by the caregiver, namely the arch, seat, and backrest, was determined, to ensure they wouldn't be too heavy, which would burden the caregiver, with the maximum value of 2.5 kg, for the arch, which is a reasonable mass for the caregiver to carry for short periods.

Afterwards, with all this information gathered, followed the completion of the 3D model of the resulting device of the dissertation. With the model, it was possible to ascertain the device's functioning. Following the explanation of the design of the most relevant components, was the detailing of the functioning of the device. Since the electric wheelchair function was sustained by the batteries and front drive wheels, the functions that were verified with the 3D model were the verticalization, which allowed an angle of 65° between the seat and horizontal plane, within 42 seconds, limited by the recline function, which allowed for a 155° angle between the seat and backrest, within 33 seconds; the lower function, which permitted a 374 mm height from the ground to the user, with the seat removed; and the transfer function, which still relied on the arch. Yet, the raise legs feature presented a shortcoming, which was that the footrest should be able to elongate further, for the legs to be fully stretched. This limitation was because the mechanism of the verticalization cannot allow the footrest to grow more, otherwise, they

would hit the floor. Then, an electric system was proposed, using the solutions already available at the company. With the model fully defined, the simulation of two critical components was carried out.

The prototype production was key to understand how the device should be assembled, and how some components could be reformulated, for better performance. Some concerns were raised during this stage that can be easily solved and would, otherwise, pass unnoticed in the 3D model, proving the usefulness of building a prototype to improve the design of the device. Due to time constraints, it was not possible to incorporate the actuators selected in the prototype, nor the gas springs, however, it was still possible to test the features that relied on the actuators, without great impact, but the same can not be said about the gas springs. Their size altered the position of the headrest, and since they did not have a locking feature, and had reduced force capacity, it was not possible to fully test the transfer feature. Overall, the prototype fulfilled the expectations foreseen through the 3D model, considering the alteration of the metal plate that limits the full verticalization and lower functions.

Ultimately, although there are still some features that can be improved, and it was not possible to deviate from the arch as the main component for the transfer of patients, it can be considered that the overall device was within the expectations for this dissertation, and fulfilled the main goal, which was to adapt the device for production at Orthos XXI, incorporating the verticalization feature, which will grant the device added comfort for everyday use.

9.2. Future prospects

Even though this dissertation consisted in reformulating and improving the HomeHoist device, since the final result was a device significantly different, not only in terms of design but also because of the new features added, there is still some work to be done, to develop a final device, ready to be marketed. Hence, to enhance this device, some aspects could be further developed, namely, following the child's growth, similar to the wheelchair presented in the market research; increase the verticalization angle, through some structural alterations; for the user to move around while verticalized, add an extra pair of wheels at the front to stabilize the device; and rethink the raise legs function, for the user to be able to straighten the legs while the footrests are up.

Because of time constraints, it was not possible to create a prototype that fully enclosed the specifications designed in the scope of this dissertation. It will be necessary to incorporate the intended actuators to assert the correct functioning of the device, as well as the knee support, for verticalization. Nonetheless, the prototype assembly carried out, raised awareness in various aspects that should be addressed in a future stage, mainly, the arch steadiness while supporting the user, the metal plate that

poses as an obstacle for the verticalization and lower features, the lack of clearance for the arch storage, and the reinforcement of the lateral metal plates of the chassis.

The electric system proposed must be implemented and tested to ensure it works as intended or if other approaches will have to be pursued.

The risk analysis and mechanical tests will be a fundamental step to ensure this product is safe for use and follows the company's expectations, as well as the legal requirements for commercialization.

One other aspect that will benefit the project, is to determine if this device could be used in patients with pathologies other than CP since it would broaden the marketed audience. Because of the arch, and the fact that the sling must be attached to it to proceed with the transfer, a patient cannot use this device alone to perform transfers, meaning that the help of a caregiver should always be considered.

REFERENCES

1. DANIEL, Virella, TERESA, Folha, MARIA DA GRAÇA, Andrada, CADETE, Ana, GOUVEIA, Rosa, GAIA, Teresa, ALVARELHÃO, Joaquim and CALADO, Eulália. *Paralisia Cerebral em Portugal no século XXI – Indicadores Regionais Crianças Nascidas entre 2001 e 2010, Registos de 2006 a 2015*. 2018. ISBN 978-989-98285-6-8.

2. CDC (CENTERS OF DISEASE CONTROL AND PREVENTION). What is Cerebral Palsy? [online]. 2019. [Accessed 25 November 2019]. Available from: https://www.cdc.gov/ncbddd/cp/facts.html

3. EUROPEAN PLATFORM ON RARE DISEASE REGISTRATION. CP definition | EU RD Platform. [online]. 2020. [Accessed 19 August 2020]. Available from: https://eu-rd-platform.jrc.ec.europa.eu/scpe/data-collection/cp-definition_en

4. BROOKS, Jordan C., STRAUSS, David J., SHAVELLE, Robert M., TRAN, Linh M., ROSENBLOOM, Lewis and WU, Yvonne W. Recent trends in cerebral palsy survival. Part II: Individual survival prognosis. *Developmental Medicine and Child Neurology*. 2014. Vol. 56, no. 11, p. 1065–1071. DOI 10.1111/dmcn.12519.

5. HAFSTRÖM, Maria, KÄLLÉN, Karin, SERENIUS, Fredrik, MARŠÁL, Karel, REHN, Eva, DRAKE, Helen, ÅDÉN, Ulrika, FAROOQI, Aijaz, THORNGREN-JERNECK, Kristina and STRÖMBERG, Bo. Cerebral palsy in extremely preterm infants. *Pediatrics* [online]. 1 January 2018. Vol. 141, no. 1. [Accessed 19 August 2020]. DOI 10.1542/peds.2017-1433. Available from: www.aappublications.org/news

6. EUROPEAN PLATFORM ON RARE DISEASE REGISTRATION. CP subtypes | EU RD Platform. [online]. 2020. [Accessed 21 August 2020]. Available from: https://eu-rd-platform.jrc.ec.europa.eu/scpe/data-collection/cp-subtypes_en

7. COOPER, Rory Alan, BECKSTROM, David, CURATOLO, Raymond A ., GRINDLE, Garrett and KOVACSICS, Richard. Systems and methods for powered wheelchair personal transfer. US10322048B2. 2019. United States.

8. EUROPEAN PLATFORM ON RARE DISEASE REGISTRATION. About the SCPE Network | EU RD Platform. [online]. 2020. [Accessed 23 August 2020]. Available from: https://eu-rd-platform.jrc.ec.europa.eu/scpe/scpe-network/about-scpe-network_en

9. ARNAUD, Catherine, JULSEN HOLLUNG, Sandra and HIMMELMANN, Kate. Surveillance of cerebral palsy in Europe (SCPE), scientific report 1998-2018. . 2019.

10. BLAIR, Eve, CANS, Christine and SELLIER, Elodier. Epidemiology of the cerebral palsies. *Cerebral Palsy: A Multidisciplinary Approach, Third Edition*. 2018. P. 19–28. DOI 10.1007/978-3-319-67858-0_3.

11. GRINDLE, Garrett G., WANG, Hongwu, JEANNIS, Hervens, TEODORSKI, Emily and COOPER, Rory A. Design and user evaluation of a wheelchair mounted robotic assisted transfer device. *BioMed Research International*. 2015. Vol. 2015. DOI 10.1155/2015/198476.

12. THEIS, Jennifer L. and FINKELSTEIN, Marsha J. Long-Term effects of safe patient handling

program on staff injuries. *Rehabilitation Nursing*. 2014. Vol. 39, no. 1, p. 26–35. DOI 10.1002/rnj.108.

13. ORTHOS XXI. Historia | orthosxxi. [online]. 2020. [Accessed 24 August 2020]. Available from: http://www.orthosxxi.com/empresa/historia

14. HOLLUNG, Sandra Julsen, VIK, Torstein, LYDERSEN, Stian, BAKKEN, Inger Johanne and ANDERSEN, Guro L. Decreasing prevalence and severity of cerebral palsy in Norway among children born 1999 to 2010 concomitant with improvements in perinatal health. *European Journal of Paediatric Neurology*. 1 September 2018. Vol. 22, no. 5, p. 814–821. DOI 10.1016/j.ejpn.2018.05.001.

15. MILLER, Freeman and BACHRACH, Steven J. Cerebral palsy: A complete guide for caregiving. In : *Cerebral palsy: A complete guide for caregiving*. 3. Baltimore, US : The Johns Hopkins University Press, 2008. p. 1–294. ISBN 0801889405.

16. ASSOCIAÇÃO PORTUGUESA DE PARALISIA CEREBRAL (APPC). Apifarma/ Associações de Doentes | Notas de uma parceria. .

17. GRIMNES, Sverre and MARTINSEN, Ørjan G. *Selected Applications*. 2015. ISBN 9780124114708.

18. Types of Cerebral Palsy. *Cerebral Palsy Guide* [online]. 2016. [Accessed 25 November 2019]. Available from: https://www.cerebralpalsyguide.com/cerebral-palsy/types/

19. WESTBOM, Lena, BERGSTRAND, Linda, WAGNER, Philippe and NORDMARK, Eva. Survival at 19 years of age in a total population of children and young people with cerebral palsy. *Developmental Medicine and Child Neurology*. 2011. Vol. 53, no. 9, p. 808–814. DOI 10.1111/j.1469-8749.2011.04027.x.

20. EUROPEAN PLATFORM ON RARE DISEASE REGISTRATION. Reference documents | EU RD Platform. [online]. 2020. [Accessed 20 August 2020]. Available from: https://eu-rd-platform.jrc.ec.europa.eu/scpe/data-collection/reference-documents_en

21. TARSUSLU, Tülay and LIVANELIOGLU, Ayşe. Relationship between quality of life and functional status of young adults and adults with cerebral palsy. *Disability and Rehabilitation*. 2010. Vol. 32, no. 20, p. 1658–1665. DOI 10.3109/09638281003649904.

22. RICHARDS, Carol L. and MALOUIN, Francine. *Cerebral palsy An Information Guide for Parents and Families* [online]. 2013. ISBN 0958741654. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23622163%5Cnhttp://linkinghub.elsevier.com/retrieve/pii/B978044452891900018X

23. Gross Motor Function Classification System (GMFCS). *Cerebral Palsy Alliance Research Foundation* [online]. 2018. [Accessed 25 November 2019]. Available from: https://cparf.org/what-is-cerebral-palsy/severity-of-cerebral-palsy/gross-motor-function-classification-system-gmfcs/

24. INSTITUTO DE BIOMECÁNICA DE VALENCIA. Deliverable Report: D1.3 Product specification. . 2013. P. 1–21.

25. *Estatuto do Cuidador Informal*. 2019. www.dre.pt. Diário da República n.º 49/2020, Série I de 2020-03-10.

26. OGG, Mary J. Introduction to the Safe Patient Handling and Movement Series. *AORN Journal* [online]. 2011. Vol. 93, no. 3, p. 331–333. DOI 10.1016/j.aorn.2010.12.004. Available from: http://dx.doi.org/10.1016/j.aorn.2010.12.004

27. ADELMAN, Ronald D., TMANOVA, Lyubov L., DELGADO, Diana, DION, Sarah and LACHS, Mark S. Caregiver burden: A clinical review. *JAMA - Journal of the American Medical Association*. 2014. Vol. 311, no. 10, p. 1052–1059. DOI 10.1001/jama.2014.304.

28. INFARMED. *Elevadores de transferência Birdie - gancho de suspensão*. 2014.

29. INFARMED. *Ganchos de ligação de gruas para transferência de doentes*. 2006.

30. INFARMED. *Gruas eléctricas para transferência de doentes*. 2005.

31. INFARMED. *Gruas e assentos para transferência de doentes*. 2007.

32. XO-202 Stand-Up Wheelchair - Power Wheelchair - Powerchair. [online]. [Accessed 15 September 2020]. Available from: https://www.karmanhealthcare.com/product/xo-202/

33. Mobilidade. *Catálogo Orthos XXI* [online]. [Accessed 26 September 2019]. Available from: http://www.orthosxxi.com/Imgs/pages/page_1/1_ORTHOS_Mobilidade_PT.pdf

34. Cadeira de Rodas Elétrica Oceania Vario Orthos XXI. *Loja Ortopédica* [online]. 2019. [Accessed 29 December 2019]. Available from: https://lojaortopedica.pt/pt/cadeira-de-rodas-oceania-vario-orthos-xxi?category_rewrite=cadeira-de-rodas-oceania-vario-orthos-xxi

35. KM-CP33 Customized Wheelchair for Cerebral Palsy Children. *Karma Medical* [online]. 2018. [Accessed 24 September 2019]. Available from: https://www.karmamedical.com/featured_item/km-cp33/

36. KARMA KM-CP33. *Bimedis* [online]. 2019. [Accessed 24 September 2019]. Available from: https://bimedis.com/a-item/wheelchair-karma-km-cp33-1007453

37. ZIPPIE GS Kids Folding or Rigid Frame Wheelchair. *Sunrise Medical* [online]. 2019. [Accessed 20 November 2019]. Available from: https://www.sunrisemedical.com/manual-wheelchairs/zippie/rigid-wheelchairs/gs#prettyPhoto

38. PIVATO, Emma and TYLER, Jonathan. Wheelchair with lift. US8622412B2. 2014. United States.

39. GANEL, Ran. Wheelchair. US9393167B2. 2016. United States.

40. WILSON, Harold Robert. Wheelchair Lift Transfer Device. US8910326B2. 2014. United States.

41. MORI, Yoshikazu, SAKAI, Norikatsu and KATSUMURA, Kaoru. Development of a wheelchair with a lifting function. *Advances in Mechanical Engineering*. 2012. Vol. 2, p. 489–492. DOI 10.1155/2012/803014.

42. BOSTELMAN, Roger and ALBUS, James. Robotic patient transfer and rehabilitation device for patient care facilities or the home. *Advanced Robotics*. 2012. Vol. 22, no. 12, p. 1287–1307. DOI 10.1163/156855308X344837.

43. WANG, Hongwu, TSAI, Chung Ying, JEANNIS, Hervens, CHUNG, Cheng Shiu, KELLEHER, Annmarie, GRINDLE, Garrett G. and COOPER, Rory A. Stability analysis of electrical powered wheelchair-mounted robotic-assisted transfer device. *Journal of Rehabilitation Research and Development*. 2014. Vol. 51, no. 5, p. 761–774. DOI 10.1682/JRRD.2013.11.0240.

44. FERREIRA DA SILVA, Luís. *Projecto de Dispositivos Médicos e Reabilitação - Capítulo 4. Clarificação e Estabelecimento dos Objectivos do Projecto*. Universidade do Minho, Escola de Engenharia, publicação interna., 2017.

45. FERREIRA DA SILVA, Luís. *Projecto de Dispositivos Médicos e Reabilitação - Capítulo 5. Estabelecimento da Estrutura de Funções do Produto* [online]. 2016. Available from: Universidade do Minho, Escola de Engenharia, publicação interna.

46. FERREIRA DA SILVA, Luís. *Projecto de Dispositivos Médicos e Reabilitação - Capítulo 6. Estabelecimento das Especificações do Produto* [online]. 2016. Available from: Universidade do Minho, Escola de Engenharia, publicação interna.

47. FERREIRA DA SILVA, Luís. *Projecto de Dispositivos Médicos e Reabilitação - Capítulo 7. Criação de Soluções Alternativas*. Universidade do Minho, Escola de Engenharia, publicação interna., 2016.

48. FERREIRA DA SILVA, Luís. *Projecto de Dispositivos Médicos e Reabilitação - Capítulo 8. Avaliação das Soluções Alternativas*. Universidade do Minho, Escola de Engenharia, publicação interna., 2016.

49. INSTITUTO DE BIOMECÁNICA DE VALENCIA. *Deliverable Report - D1.1 Person lifting specification with testing schedule*. 2013.

50. SANINDUSA. Louças sanitárias. [online]. 2015. [Accessed 15 November 2020]. Available from: https://www.sanindusa.pt/index.php?id=434

51. MINISTÉRIO DO TRABALHO E DA SOLIDARIEDADE SOCIAL. Decreto-Lei n.º163/2006 de 8 de agosto (Regime de acessibilidade e normas técnicas para melhoria da acessibilidade das pessoas com mobilidade condicionada). *Diário da República, 1.ª série* [online]. 2006. P. 5670–5689. Available from: https://dre.pt

52. LEROY MERLIN. Louça Sanitária. [online]. 2020. [Accessed 10 November 2020]. Available from: https://www.leroymerlin.pt/Produtos/Casa-de-banho/Louca-sanitaria

53. ROCA. Roca | catálogo. [online]. 2020. [Accessed 20 November 2020]. Available from: http://www.roca.pt/catalogo/procura/pesquisa-avancada/sanitas/sanitas/?filter

54. SANITANA. Louças sanitárias. [online]. 2020. [Accessed 15 November 2020]. Available from: https://www.sanitana.com/pt/loucassanitarias_beyou.php

55. IKEA. Colchões. [online]. 2021. [Accessed 20 March 2021]. Available from:

https://www.ikea.com/pt/pt/cat/colchoes-bm002/

56. JOM. Colchões e descanso. [online]. 2018. [Accessed 20 March 2021]. Available from: https://www.jom.pt/pt/descanso/colchoes_575-494.html

57. CONFORAMA. Colchões. [online]. [Accessed 20 March 2021]. Available from: https://www.conforama.pt/colchoes-e-bases/colchoes

58. PERSONO. Persono - Colchões personalizados. . 2020. P. 1.

59. ORTHOS XXI. Catálogo Geriatria. . 2019. P. 6–27.

60. INVACARE. Camas articuladas. [online]. 2021. [Accessed 10 January 2021]. Available from: https://www.invacare.pt/pt/camas-articuladas-e-poltronas/camas-articuladas

61. STIEGELMEYER. Care beds. [online]. [Accessed 20 March 2021]. Available from: https://www.stiegelmeyer.com/en/nursing-home/care-beds/

62. YANG, Yu Sheng, CHEN, Ming De, FANG, Wei Chien, CHANG, Jyh Jong and KUO, Chang Chih. Sliding and lower limb mechanics during sit-stand-sit transitions with a standing wheelchair. *BioMed Research International*. 2014. Vol. 2014. DOI 10.1155/2014/236486.

63. FLORES, Paulo. *Biomecânica das Articulações Humanas*. Guimarães : Universidade do Minho, Escola de Engenharia, publicação interna., 2006.

64. Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels. . 2004.

65. ORTHOS XXI. Catálogo Posicionamento. . 2019. P. 3.

66. CURTISS-WRIGHT. R-Net. [online]. 2017. [Accessed 15 May 2021]. Available from: https://www.cw-industrialgroup.com/Products/Mobility-Vehicle-Solutions/R-net%09

67. MELISSA STEHR. Different Types of Patient Hoists. *HLS Healthcare* [online]. 2018. [Accessed 20 November 2019]. Available from: https://www.hlshealthcare.com.au/everything-you-need-to-know-about-the-different-types-of-patient-hoists/

68. Hoyer® Presence. *Joerns Healthcare* [online]. 2020. [Accessed 21 November 2019]. Available from: https://www.joerns.com/product/2471/Hoyer®-Presence.aspx

69. Hoyer Presence Professional, 500 lb capacity patient lift. *Amica Medical Supply* [online]. 2019. [Accessed 21 November 2019]. Available from: https://www.amicamedicalsupply.com/hoyer-presence-professional.html

70. Track Systems. *Care & Independence* [online]. 2020. [Accessed 20 November 2019]. Available from: https://www.careandindependence.com/product/x-y-ceiling-track-hoist-systems/

71. A2B Ceiling Track Hoist | Astor-Bannerman. [online]. 2019. [Accessed 15 December 2019]. Available from: https://www.astorbannerman.co.uk/product/a2b-ceiling-track-hoist/

72. HUDSON, Lucie. How much does a ceiling track hoist cost? *Innova Care Concepts* [online]. 2018.

[Accessed 20 November 2019]. Available from: https://www.innovacareconcepts.com/en/blog/news/how-much-does-a-ceiling-track-hoist-cost/

73. Ceiling Hoist Tracking System. *Active Mobility Systems* [online]. 2020. [Accessed 22 November 2019]. Available from: https://www.activemobility.com.au/tracking-system/

74. Prism Easy Fit Gantry System. *Prism Medical UK* [online]. 2020. [Accessed 22 November 2019]. Available from: https://prismmedical.co.uk/product/prism-easy-fit-gantry-system-for-patient-transfer/

75. Prism CP200 Portable Track Hoist. *Prism Medical UK* [online]. 2020. [Accessed 23 November 2019]. Available from: https://prismmedical.co.uk/product/prism-cp200-portable-track-hoist-for-patient-transfers/

76. How to Choose the Proper Sling. *Handicare USA* [online]. 2018. [Accessed 13 December 2019]. Available from: https://www.handicareusa.com/blog/2018/08/24/how-to-choose-the-proper-sling/

77. Prism Universal Sling. *Prism Medical UK* [online]. 2020. [Accessed 11 December 2019]. Available from: https://prismmedical.co.uk/product/universal-sling/

78. Invacare Product Catalog - Invacare Full Body, Mesh Sling with Commode Opening, Medium. *Invacare* [online]. 2019. [Accessed 11 December 2019]. Available from: http://www.invacare.com/cgi-bin/imhqprd/inv_catalog/prod_cat_detail.jsp?s=0&prodID=R114&catOID=-536885362

79. Access Padded Sling - Oxford Slings. *Joerns Healthcare* [online]. 2019. [Accessed 11 December 2019]. Available from: https://joerns.co.uk/product/access-padded-sling/

80. Oxford Toileting Sling. *Complete Care Shop* [online]. 2020. [Accessed 10 December 2019]. Available from: https://www.completecareshop.co.uk/oxford-hoists-and-slings/oxford-toileting-slings/oxford-toileting-sling

81. SUREHANDS LIFT & CARE SYSTEMS. *SureHands ® Body Support* [online]. [no date]. [Accessed 10 December 2019]. Available from: www.surehands.com

82. SUREHANDS LIFT & CARE SYSTEMS. *SureHands Lift & Care Systems 1/1/09 Price List*. 2009.

83. STOCK VECTOR. Acromion Vectors. [online]. [Accessed 31 October 2020]. Available from: https://wdrfree.com/stock-vector/acromion

84. AZ, Chandler. Chiropractor Chandler AZ – Snapping Hip Syndrome. [online]. 2013. [Accessed 30 October 2020]. Available from: https://chandlerazchiropractor.wordpress.com/2013/02/22/chiropractor-chandler-az-snapping-hip-syndrome/amp/

85. TÖZEREN, Aydın. *Human Body Dynamics: Classical Mechanics and Human Movement*. New York : Springer, 200AD. ISBN 0387988017.

86. BANSBACH. EasyE-line. [online]. [Accessed 7 June 2021]. Available from: https://www.bansbach.com/index.php/en/products/easye-line/easye/easye-35

ANNEX I – INFARMED information notices

Below are brief explanations of some informative newsletters published by the Infarmed, concerning the use of hoisting devices.

- **Birdie transfer hoists, suspension hook, no. 197/CD/8.1.7. (05/09/2014)**

Invacare announced in 2012 that there is a need to replace and modify the suspension hooks, used to attach the spreader bar to the hoist, of all Birdie transfer hoists since these could suffer wear and tear. The measures taken were to replace the aluminium suspension hooks with steel, modify the plastic part where the hook is fixed and change the fixing position of the steel hooks on recent devices [28].

- **Hoist connection hooks for patient transfer, no. CA /139 (28/12/2006)**

An incident in which a patient fell during a hoist-assisted transfer occurred, which led to INFARMED being notified by the Canadian competent authority. Analysis of the incident revealed that the problem could be due to the design of the hoist connection hooks for the transfer of patients that allow the patient supports to be placed in the wrong way. If these are misplaced it could lead to the patient falling. Corrective action has been initiated but it is always recommended that the manufacturer's instructions for the correct use of these devices are followed [29].

- **Electric hoists for the transfer of patients, no. 059/CA (17-05-2005)**

INFARMED has been informed by the UK competent authority of the occurrence of unexpected breakdowns of electric hoist actuators for patient transfer, which can cause the hoist arm to fall abruptly and, in some cases, lead to serious injuries to patients. The investigation revealed that these breakdowns are mainly influenced by the number of cycles performed (a cycle consists of one patient transfer), rather than by the age of the actuator. There is also a risk of failure caused by incorrect handling, abnormal use, and lack of proper maintenance of the actuator support points. INFARMED's recommendation is to identify the hoists with electric actuators and evaluate the need for actuator replacement; if the number of cycles exceeds 100000 the actuator should be replaced; in all future inspections/maintenance, the need for electric actuator replacement should be evaluated [30].

- **Hoists and seats for the transfer of patients, no. 055/CD (24/04/2007)**

This informative newsletter no. 055/CD is due to patient falls that were reported following the misuse of this type of device. The misuse translates into low compatibility between the hoists and the

transfer seats; inadequate cleaning of the seats, which led to their premature wear; and incorrect maintenance of the hoists. INFARMED's recommendation to solve this problem is that the equipment in question should be used under the manufacturer's instructions; only compatible equipment should be used, that is also suitable for the patient; visual inspection of the equipment before use and removal from service if it is defective; wash seats in accordance with the manufacturer's instructions, and all equipment should be inspected by a competent technician at least every six months [31].

ANNEX II – Market research for hoists and slings

The current hoisting systems available on the market can be grouped into different categories, according to their mode of operation and structure, and for this research, mobile hoists, ceiling hoists, and static or gantry hoists were considered the most relevant. Mobile hoists have an arm with a spreader bar, to which the sling is attached and since the hoist is mobile and has wheels, the patient can be moved around to a different location, while secured to the hoist. Both ceiling and static hoists rely on an elevator that connects to the hoist and the sling, moving the patient up and down [67]. Below is an example of each type of hoist mentioned above.

- **Mobile hoist: Hoyer® Presence**

The Hoyer® Presence hoist, shown in **Figure 91**, is a mobile hoist developed by Joerns®. Its aluminium structure provides a low-mass device, about 40 kg, capable of carrying a user up to 227 kg in mass. This device has an electronic system that assists the caregiver in performing a safe and correct transfer. The upward or downward movement of the arm is accomplished by an actuator.

Moreover, the legs of this hoist can be used in a wide range of positions, since they can be opened or closed, or stay in any position in-between. The position of the legs can be chosen by the caregiver, according to what's most convenient in each situation. When the hoist legs are closed, the outer width of the device is 670 mm, on the other hand, when the legs are completely open, the inner space of the crane is 1019 mm. The legs have also been developed to fit under beds, stretchers, or other types of furniture to facilitate the transfer process. This hoist is on the market for a price of 5 848 €, which may vary with sellers [68, 69].

Figure 91 - *Hoyer® Presence hoist by Joerns® (adapted from* [68]*).*

- **Ceiling hoist**

When buying a transfer system that is mounted and fixed to the ceiling, as illustrated in **Figure 92**, one must consider the route the elevator is intended to take, as well as any curves or crossing points that may exist. These systems can be convened into different types, depending on their mode of operation. Therefore, there are linear structures, which allow straight movements; H or X-Y structures, which allow both horizontal and vertical movements; structures with curves; structures with rotation points, in which the lift can change direction, and finally linked structures, which consist of a combination of the different types of structures mentioned [70].

***Figure 92** - Ceiling hoist example (adapted from* [71]*).*

Hence, the price of the whole structure may vary depending on the path that is built. **Table 18** comprises a price list of different parts, from Active Mobility, used to build the most convenient structure for each case, along with the total cost of 2 types of structure, by Innova® Care Concepts, to provide a better understanding of the charges for this type of system. The latter may vary with the size and number of rooms in which the installation is made [72, 73].

***Table 18** - Ceiling hoist parts and prices.*

Type of part	Material	Price
Straight bar 2m	Aluminium	499€
90° curve	Aluminium	951€
Turntable mechanism	Aluminium/steel	2 563€
Linear structure	Aluminium	2 922€
X-Y structure	Aluminium	4 091 €
Additional cost per room	-	117€

- **Static Hoist: Easy Fit Gantry System**

Figure 93 shows the Easy Fit Gantry System, developed by Prism Medical UK. This hoist is fixed under pressure between the ceiling and the floor of a certain room, whose height must be at most 2,8 meters, without the need for structural changes in the room, and can later be dismantled and reused elsewhere. It's made out of aluminium, which provides low mass to the structure without affecting its resistance and is also easy to assemble. The maximum load mass it allows is 200 kg and the hoist dimensions are 2.1 to 3 m wide, 2 to 2.8 m in height, allowing the patient to move 1.9 to 2.8 m in a straight line. The mass of this device is 24 kg and the price listed for sale on the manufacturer's website is 1 112 € [74]. It should be kept in mind that this price does not include the lift, marked with a circle in **Figure 93**, as it must be bought separately and is for sale, by the same company, for an additional cost of 1 199 € [75].

Figure 93 *- Easy Fit Gantry System hoist by Prism Medical UK (adapted from* [74]*).*

- **Overall conclusions**

In **Table 19** is possible to view a summary of the information acquired from the hoist market research. Concerning the disadvantages of the hoisting systems presented above, two facts that stand out are the price of these devices, which is considerably high, even more, when installation in the house is required, and the impact on the appearance of the house. The advantages of using these devices vary considerately according to the type of hoist used, due to the mobility they allow and the space they occupy. Although these devices are usually easy to operate, there still can be risks and errors, that may lead to injuries, as was stated in the preceding chapter.

Table 19 – *Hoist market research overview.*

Product / Specifications	Mobile hoist	Ceiling hoist	Static hoist
			
Name	Hoyer® Presence	-	Easy Fit Gantry System
Company	Joerns®	Active Mobility/ Innova ® Care Concepts	Prism Medical UK
Material	Aluminium	Aluminium/steel	Aluminium
Dimensions	Exterior width: 670 mm; Interior width: 1019 mm; Mass: 40 kg	-	Width: 2103 a 2973 mm; Height: 2046 a 2750 mm; Mass: 24 kg
Mass capacity	227 kg	-	200 kg
Price	5 848€	2922 – 4 091€	1 112€
Advantages	Mobile; does not require installation in the house	Does not cause limitations in terms of space, since it is installed on the ceiling; practical and predictable use	Easy to assemble; non-permanent installation
Disadvantages	Expensive; impact on the appearance of the house; occupies useful space in the house	Expensive; requires permanent installation in the house; impact on the appearance of the house; motion constricted by installation	The lift is sold separately; only allows straight-line movements in a certain space; impact on the appearance of the house

As far as slings are concerned, they should be chosen according to the patient's abilities and the function they are intended to perform. Therefore, the characteristics to be taken into account are the shape, fabric, and size of the sling. The sling classification depends on these features [76]. Below, examples of different types of slings, that may be relevant to the project at hand, will be provided.

- **Universal Sling: Prism Universal Sling**

The sling shown in **Figure 94**, the Prism Universal Sling, is manufactured by Prism Medical UK and is U-shaped for universal use. The straps positioned on the sides ensure greater weight distribution and the leg sections are padded, both to ensure greater comfort. Because of the sling shape, the patient can use a toilet without adjustments to the sling. This product is available from child sizes to adult XL sizes and the material can be chosen by the buyer.

There are different types of material to choose from: polyester, padded material, and slipfit[9]. The polyester version is the most versatile because it allows the best balance between use for general transfers, for bathing, and for placing and removing it. Depending on these two characteristics, size and material, the price of the sling can range from 118 up to 310 €. Depending on the chosen size, the maximum mass of the sling wearer can reach 229 kg [77].

Figure 94 *- Universal Sling by Prism Medical UK (adapted from* [77]*).*

- **Full-body sling: Full Body Mesh Sling with Commode Opening**

Another type of sling on the market is the one represented in **Figure 95**. This one is developed by Invacare® and falls on the full-body category, having a commode aperture[10] at the bottom for toilet use, coupled with full head and neck support, as well as partial support under the

[9] Material that provides easier fitting and removing. Ideal for users with limited ability to move. Not ideal for bathing as it retains water.

[10] Opening on slings and seats to facilitate the use of a toilet or shower.

thighs. It can be used by amputees or patients with little head control. The fabric of this sling is polyester, which means it's washable and can be used in wet or dry environments. The maximum user mass is 204 kg and the price listed by the developer company is 158 € [78].

Figure 95 - *Full Body Mesh Sling with Commode Opening by Invacare® (adapted from* [78]*).*

- **Toileting Sling: Oxford Toileting Sling**

Figure 96 shows another example of a sling, which was specifically developed for sanitary purposes. It's manufactured by Joerns® and is completely padded to offer greater comfort, however, it's not appropriate for other purposes and only fits about 25 % of patients. As for the materials of this sling, it can be purchased in polyester, more suitable for use in wet environments; in a padded material, breathable and adjustable to the user, providing greater comfort; in nylon, a soft material, which generates little friction; and a disposable material for single use. The versions in non-deposable materials can be washed in the washing machine and have a maximum user mass of 227 kg. This sling is available for purchase with or without a headrest and it's priced around 116 € [79, 80].

Figure 96 - *Oxford Toileting Sling by Joerns® (adapted from* [79]*).*

- **Rigid system: SureHands® body support**

The SureHands® body support is a different kind of system that does not fit the sling category but has the same purpose, and for the sake of this research, it was considered relevant. The user should have sufficient control over the arms and hands, which makes it ideal for independent use in transfers to and from bed, toilet, bath, among others. This device allows an easier and faster placement than a common sling, since it's rigid and only needs the user to fit the arms in the appropriate place. Since both the bottom and the back of the user's body are free, the tasks of dressing and undressing, and using a toilet are simplified.

In addition to the arm support, which generates pressure on the torso and under the arms, this device also includes a patented leg support system, marked with B in **Figure 97**, which allows the distribution of the user's weight, making the transfer more comfortable. The frame is made of stainless steel, which makes it hygienic and easy to clean, and the supports to put under the arms, which are identified with A in **Figure 97**, are made of polyurethane. The user mass capacity of this system is 182 kg. There are several sizes of structure and leg supports available, which allows the user to find suitable support for his needs [81].

This device was developed by SureHands® which valued it at around 1 216 €, this price may vary with the size and finishing of the frame. The leg rest is an add-in and thus, can be purchased separately at around 173 € [82].

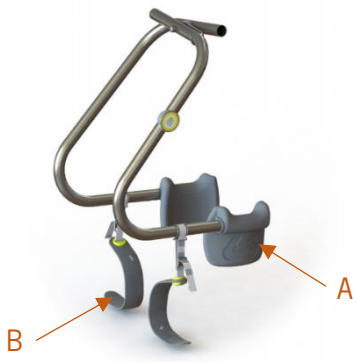


Figure 97 *-Body support by SureHands® (adapted from* [81]*).*

- **Overall conclusions**

For the transfer process of patients with low mobility, and with the aid of a transfer device, such as hoists, the use of a sling is always required. The market has a wide range of different options and solutions that can fit the particular needs of each patient. The price point is

considerably higher in the rigid body support, but it's not the direction intended for the final design of the HomeHoist device, as the sling used will be similar to the remaining products presented. Table 20 comprises the overall information for all the slings covered in this market research.

Table 20 - Sling market research overview.

Product / Specifications	Universal sling	Full body sling	Toileting sling	Rigid system
				
Name	Prism Universal Sling	Full Body Mesh Sling with Commode Opening	Oxford Toileting Sling	SureHands® body support
Company	Prism Medical UK	Invacare®	Joerns®	SureHands®
Material	Polyester; padded; slipfit	Polyester	Polyester; soft material; padded; nylon; disposable	Stainless steel and polyurethane
Mass capacity	229 kg	204 kg	227 kg	182 kg
Price	118 to 310 €	158 €	116€	1 216€ + 173 € (leg support)
Advantages	Can be used in every kind of transfer	Can be used by amputees and patients with reduced head control	Eases sanitary tasks, such as using a toilet and removing clothes	Multipurpose; easy and quick to place
Disadvantages	-	-	For sanitary purposes only; serves only 25% of patients	Expensive; leg rest sold separately; may be uncomfortable; requires user movement control

ANNEX III – Anthropometric measures

Below is **Table 21**, which pertains to the most relevant anthropometric measurements of wheelchair users, with some neurologic impairment. Both the minimum and maximum values recorded on the study referenced are presented.

Table 21 - *Anthropometric measures of wheelchair users with neurological impairments [49].*

Corresponding figure	Dimension	Relation to chair dimension	Minimum value (mm)	Maximum value (mm)
Figure 98 a)	Height, sitting	Back height	589	960
	Shoulders height, siting	Back height	433	682
	Shoulders width (deltoid to deltoid)	Back width	350	639
	Elbows width	Outer distance between right and left armrest	364	765
Figure 98 b)	Hip width, sitting	Seat width	184	469
	Popliteal to gluteus	Seat depth	317	672
Figure 98 c)	Elbow height, sitting	Height of armrest	133	297
	Free space for the thigh	Thickness of armrest	68	142
	Elbow to fist length	Length of armrest	411	532
Figure 98 d)	Height of the Popliteal fossa	Footrest height (distance from seat to footrest)	315	513
	Foot length	Footrest length	215	295
	Foot width	Footrest width	71	110
Figure 98 e)	Chest thickness, sitting	Maximum depth of the harness	180	340
	Chest width (armpit level)	Upper width of the harness support under armpit	308	422
	Chest width (nipples level)	Lower width of the harness	238	381
	Width of torso from abdomen to gluteus, sitting	Frontal displacement of harness	273	488

To clarify the description of the measurements present, each relates to a figure, referenced in **Table 21**, and the figures can be found below.

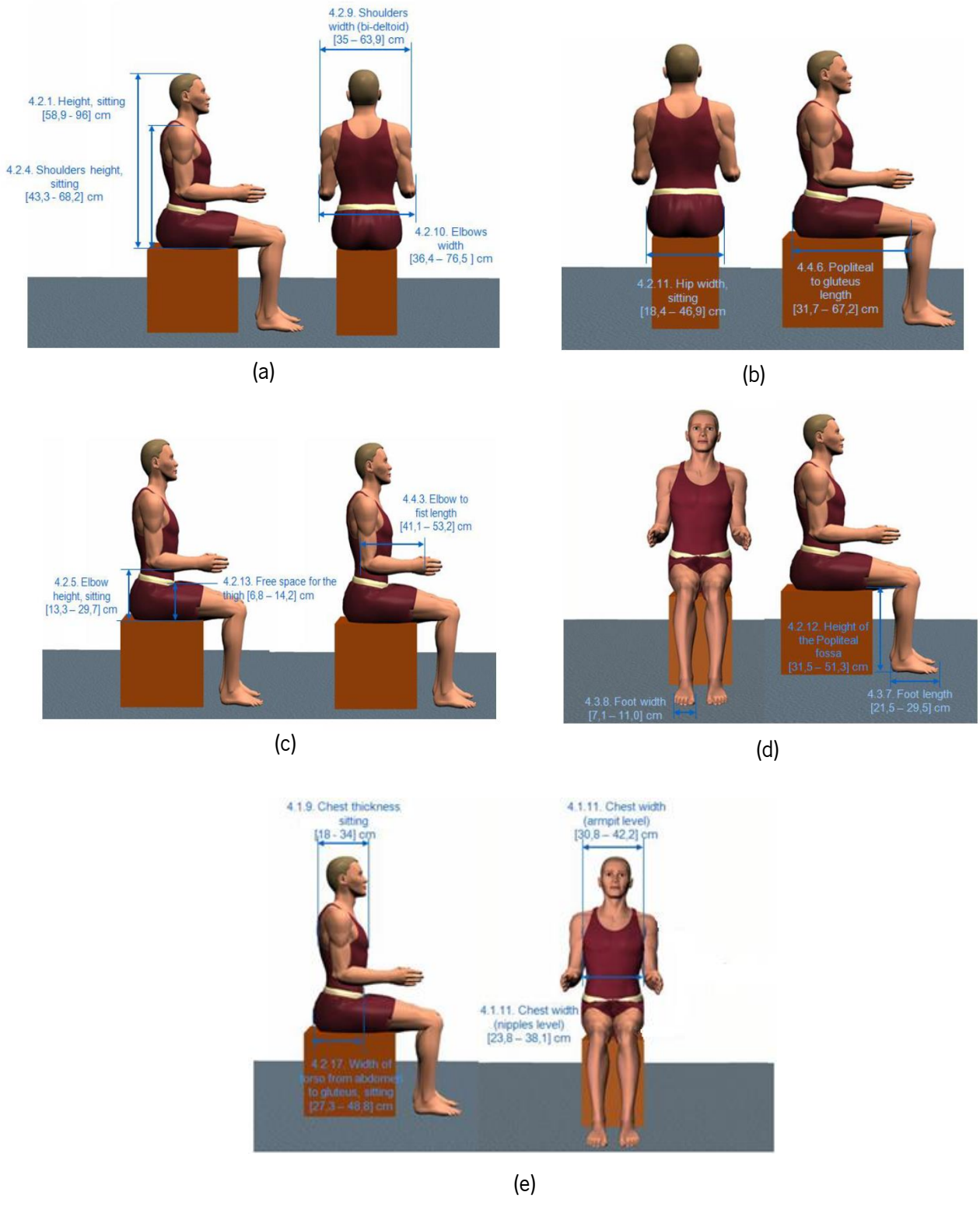


Figure 98 *– Anthropometric measurements represented in a virtual model: (a) height sitting, shoulders height sitting, shoulders and elbows width, (b) hip width siting and popliteal to gluteus length, (c) elbow height sitting, free space for the thigh and elbow to fist length, (d) foot width and length, (e) Chest thickness sitting, chest width (armpit and nipple level) (adapted from [49]).*

ANNEX IV – Market research on toilets, beds, and mattresses

Table 22 pertains to the information gathered in four retail sellers, of different toilet formats available.

Table 22 – *Toilet measurements research [50, 52–54].*

Seller 1 (Leroy Merlin)			Seller 2 (Roca)			Seller 3 (Sanindusa)			Seller 4 (Sanitana)		
Depth (mm)	Width (mm)	Height (mm)	Depth (mm)	Width (mm)	Height (mm)	Depth (mm)	Width (mm)	Height (mm)	Depth (mm)	Width (mm)	Height (mm)
-	365	400	400	370	400	415	385	400	420	370	395
-	362	430	425	370	400	455	420	415	420	370	400
-	360	415	425	360	400	450	370	400	395	365	395
-	350	410	445	395	410	420	365	405	450	360	390
-	335	400	435	370	400	420	345	392	400	355	390
-	360	405	400	340	400	410	345	450	430	345	395
-	360	390	400	350	400	427	365	403	420	350	395
-	320	395	430	340	400	405	360	410	470	365	400
-	370	395	430	340	440	425	345	400	465	365	390
-	380	415	408	355	400	423	372	418	510	395	385
-	360	385	400	360	400	-	-	-	440	360	480
-	365	390	400	360	440	-	-	-	420	360	395
-	360	400	392	360	400	-	-	-	-	-	-
-	365	400	430	360	400	-	-	-	-	-	-
-	320	395	425	355	400	-	-	-	-	-	-
-	345	395	425	355	385	-	-	-	-	-	-
-	-	-	430	360	430	-	-	-	-	-	-

Table 23 pertains to the bed heights gathered from three different companies, of different articulated bed types.

Table 23 – *Articulated beds height research [59–61].*

Articulated beds (Orthos XXI) (mm)	Articulated beds (Invacare) (mm)	Articulated beds (Stiegelmeyer) (mm)
490	380	350
460	280	280
490	400	280
410	320	380
490	400	430
420	320	400
490	350	390
420		450
350		320
500		320
260		430

Finally, **Table 24** contains the mattress height search, which takes into account four different companies.

Table 24 – *Mattress height research [55–58].*

Seller 1 (IKEA)	Seller 2 (JOM)	Seller 3 (Conforama)	Seller 4 (Persono)
240	190	230	230
180	200	210	170
170	220	240	150
210	220	180	140
270	90	200	150
310	240	160	120
260	250	270	240
250	240	260	230
130	240	230	200
100	220	270	230
120	250	320	230
180	240	270	190
180	220	260	-
180	250	310	-
210	280	210	-
180	270	280	-
200	270	290	-

ANNEX V – Supporting images for verticalization study

Figure 99 pertains to the anatomical references used in the verticalization study mentioned in sub-chapter 6.2. Verticalization.

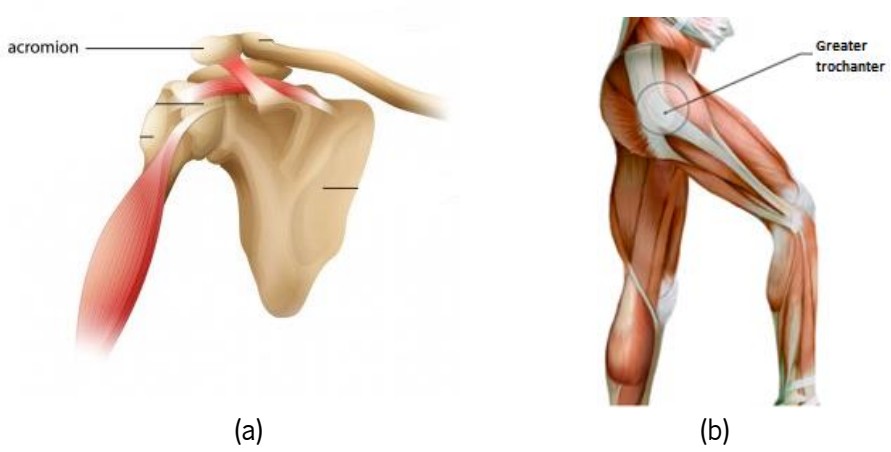


Figure 99 *– Anatomical references (a) acromion, (b) greater trochanter. (adapted from [83, 84]).*

Figure 100 pertains to the directional references used in the verticalization study mentioned in sub-chapter 6.2. Verticalization.

Figure 100 – *Directional references signalled in a stand-up wheelchair. (adapted from [32]).*

ANNEX VI – Actuator and gas spring calculations

After determining the actuator length and stroke, it was necessary to understand the force that the pair of actuators should be able to withstand to perform correctly and safely. For this purpose, a free body diagram was elaborated to study and calculate the minimum force each actuator should present in the situation in which it stands more load.

For the **seat actuators**, the maximum force required happens when the seat is lifting from the lowest height. The resulting diagram can be found in **Figure 101**.

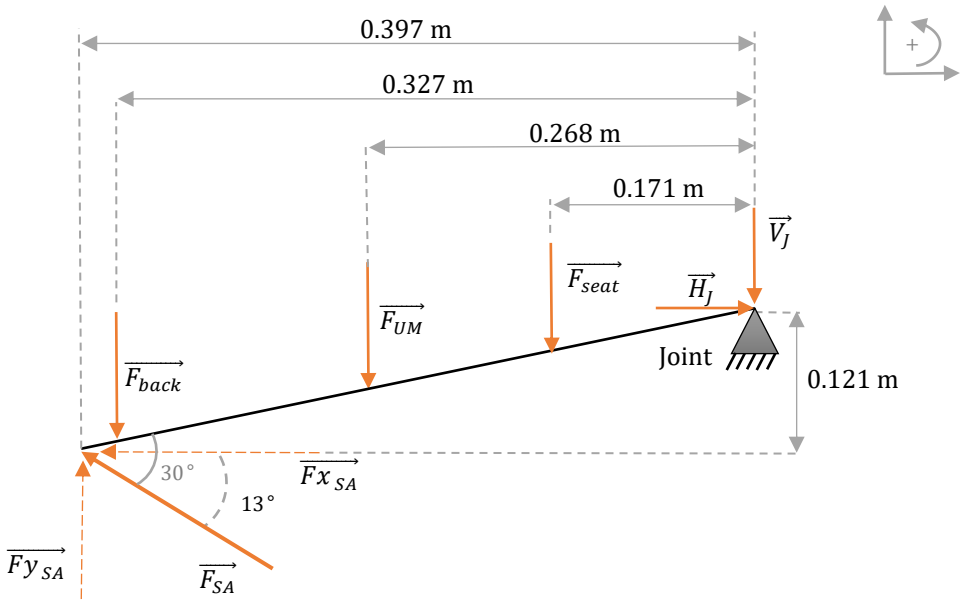


Figure 101 – *Seat actuators free body diagram.*

The different components that are at play in this free body diagram are the backrest mass, which is 12.6 kg, the seat mass, which is 4.4 kg, and the maximum user mass, 95 kg. The corresponding force for each component was calculated using the following equation:

$$F = m \times a$$

In which a relates to the gravitational acceleration, which value is around 9.80 $\frac{m}{s^2}$. Below follows the individual calculation of forces, respectively, for the backrest, the seat, and the user.

$$\overrightarrow{F_{backrest}} = 12.6 \times 9.80$$

$$\overrightarrow{F_{backrest}} = 123.48N$$

$$\overrightarrow{F_{seat}} = 4.4 \times 9.80$$
$$\overrightarrow{F_{seat}} = 43.12N$$

$$\overrightarrow{F_{UM}} = 95 \times 9.80$$
$$\overrightarrow{F_{UM}} = 931\ N$$

After, followed the calculation of the force need for the seat actuators, according to the free body diagram. For the torque to be 0 N.m, meaning that the system is balanced, the result of the following equation relates to the actuator's minimum load capacity.

$$\tau = F \times r$$
$$\tau_{joint} = 0$$
$$\tau_{joint} = \overrightarrow{H_J} \times 0 + \overrightarrow{V_J} \times 0 + \overrightarrow{F_{UM}} \times 0.268 + \overrightarrow{F_{seat}} \times 0.171 + \overrightarrow{F_{back}} \times 0.327$$
$$- \overrightarrow{F_{SA}} \sin(13) \times 0.397 - \overrightarrow{F_{SA}} \cos(13) \times 0.121$$
$$0 = 931 \times 0.268 + 43.12 \times 0.171 + 123.48 \times 0.327 - 0.0893\overrightarrow{F_{SA}} - 0.118\overrightarrow{F_{SA}}$$
$$\overrightarrow{F_{SA}} = \frac{-297.259}{-0.207}\ N$$
$$\overrightarrow{F_{SA}} = 1436.034\ N$$

Applying a safety coefficient of 2:

$$\overrightarrow{F_{SA}} = 1436.034 \times 2 = 2872.068\ N$$

Since the load is distributed between the two actuators that comprise the pair, each actuator should be able to support a load of 1436 N, half of the value obtained.

For the **backrest actuators**, the maximum force required happens when the seat is lifting from the lowest height. The resulting diagram can be found in **Figure 102**.

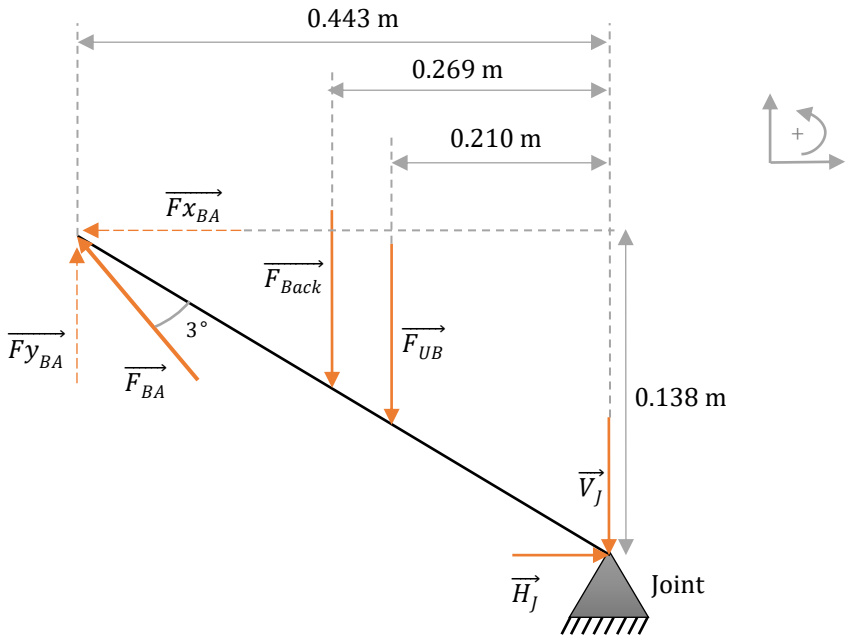


Figure 102 – *Backrest actuators free body diagram.*

Since the backrest actuators, don't need to support all of the user's mass, **Figure 103** was used to understand the relative user's mass, that the backrest would have to support. For the mass calculation, it was accounted the head, two upper arms, forearms and hands, and the trunk, which pertains to 68.02% of the user's mass. For a user with 95 kg (maximum user mass), the relative mass that the backrest withstands is 64.62 kg [85].

302 Appendix 2: Geometric Properties of the Human Body

B. Segment Properties (Tables A.2.2 and A.2.3)

TABLE A.2.2. Body segment parameters (Dempster 1955)

Segment	*p* (%)	*m* (%)	I_1 (kg-m^2)	I_3 (kg-m^2)
Head	0.5358	0.0730	0.0248	
Upper arm	0.4360	0.0270	0.0213	
Forearm	0.4300	0.0160	0.076	
Hand	0.5060	0.0066	0.0005	
Trunk	0.4383	0.5080	1.3080	0.3119
Thigh	0.4330	0.0988	0.1502	
Lower leg	0.4330	0.0465	0.0505	
Foot	0.4290	0.0145	0.0038	

p, the distance from the center of gravity of the segment to the proximal endpoint expressed as a fraction of the segment length.
m, segment weight as a percentage of whole body weight.
I_1 and I_3, mass moments of inertia with respect to the center of mass of a body segment about the transverse and longitudional axis, respectively, for a subject with mass of 74.2 kg and standing height of 1.755 m. For more detailed information on segment properties, see de Leva (1996).

Figure 103 – *Relative body segments mass (adapted from* [85]*).*

Below follows the force calculations for the components at play in the free body diagram, namely, the user's upper body, since the backrest force was previously calculated.

$$\overrightarrow{F_{UB}} = 64.62 \times 9.80$$

$$\overrightarrow{F_{UB}} = 633.28\ N$$

$$\tau = F \times r$$

$$\tau_{joint} = 0$$

$$\tau_{joint} = \overrightarrow{H_J} \times 0 + \overrightarrow{V_J} \times 0 + \overrightarrow{F_{UB}} \times 0.210 + \overrightarrow{F_{Back}} \times 0.269 - \overrightarrow{F_{BA}} \sin(3) \times 0.443 - \overrightarrow{F_{BA}} \cos(3) \times 0.138$$

$$0 = 633.28 \times 0.282 + 123.48 \times 0.269 - 0.0232\overrightarrow{F_{BA}} - 0.138\overrightarrow{F_{BA}}$$

$$\overrightarrow{F_{BA}} = 1032.36\ N$$

Applying a safety coefficient of 2:

$$\overrightarrow{F_{BA}} = 1032.36 \times 2 = 2064.71\ N$$

Since the load is distributed between the two actuators that comprise the pair, each actuator should be able to support a load of 1032 N, half of the value obtained.

Finally, followed the calculation of the **gas spring** minimum load capacity. The respective free body diagram is presented in **Figure 104**, for a user mass of 95 kg, applied at the hoops of the arch, which are at a distance of 337mm from the gas springs.

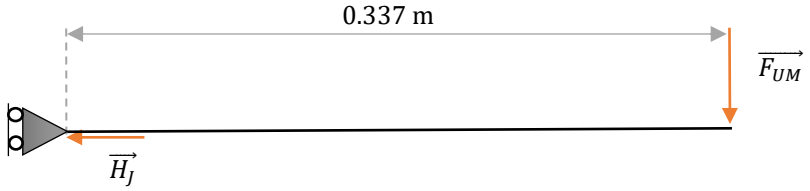


Figure 104 – *Gas spring free body diagram.*

Below follows the respective calculations, for the torque to be 0 N.m, for the system is in equilibrium.

$$\tau = F \times r$$

$$\tau = \overrightarrow{H_J} \times 0 + \overrightarrow{F_{UBT}} \times 0.337$$

$$\tau = 0 + 931 \times 0.337$$

$$\tau = 313.747\ N$$

Applying a safety coefficient of 2:

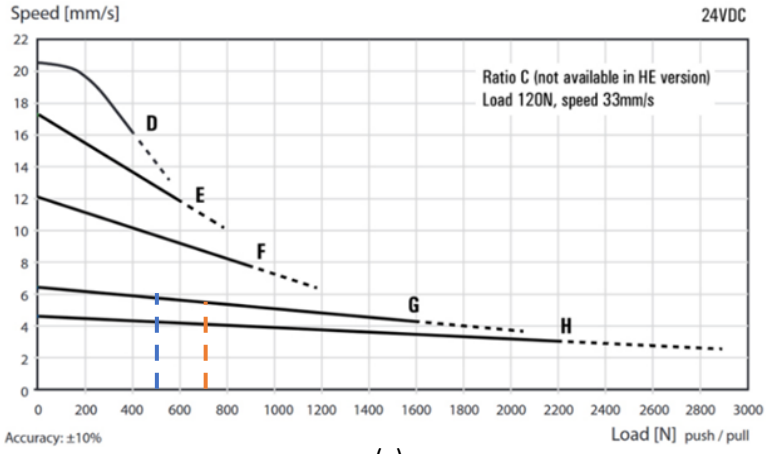
$$\overrightarrow{F_{BA}} = 313.747 \times 2 = 627.494\ N$$

Since the load is distributed between the two gas springs, each one should be able to support a load of 314 N, half the value.

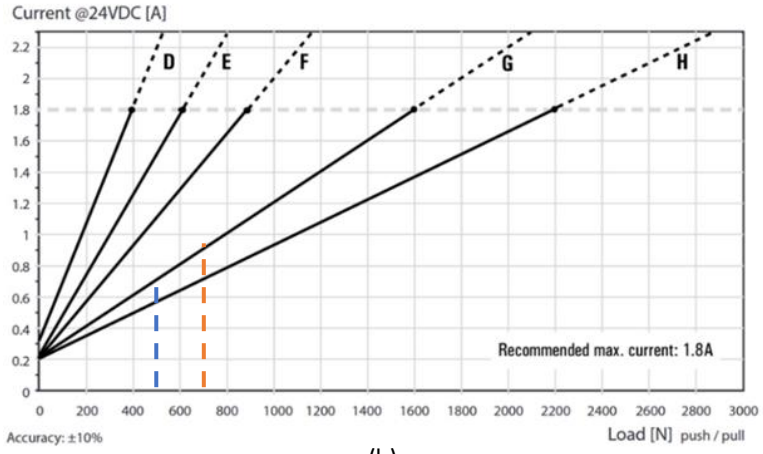
ANNEX VII – Battery power requirements

The first step to verify if the batteries can withstand the electrical requirements of the electric components is to identify the power needs for the actuators.

Figure 105 pertains to information available by the manufacturer of the actuators and gives details about speed, **Figure 105 a)**, and current usage, **Figure 105 b)**, during functioning. The curve considered in both graphs was the G curve, which correlates with the maximum load the actuators selected can bear, with the blue line relating to the backrest actuators, and the orange line to the seat actuators [86].



(a)



(b)

Figure 105 – *Actuator working curves: (a) speed (mm/s) vs load (N), (b) current (A) vs load (N) (adapted from* [86]*).*

Table 25 contains the information gathered. Maximum stroke refers to the maximum extension of the actuator while being used in the device developed. The maximum load was calculated for a user with 95 kg of mass.

Table 25 – Actuator specifications.

Characteristic	Seat actuators	Backrest actuators
Maximum stroke (mm)	232	198
Maximum load (N)	718	516
Speed (mm/s)	5.5	6
Time for full extension (s)	42.18	33
Current (A)	0.9	0.6
Voltage (V)	24	24

To calculate the power each actuator uses per actuation, the following equations were used:

$$W\ (power) = V \times I$$

$$Wh\ (power\ per\ actuation) = \frac{W}{3600} \times time\ for\ full\ extension$$

For the seat actuator:

$$W = 24 \times 0.9$$

$$W = 21.6\ W$$

$$Wh = \frac{21.6}{3600} \times 42.18$$

$$Wh = 0.25\ Wh$$

For the backrest actuator:

$$W = 24 \times 0.6$$

$$W = 14.4\ W$$

$$Wh = \frac{14.4}{3600} \times 33$$

$$Wh = 0.132\ Wh$$

Since there are two actuators of each kind, and it's intended that the device permits at least 10 transfers per day, which, there and back, results in 20 actuations per pair, the power per actuation for each kind of actuator will be multiplied by 2 and by 20, to obtain how many watt-hours the four actuators will require to work as intended.

$$Total\ Wh_{actuators} = 0.25 \times 2 \times 20 + 0.132 \times 2 \times 20$$

$$Total\ Wh_{actuators} = 15.28\ Wh$$

Finally, follows the identification of the power needed to supply the drive wheel motors. Since both the batteries and drive wheels are used in another Orthos XXI device, it was possible to figure out that the drive wheels' total consumption is 0.014 Wh/m. Then, since it is required for the device to at least have an autonomy of 1 km, the total power per hour required by the drive wheels is 14 Wh.

With this information gathered, the total power consumed by the actuators and drive wheel motors in one day is 29.28 Wh, which reflects in 1.22 Ah, following the equation below.

$$I = \frac{Wh}{V}$$

However, given that the capacity of the batteries used is 34.8 Wh, a consumption of 29.28 Wh translates in a safety coefficient of 1.19, as can be seen from the calculation below.

$$Safety\ coefficient = \frac{34.8}{29.28}$$
$$Safety\ coefficient = 1.19$$

This value is too low to ensure that the friction mechanisms are encompassed in the consumption. In order to ensure a higher safety coefficient, without seriously compromising the device's functionality, the number of daily transfers should be a maximum of 6, reflecting a total of 12 actuations per actuator pair. Below are the calculations reflecting this change.

$$Total\ Wh_{actuators} = 0.25 \times 2 \times 12 + 0.132 \times 2 \times 12$$
$$Total\ Wh_{actuators} = 9.17\ Wh$$

Thus, with the drive wheels, the total consumption is 23.17 Wh, which relates to a safety coefficient of 1.5 and 0.97 Ah.

ANNEX VIII – Mechanical properties of steel S235JR

Table 26 pertains to the mechanical properties of the steel used for the manufacture of the device's metallic components [64].

Table 26 – *Steel S235 JR mechanical properties.*

Mechanical property (nominal thickness ≤16 mm)	Value
Yield strength	235 MPa
Young's Modulus	210 GPa
Density	7800 kg/m^3
Poisson's ratio	0.3

ANNEX IX – Overall device dimensions, supporting images

Figure 106 pertains to the different measurements conducted to determine the dimensions mentioned in **Table 16**. This figure serves to better clarify how these measurements were determined.

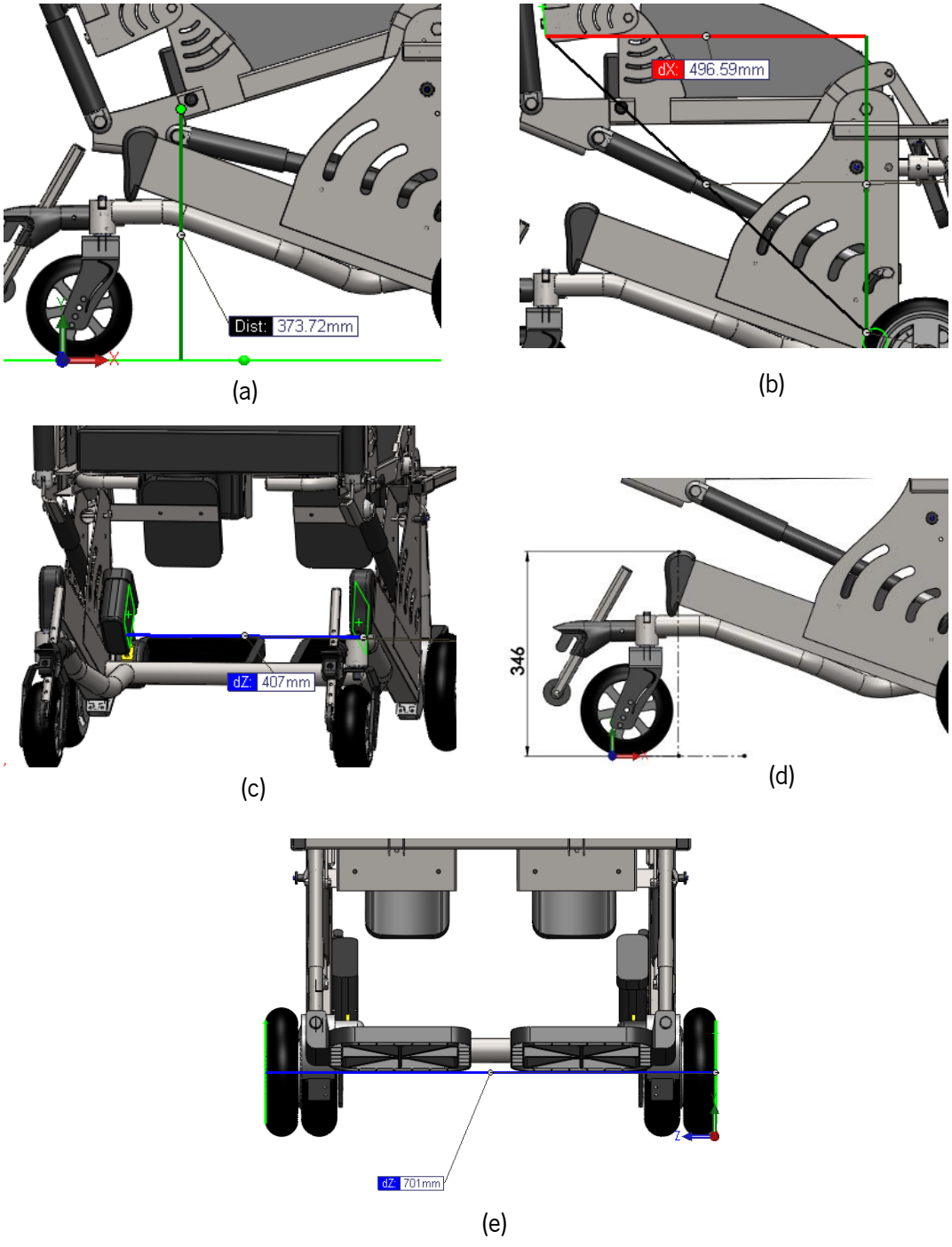


Figure 106 *– Relevant structural sizing measurements: (a) minimum seat height, (b) interior depth, (c) interior width, (d) maximum rear components height, (e) overall width.*

ANNEX X – Relation between seat and floor angle, and actuator length

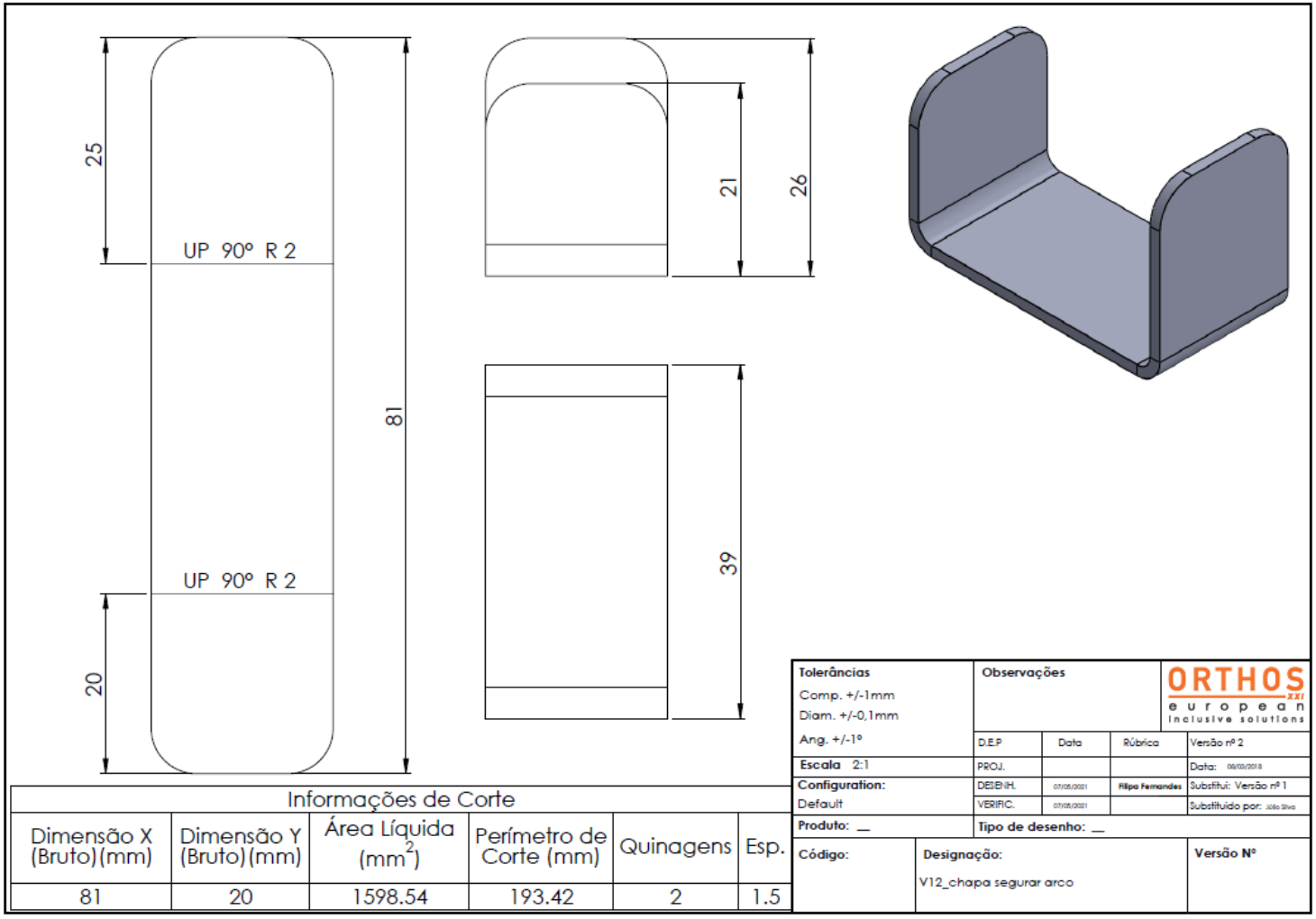
Table 27 pertains to the size of both the seat and backrest actuators, in different angle positions between the seat and floor, and the respective angle between the backrest and seat.

Table 27 – *Relation between seat and floor angle, and actuator length.*

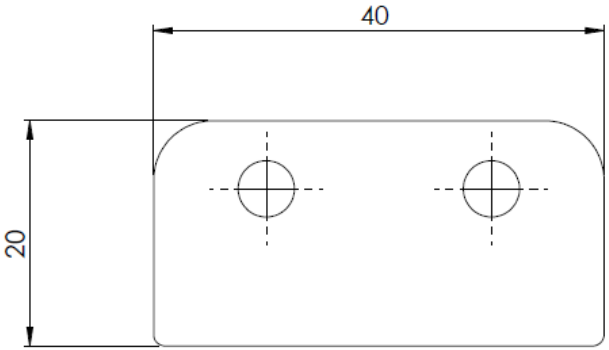
Angle between seat and floor	Angle between backrest and seat	Backrest actuator length (mm)	Seat actuator length (mm)
0°	95°	568	498
10°	105°	538	534
20°	115°	506	567
30°	125°	472	596
40°	135°	437	621
50°	145°	402	640
60°	155°	369	656
65°	155°	369	662

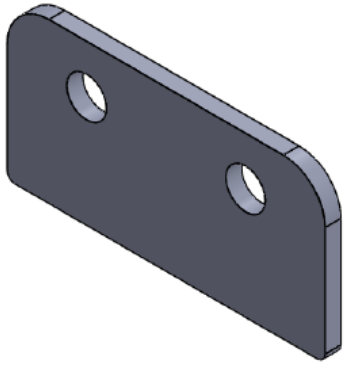
ANNEX XI – Technical drawings for production

- **Laser-cut steel plates – straight and bended**



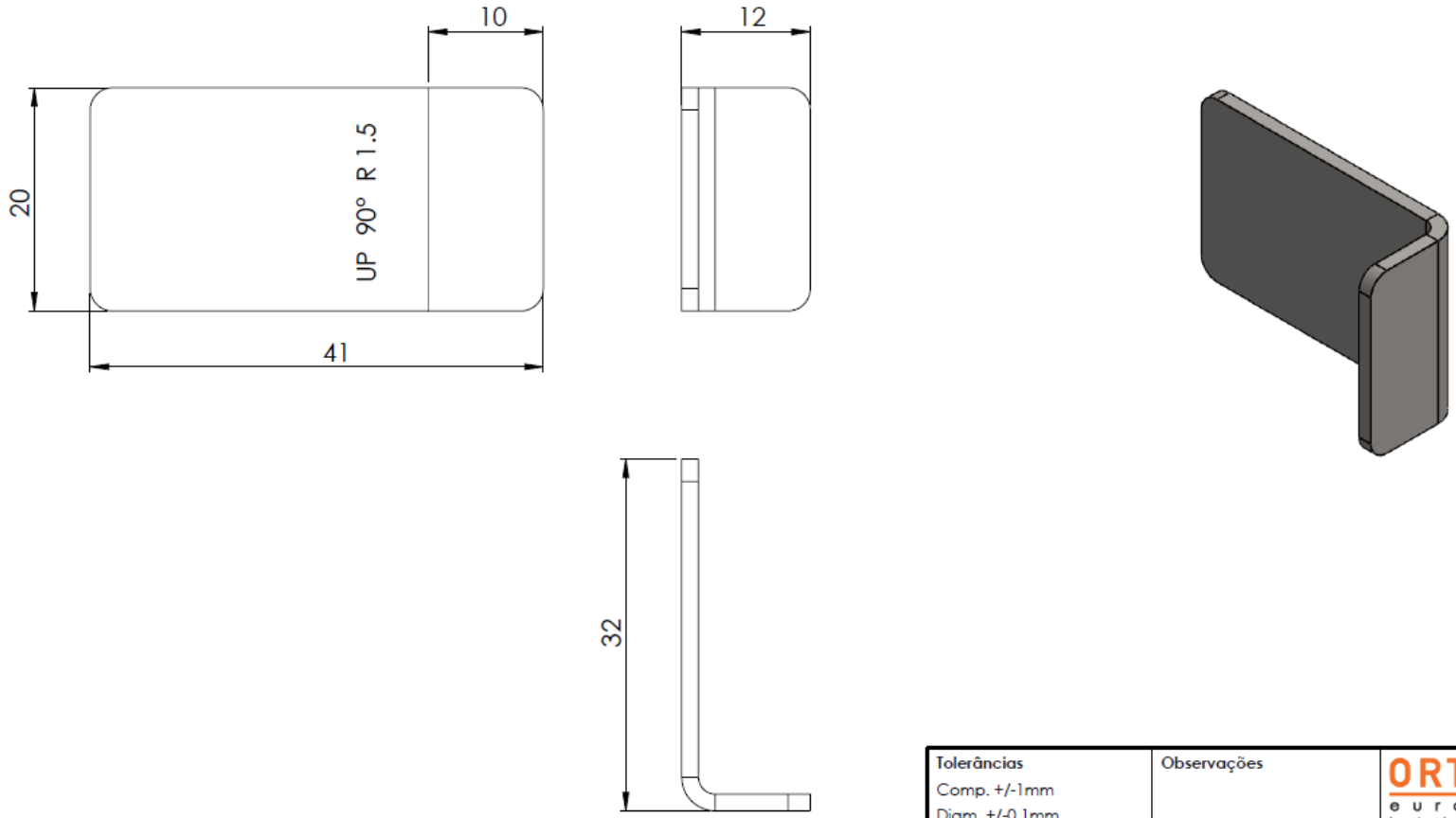
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
81	20	1598.54	193.42	2	1.5





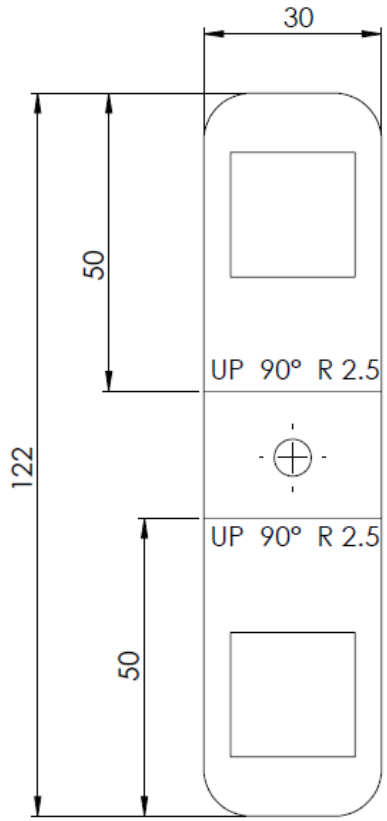
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
40	20	748.47	146.05	0	2

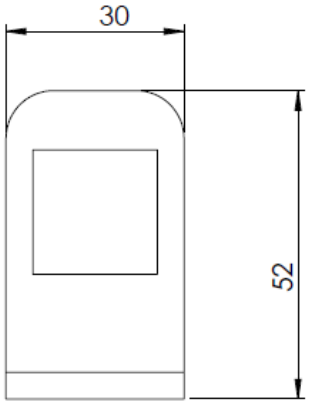
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	06/05/2021	**Filipa Fernandes**	Substitui: Versão nº 1
	VERIFIC.	06/05/2021		Substituído por: Júlia Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** chapa bateria			**Versão Nº**

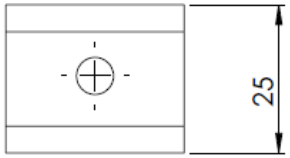


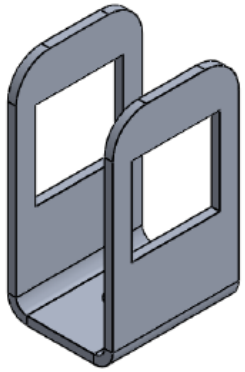
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
40.53	20	807.25	117.63	1	1.5

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	07/05/2021	**Filipa Fernandes**	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituído por: Júlio Silva
Produto: _	**Tipo de desenho:** _			
Código:	**Designação:** encaixe salva			**Versão Nº**



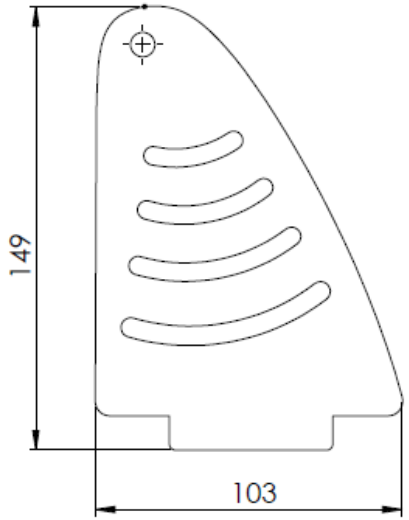


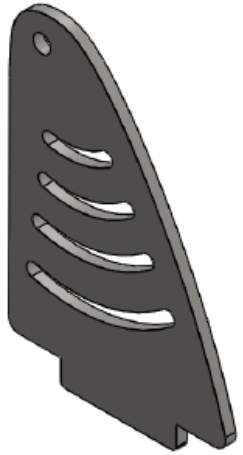




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
122	30	2692.25	477.89	2	2

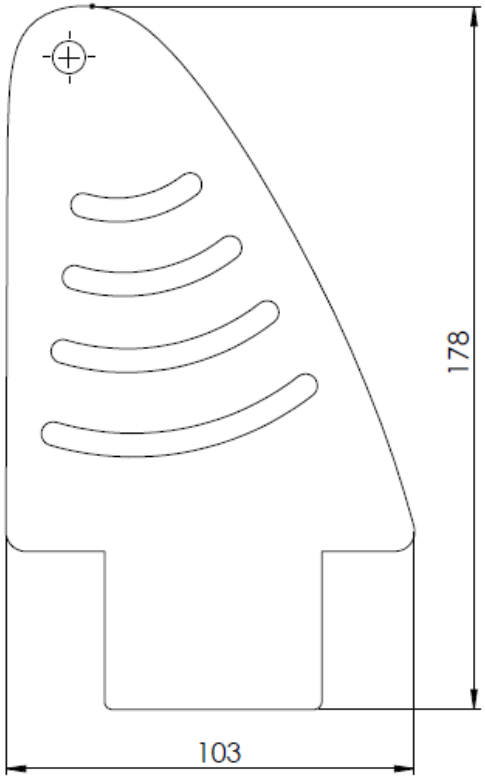
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european Inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	07/05/2021	**Filipa Fernandes**	Substituí: Versão nº 1
	VERIFIC.	07/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_alheta apoio joelhos			**Versão Nº**

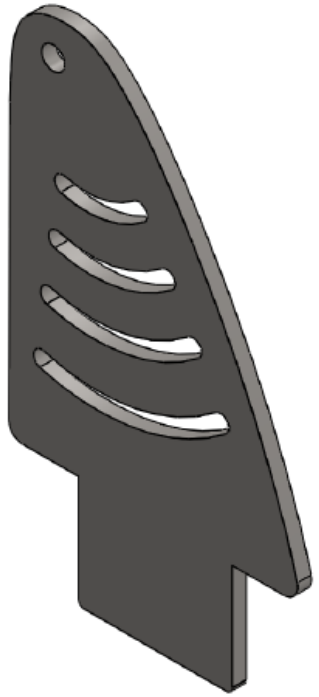




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
149.46	103.53	9511.68	926.67	0	5

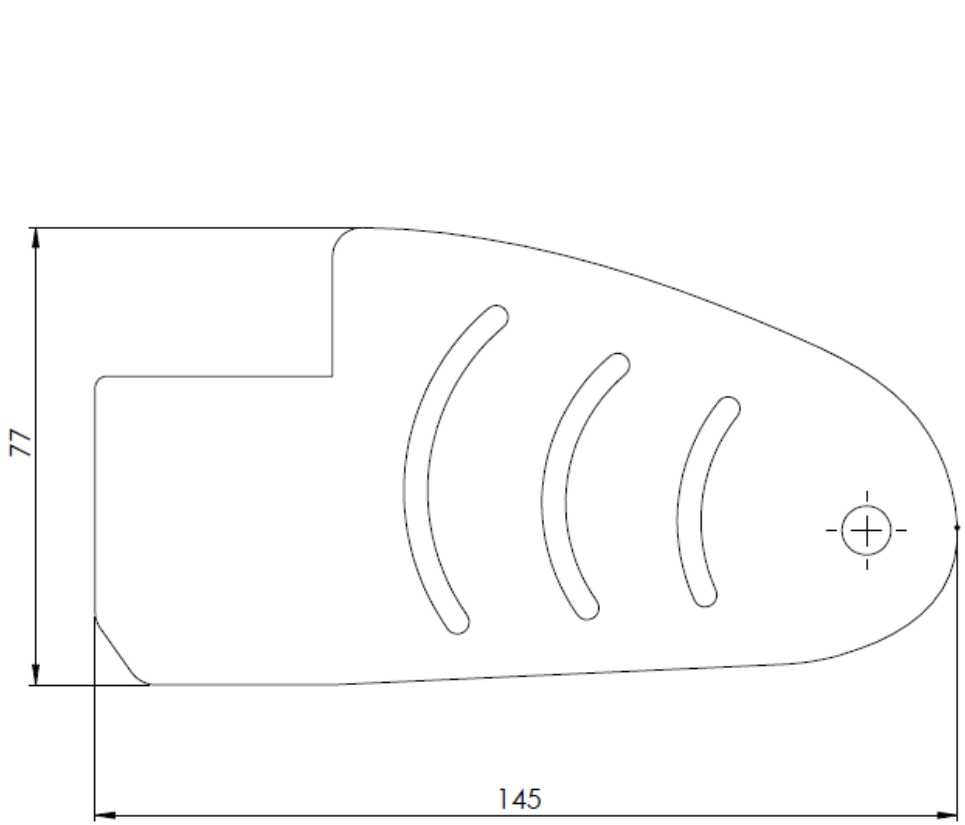
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	**Filipa Fernandes**	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: _	**Tipo de desenho:** _			
Código:	**Designação:** V12_alheta articulaçao assento curta			**Versão N°**

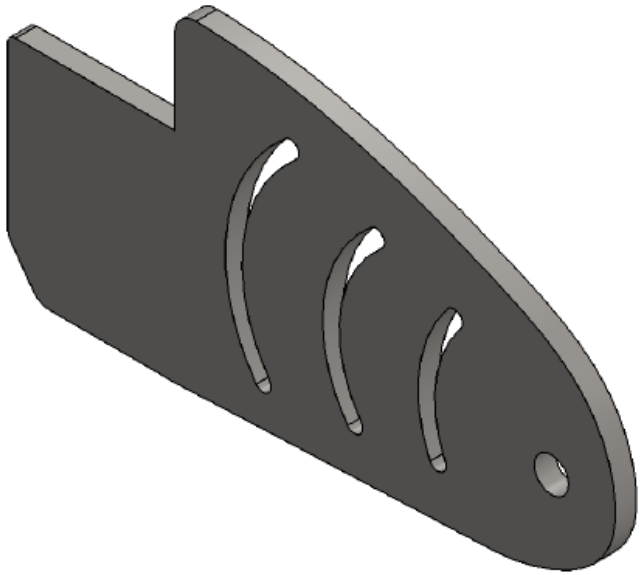




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
177.96	103.53	11152.12	980.94	0	5

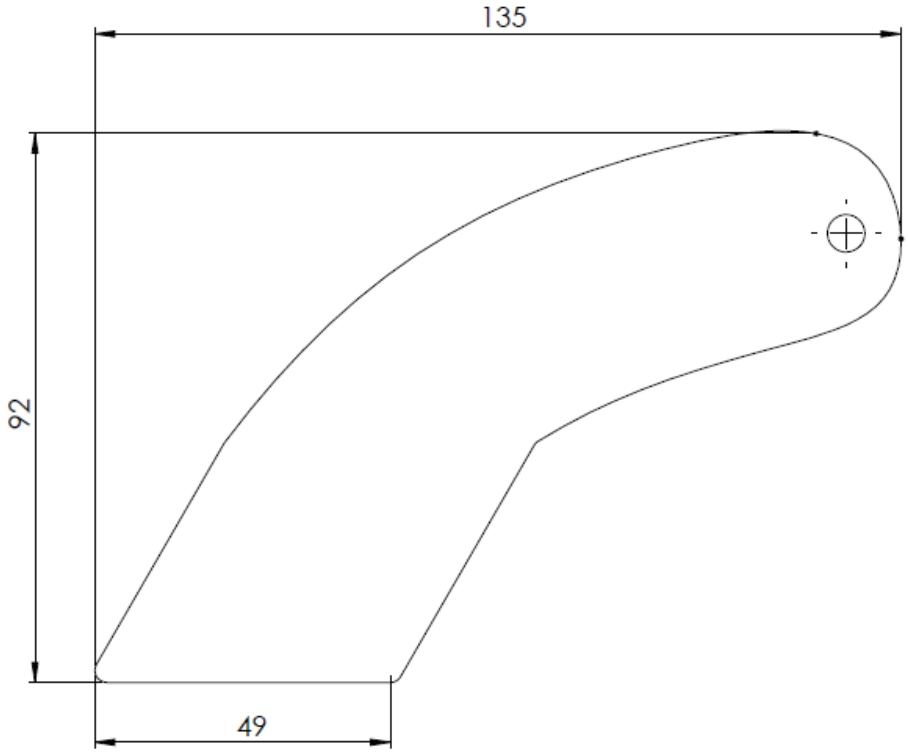
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1.	PROJ.			Data: 08/03/2018
Configuration: DefaultSM-FLAT-PATTERN	DESENH.	30/04/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_alheta articulaçao assento			Versão Nº

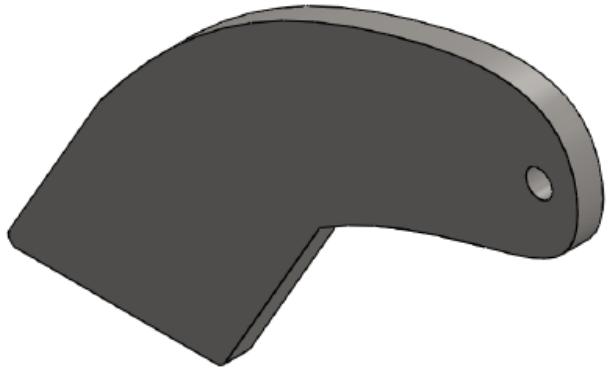




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
145.81	76.74	7905.25	726.08	0	5

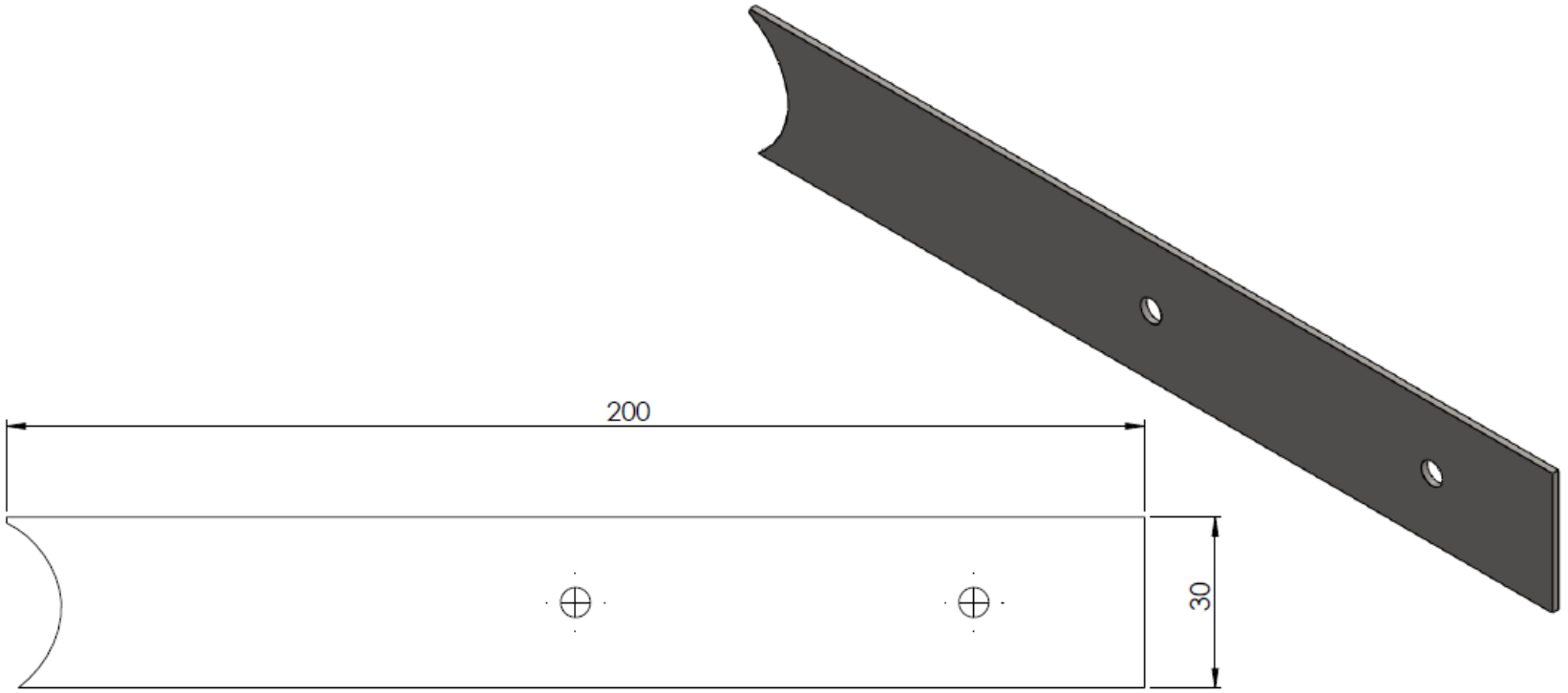
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	11/06/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	11/06/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_alheta articulaçao costas			**Versão N°**





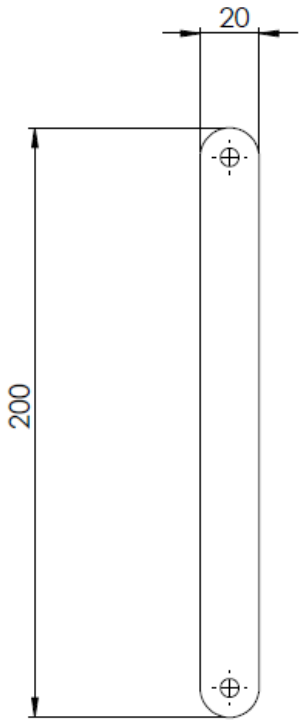
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
155.21	54.36	5519.14	375.92	0	6

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	30/04/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_alheta joelho assento 6 mm			**Versão Nº**



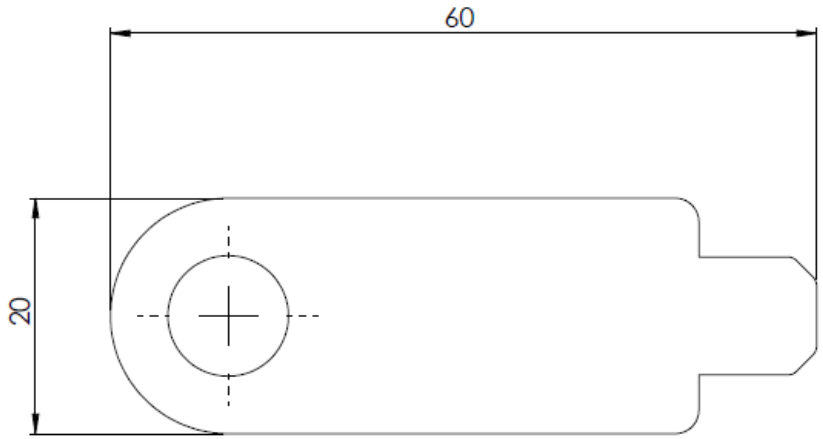
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
200	30	5753.01	497.09	0	1.5

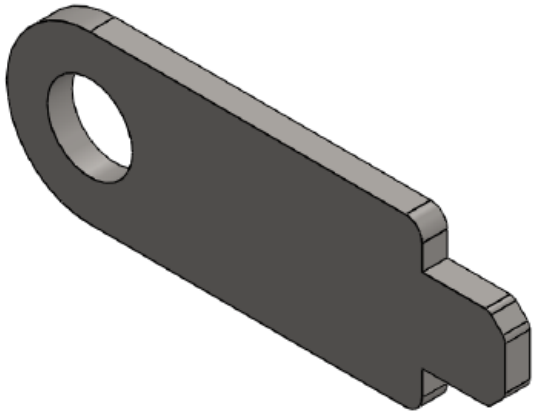
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_chapa apoio gemeos 1.5mm			Versão Nº



Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
200	20	3852.8	462.1	0	4

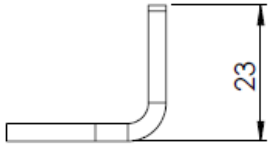
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa apoio pes 4mm			**Versão Nº**

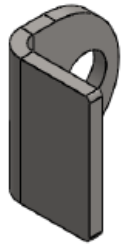


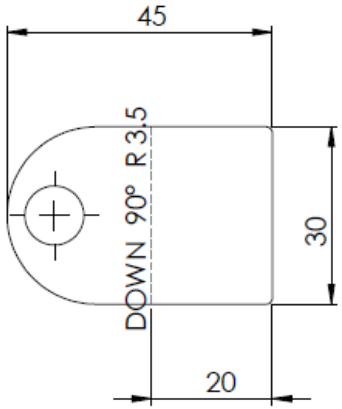


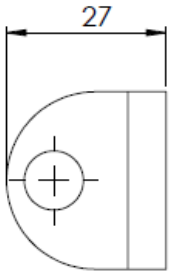
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
60	20	968.76	179.38	0	3

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 06/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa atuador costas cima 3mm			**Versão Nº**



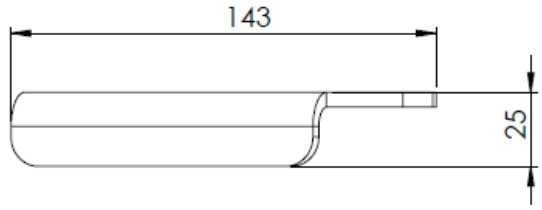


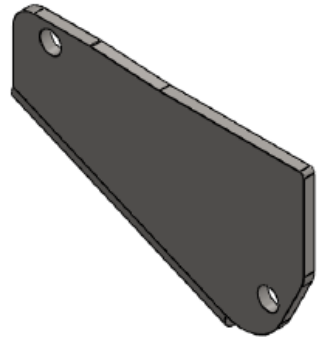


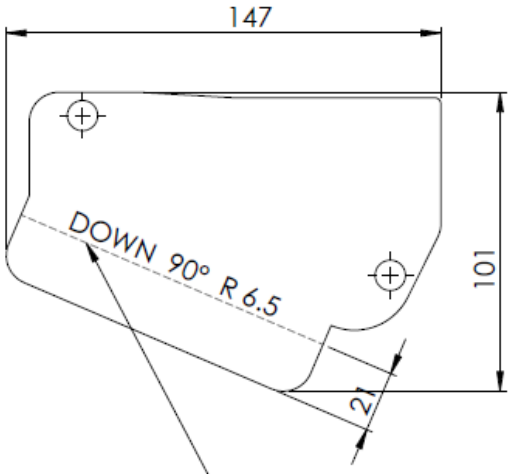


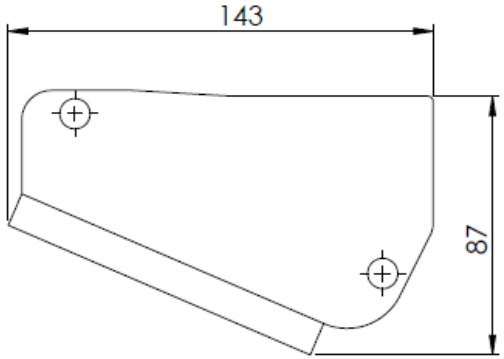
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
44.85	30	1170.08	167.39	1	3

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa atuador frente 3mm			**Versão N°**





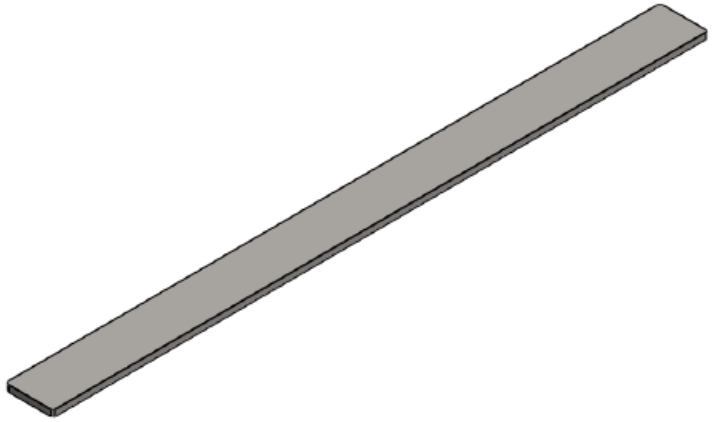


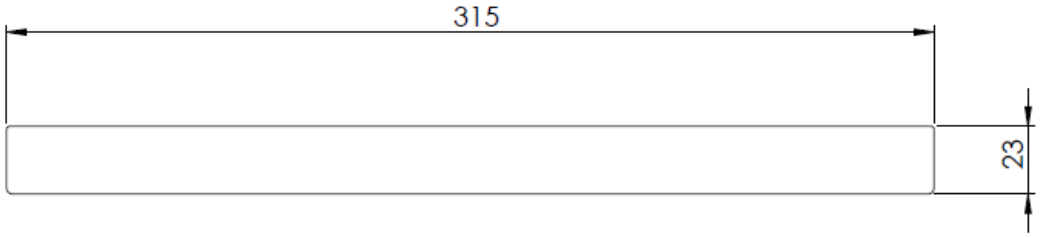


uma chapa é para dobrar para cima e a outra com o mesmo nome é para dobrar para baixo (uma é a esquerda e a outra é a direita)

Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
146.51	100.12	11140.65	491.21	1	5

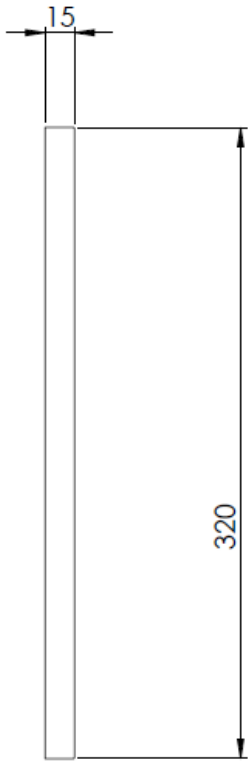
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions	
	D.E.P	Data	Rúbrica	Versão nº 2	
Escala 1:2	PROJ.			Data: 08/03/2018	
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1	
	VERIFIC.	07/05/2021		Substituído por: João Silva	
Produto: _	Tipo de desenho: _				
Código:	Designação: V12_chapa atuadores trás 5mm			Versão Nº	





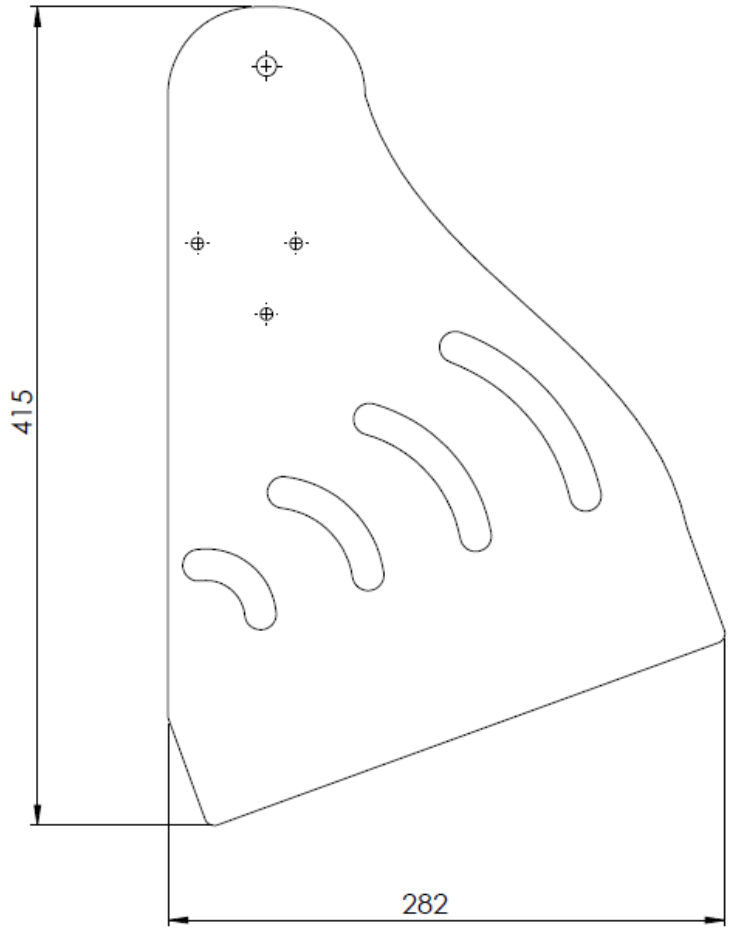
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
315	23	7242.85	673.42	0	3

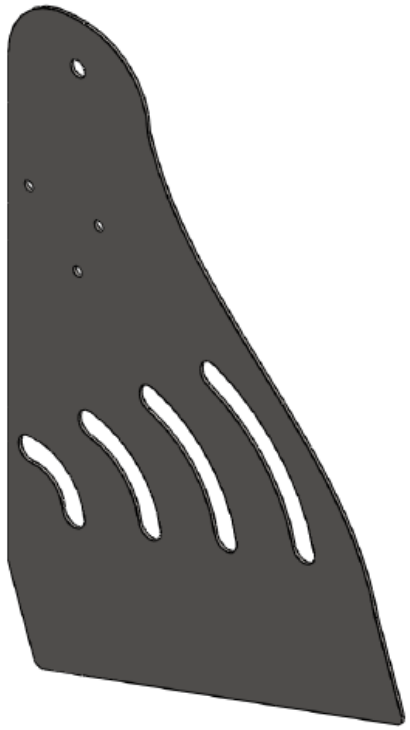
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european Inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa correr assento 3mm			**Versão Nº**



Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
320	15	4799.57	669.14	0	2

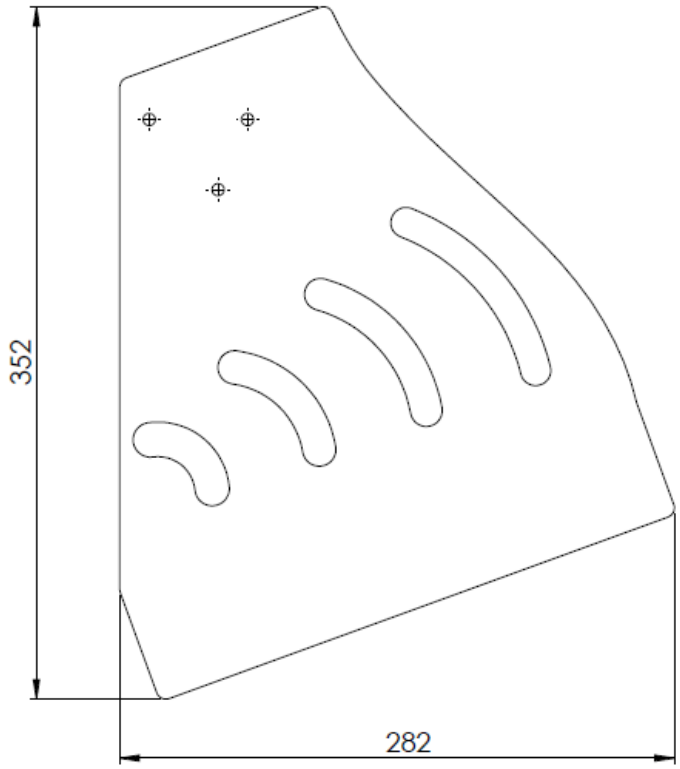
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	03/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	03/05/2021		Substituído por: João Silva
Produto: _	**Tipo de desenho:** _			
Código:	**Designação:** V12_chapa correr costas 2mm			**Versão Nº**

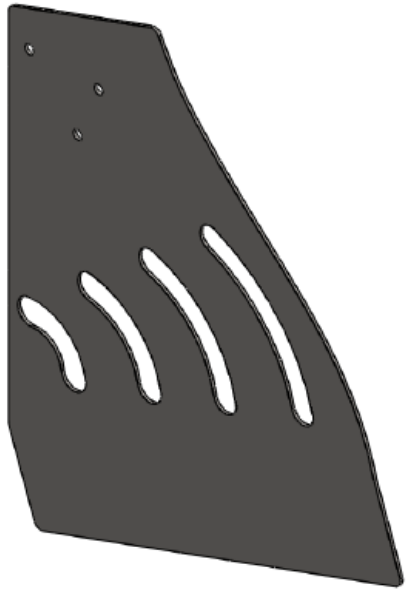




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
385.61	281.16	67543.22	2027.17	0	2

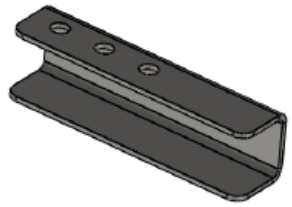
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa lateral 2 mm			**Versão Nº**

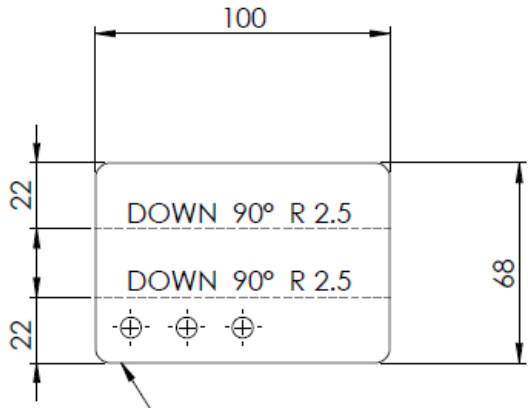


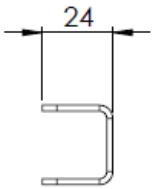


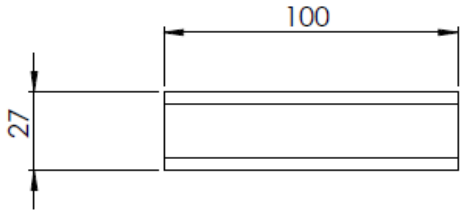
Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
304.32	280.98	60067.71	1887.93	0	2

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_ chapa lateral pequena 2 mm suporte			**Versão Nº**





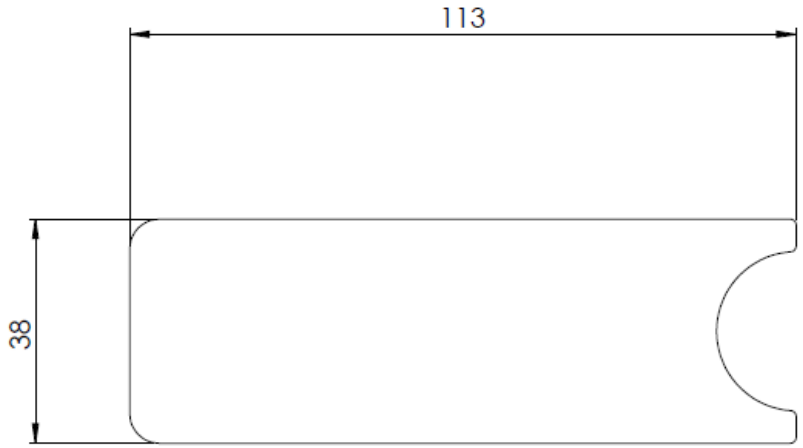


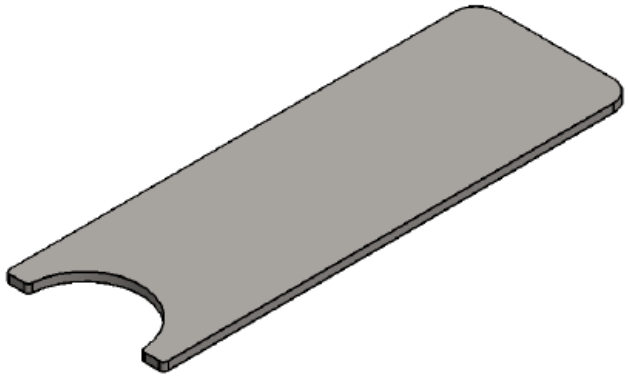


uma chapa dobrar para cima e a outra chapa com o mesmo nome dobrar para baixo (uma é esquerda e outra é direita)

Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
100	68	6662.64	393.38	2	2

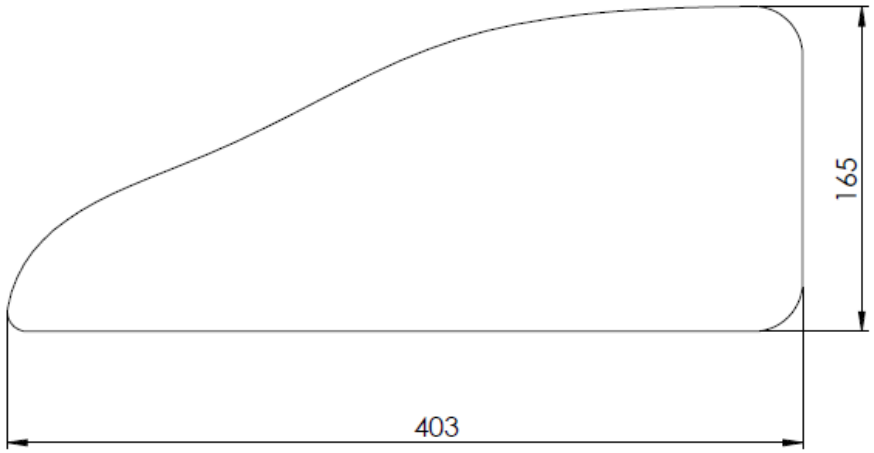
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituido por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_chapa lig joelhos-cadeira			Versão Nº

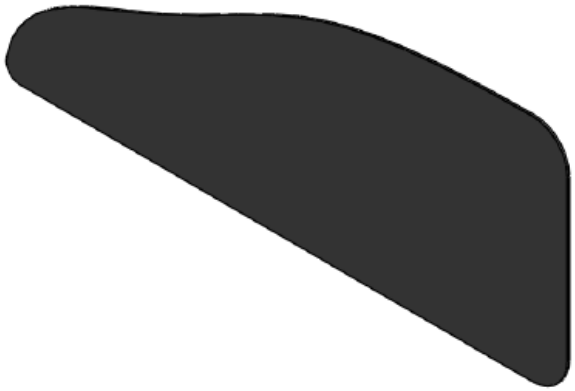




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
113	38	3996.18	311.47	0	2

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	**Observações**			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituido por: João Silva
Produto: __	**Tipo de desenho:** __			
Código:	**Designação:** V12_chapa resistencia lateral 2mm			**Versão N°**

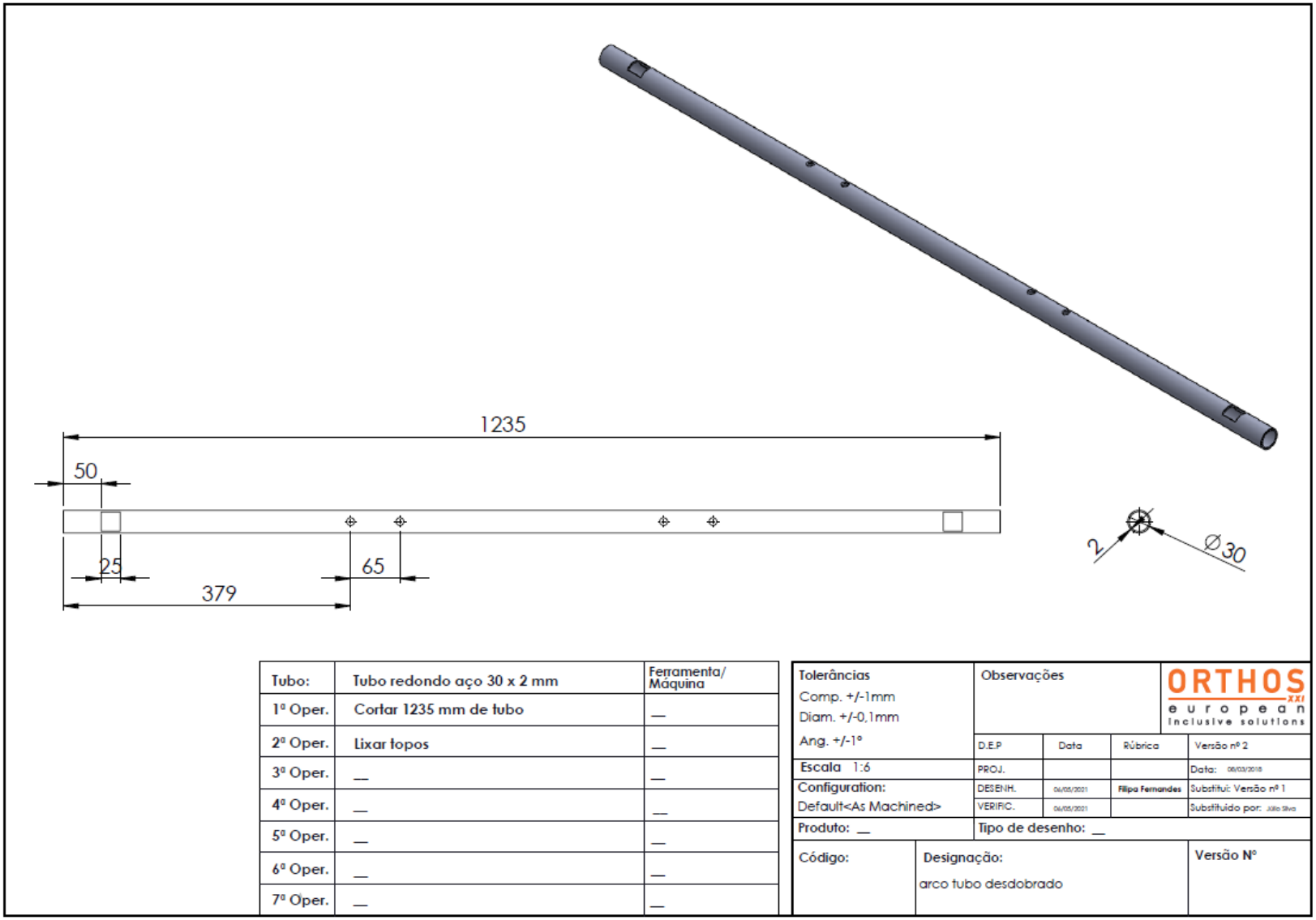




Informações de Corte					
Dimensão X (Bruto) (mm)	Dimensão Y (Bruto) (mm)	Área Líquida (mm^2)	Perímetro de Corte (mm)	Quinagens	Esp.
403.64	165	49733.54	1005.57	0	1.5

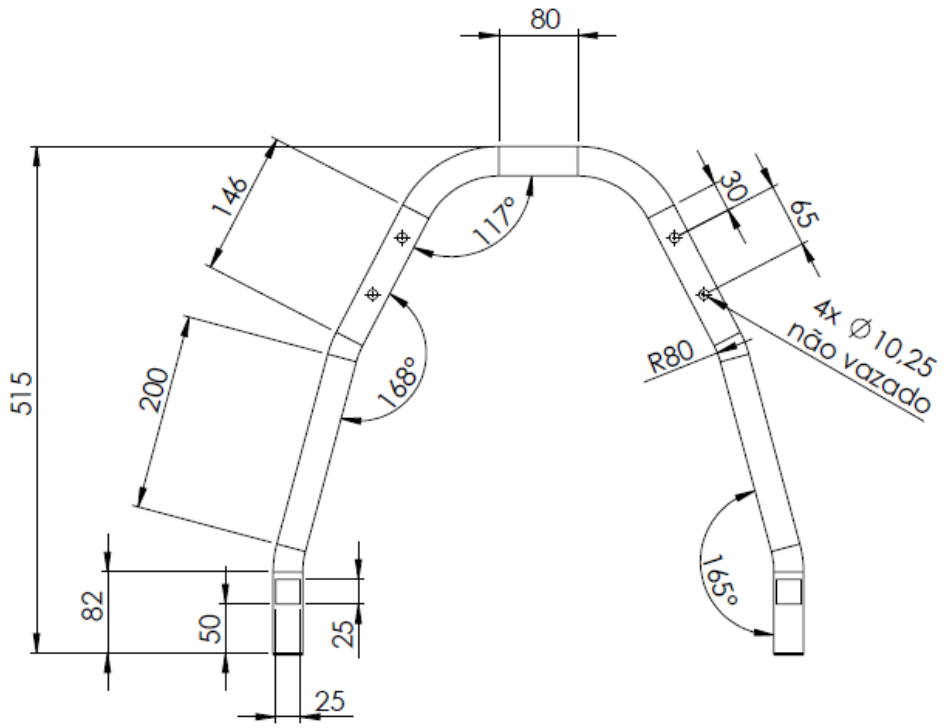
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_chapa salva roupa 1.5mm			Versão Nº

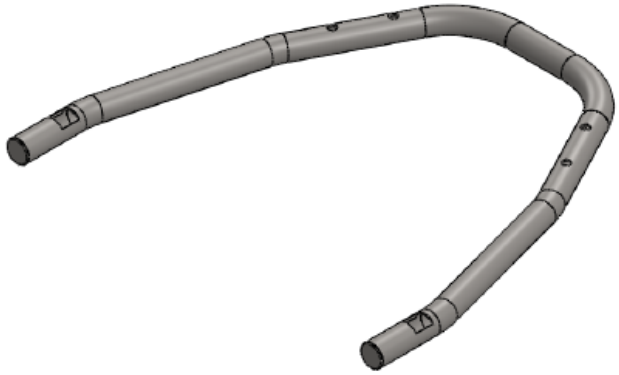
- Tubes - straight, bent, and laser cut



Tubo:	Tubo redondo aço 30 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 1235 mm de tubo	__
2º Oper.	Lixar topos	__
3º Oper.	__	__
4º Oper.	__	__
5º Oper.	__	__
6º Oper.	__	__
7º Oper.	__	__

Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º		D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:6		PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>		DESENH.	04/05/2021	Filipa Fernandes	Substitui: Versão nº 1
		VERIFIC.	04/05/2021		Substituído por: João Silva
Produto: __		Tipo de desenho: __			
Código:	Designação: arco tubo desdobrado				Versão Nº

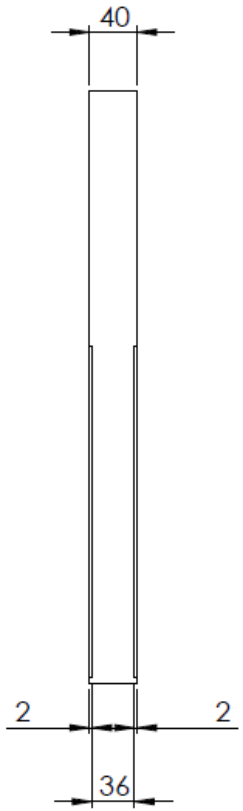


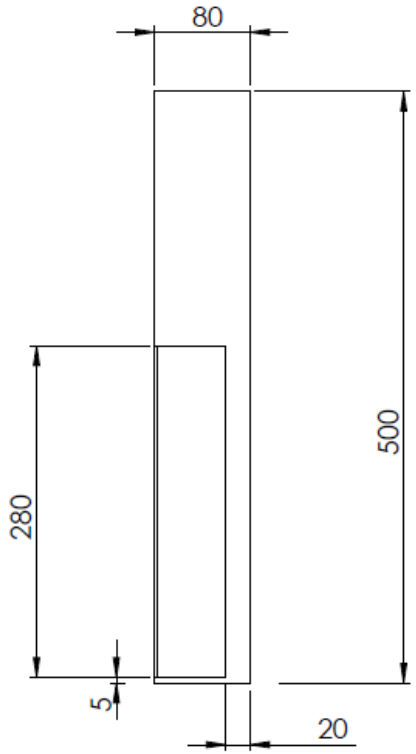


Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1º Dobra	82	165		80
2º Dobra	200	168		80
3º Dobra	146	117		80
4º Dobra	80	117		80
5º Dobra	146	168		80
6º Dobra	200	165		80

Tubo:	Tubo redondo aço 30 x 2 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 1235 mm de tubo	—
2ª Oper.	Dobrar conforme tabela	—
3ª Oper.	Furar conforme desenho	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

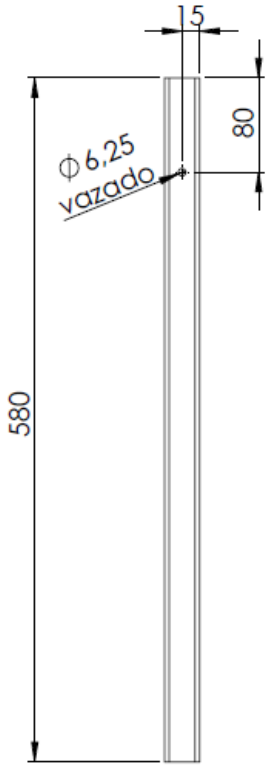
Tolerâncias	Observações				ORTHOS XXI european inclusive solutions
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2	
Escala 1:6	PROJ.			Data: 08/03/2018	
Configuration: Default<As Machined>	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1	
	VERIFIC.	30/04/2021		Substituído por: João Silva	
Produto: —	Tipo de desenho: —				
Código:	Designação: V12_arco tubo 30mm			Versão N°	

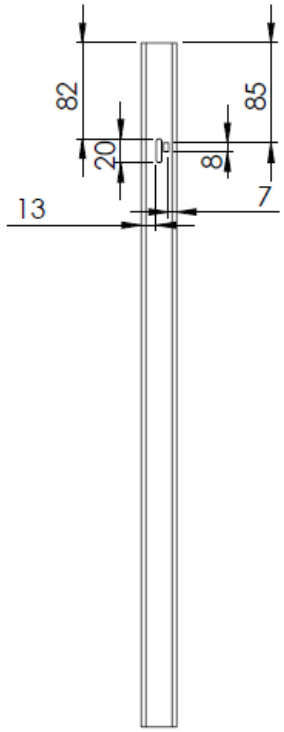


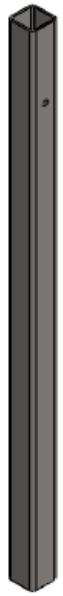


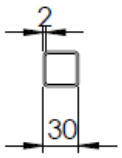
Tubo:	Tubo retangular 80 x 40 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 500 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo bateria 80x40mm			Versão Nº



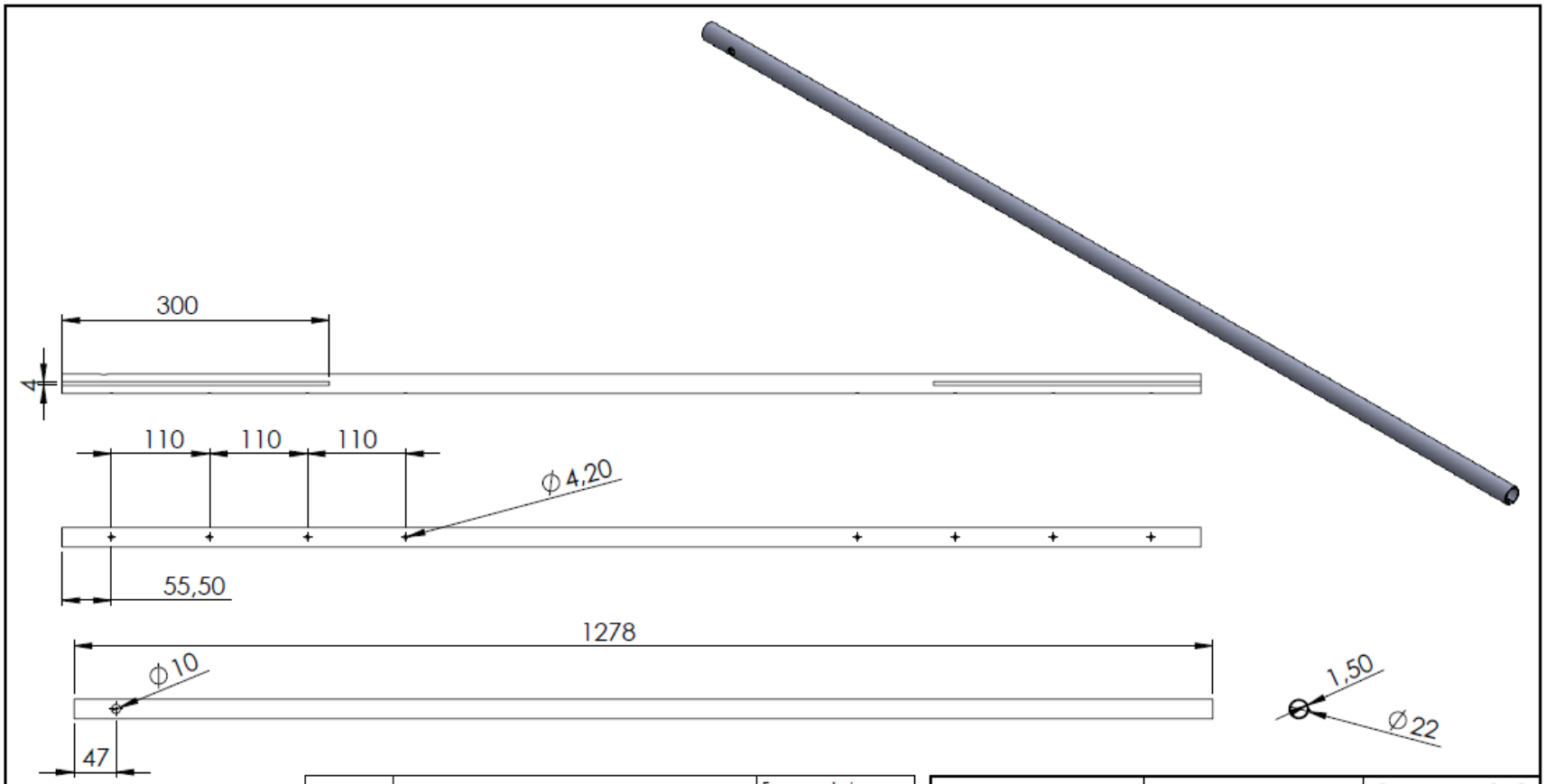






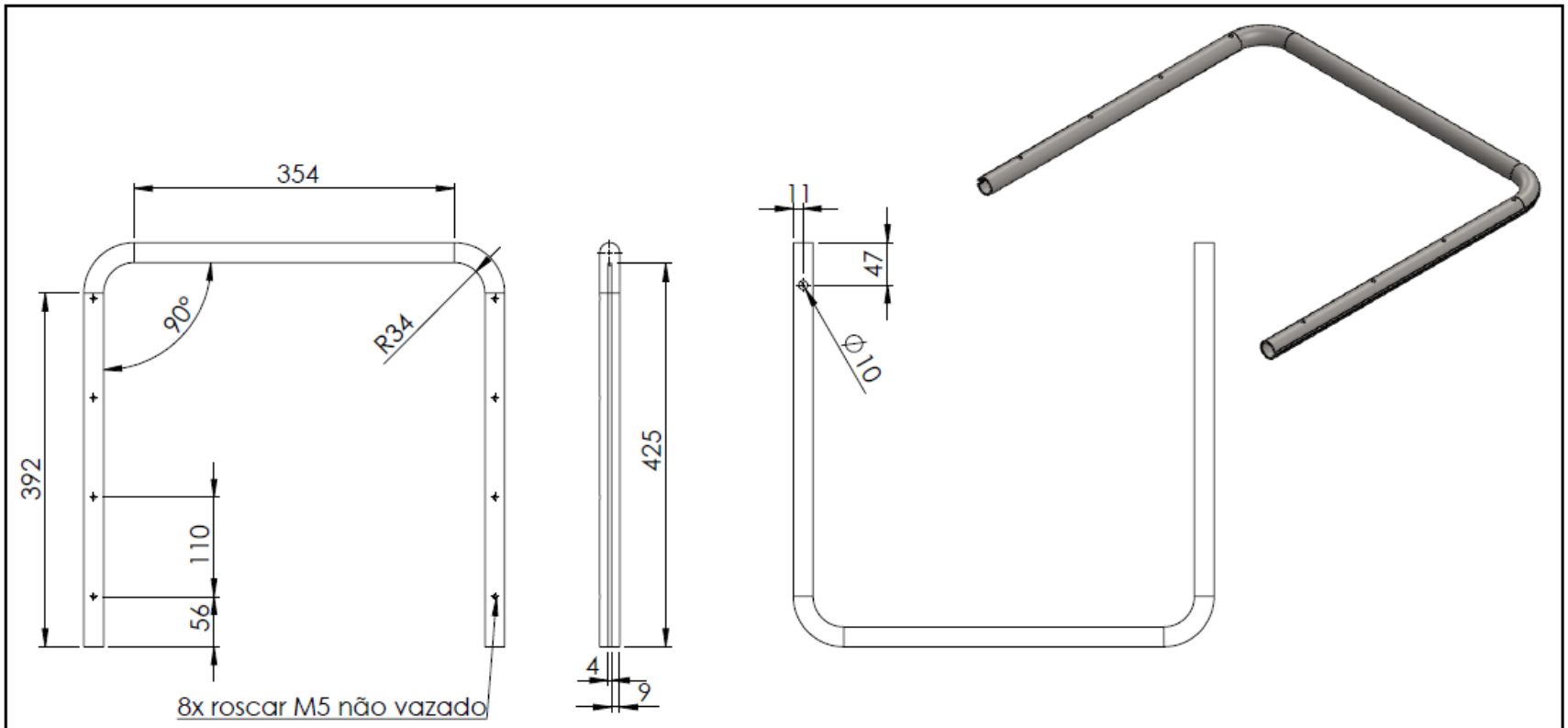
Tubo:	Tubo quadrado aço 30 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 580 mm de tubo	__
2º Oper.	Lixar topos	__
3º Oper.	__	__
4º Oper.	__	__
5º Oper.	__	__
6º Oper.	__	__
7º Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_tubo interior costas 30x30mm			Versão Nº



Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 1278 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

Tolerâncias	Observações				ORTHOS XXI european inclusive solutions
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2	
Escala 1:6	PROJ.			Data: 08/03/2018	
Configuration:	DESENH.	03/06/2021	Filipa Fernandes	Substitui: Versão nº 1	
Default<As Machined>	VERIFIC.	03/06/2021		Substituído por: João Silva	
Produto: __	Tipo de desenho: __				
Código:	Designação: tubo costas desdobrado			Versão Nº	



Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1ª Dobra	392	90		34
2ª Dobra	354	90		34
3ª Dobra				
4ª Dobra				
5ª Dobra				
6ª Dobra				

Tubo:	Tubo redondo aço 22x1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 1279 mm de tubo	—
2ª Oper.	Dobrar conforme tabela	—
3ª Oper.	Furar conforme desenho	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

Tolerâncias
Comp. +/-1mm
Diam. +/-0,1mm
Ang. +/-1°

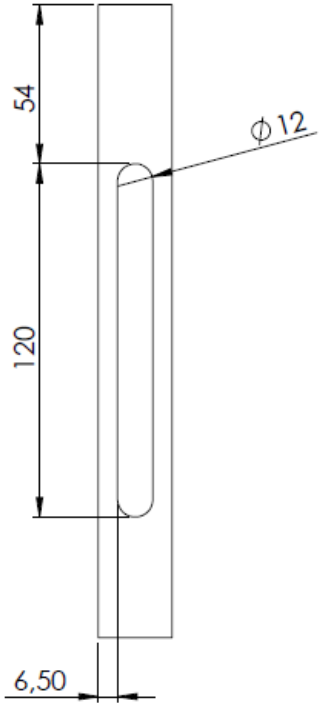
Observações

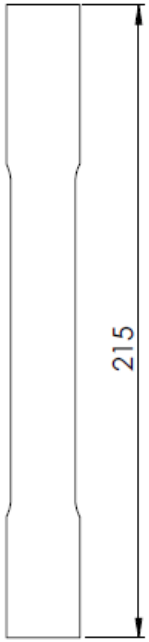
ORTHOS XXI european inclusive solutions

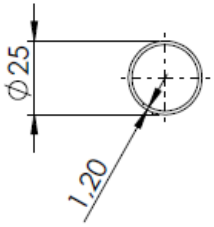
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:6	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva

Produto: —
Tipo de desenho: —

Código:	Designação:	Versão N°
	V12_tubo costas 22mm	



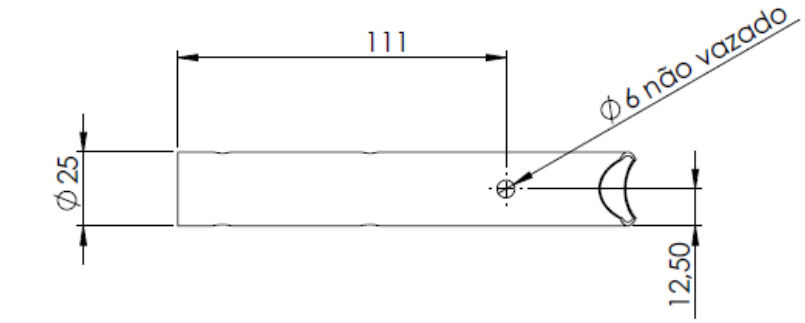


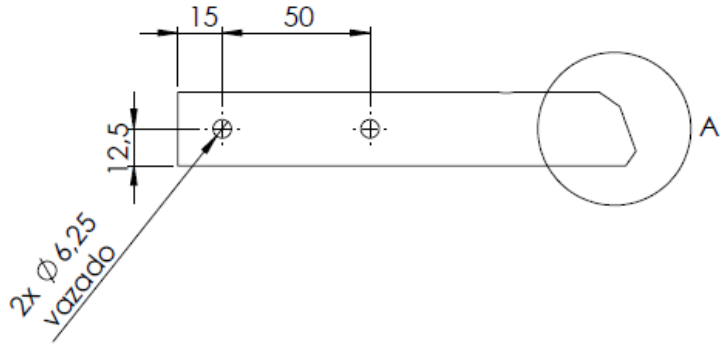


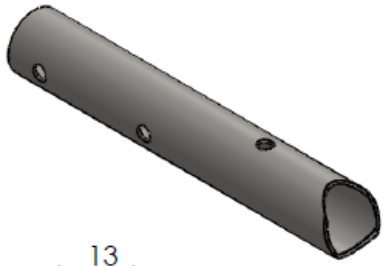
Tubo:	Tubo redondo aço 25 x 1,2 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 215 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

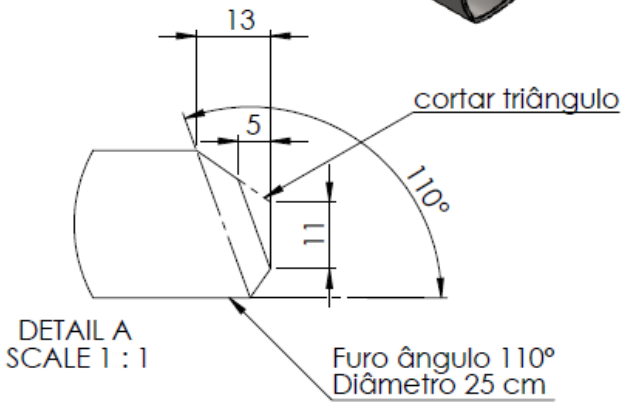
Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°		D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2		PROJ.			Data: 08/03/2018
Configuration:		DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
Default<As Machined>		VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __		Tipo de desenho: __			
Código:	Designação: V12_tubo exterior apoio pés 25mm				Versão Nº

ORTHOS XXI european inclusive solutions







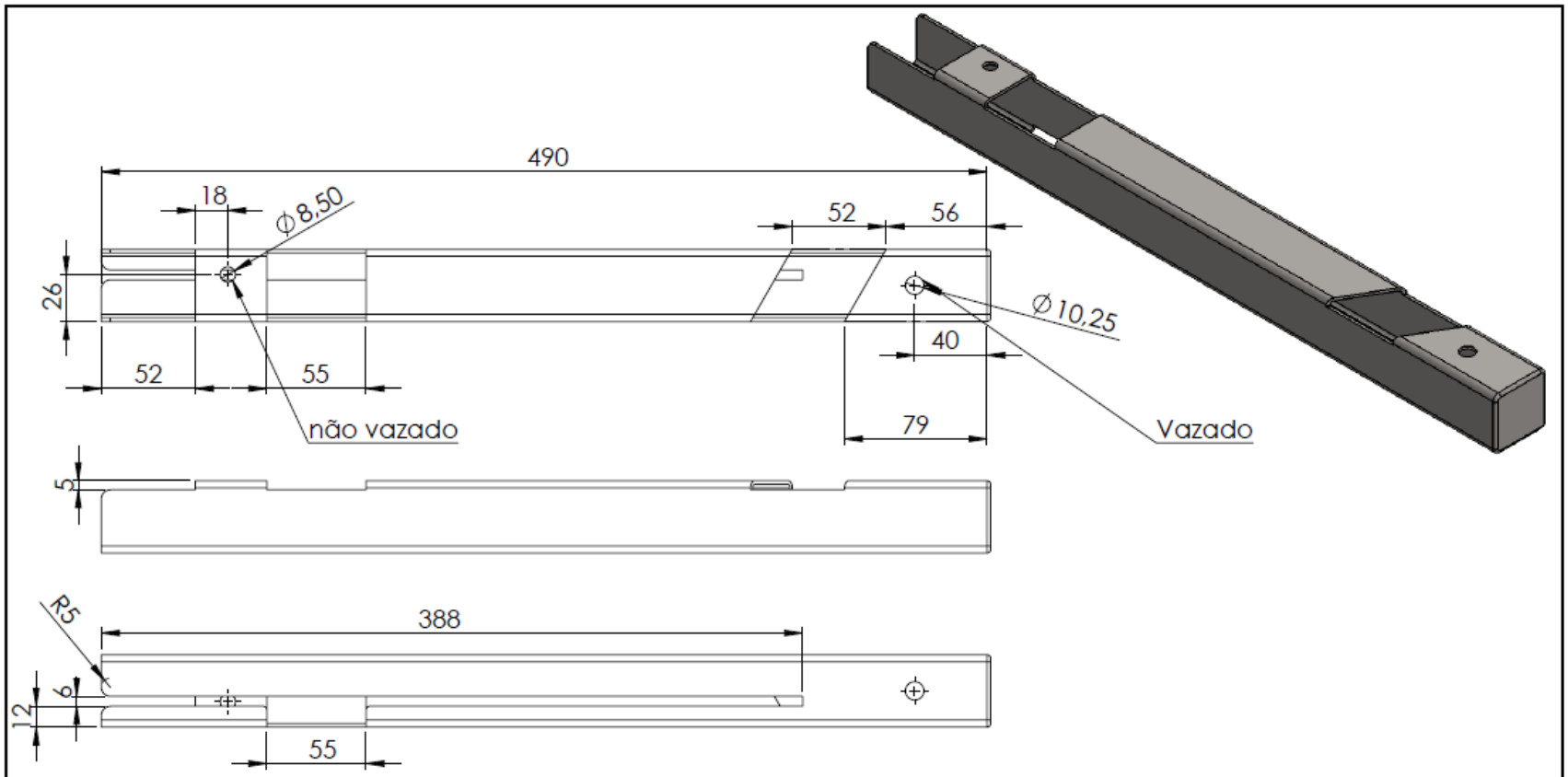


Tubo:	Tubo redondo aço 25 x 1,25 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 155 mm de tubo	—
2ª Oper.	Lixar topos	—
3ª Oper.	—	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

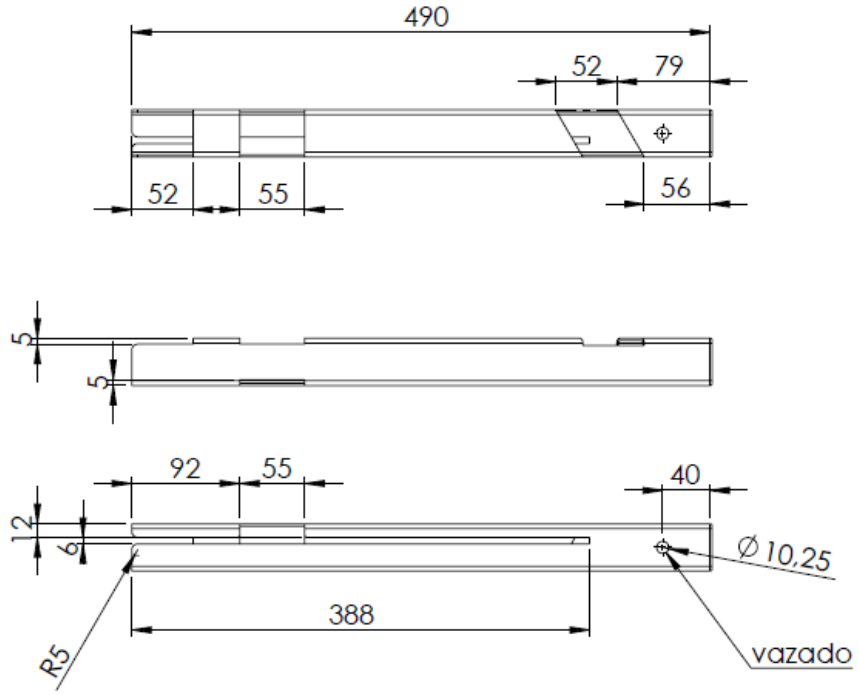
Código:	Designação:	Versão N°
	V12_tubo lig apoio pes-cadeira 25mm	

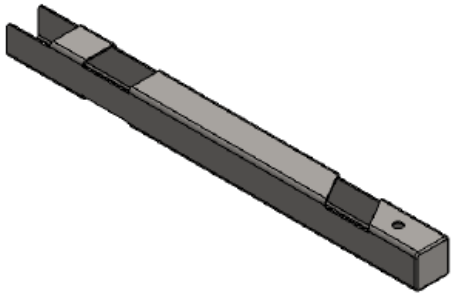
ORTHOS XXI european inclusive solutions



Tubo:	Tubo quadrado 40 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 490 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

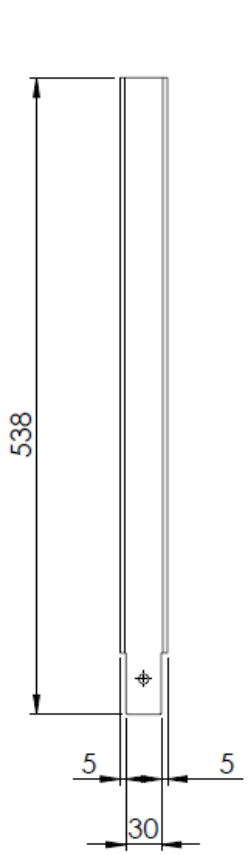
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo assento dir 40x40mm			Versão N°

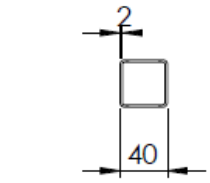


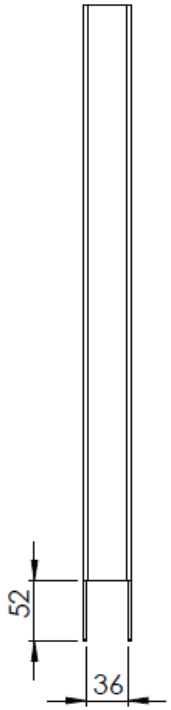


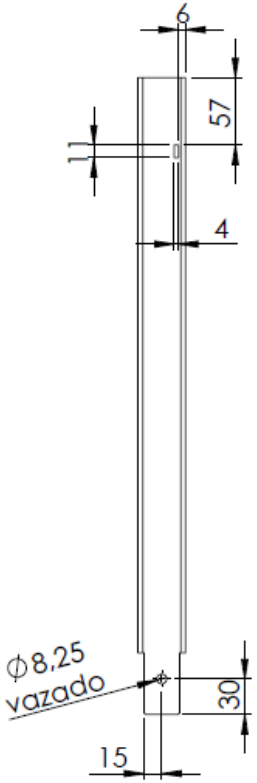
Tubo:	Tubo quadrado aço 40x2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 490 mm de tubo	__
2º Oper.	Lixar topos	__
3º Oper.	__	__
4º Oper.	__	__
5º Oper.	__	__
6º Oper.	__	__
7º Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_tubo assento esq 40x40mm			Versão Nº



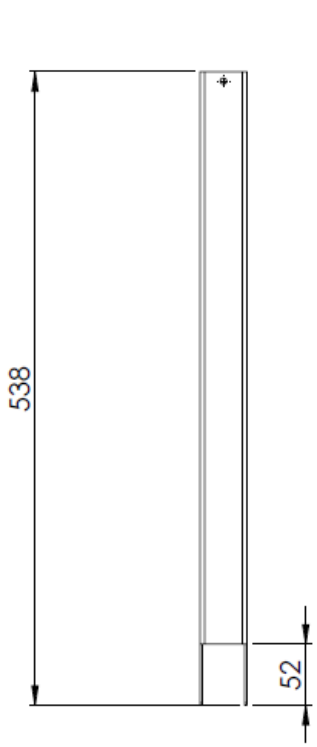


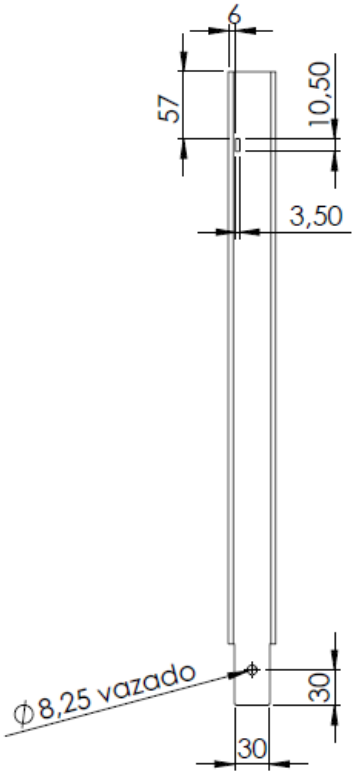




Tubo:	Tubo quadrado aço 40 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 538 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

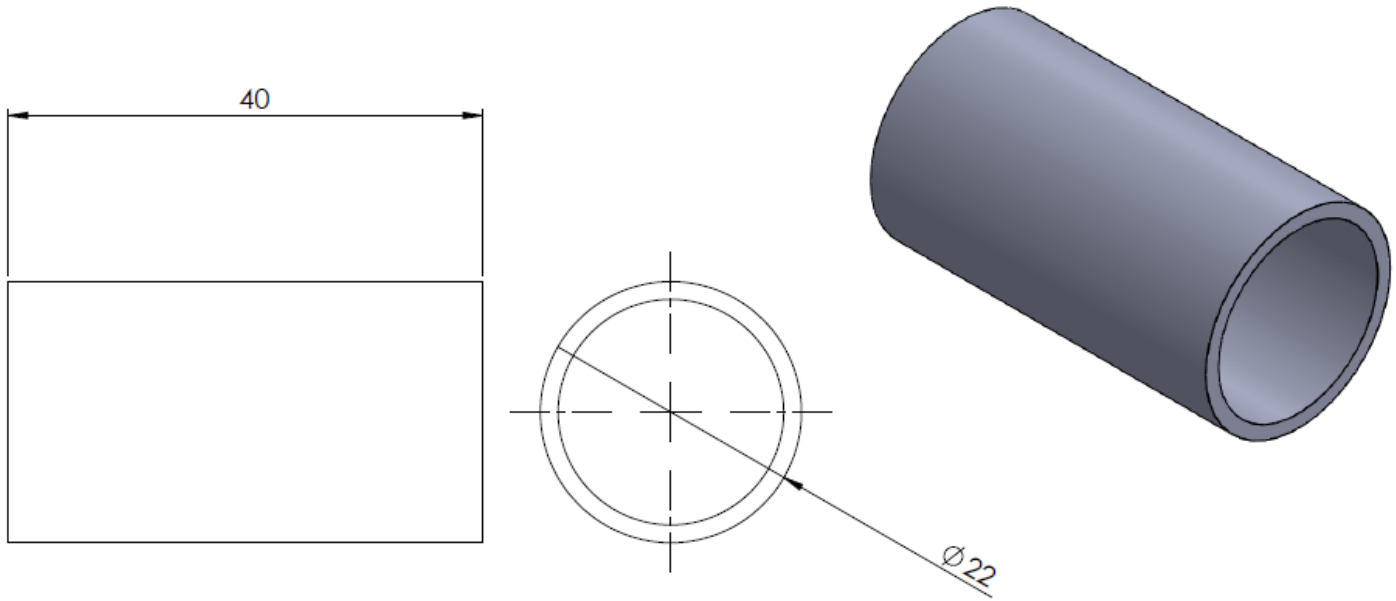
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo costas dir 40x40mm			Versão Nº





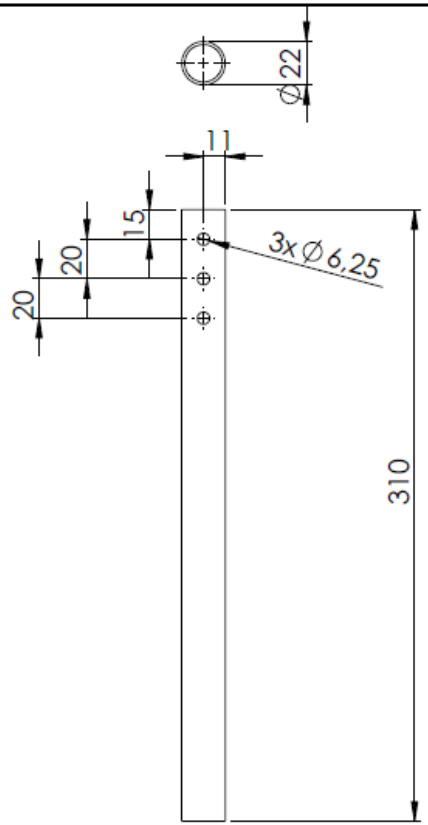
Tubo:	Tubo quadrado aço 40 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 538mm de tubo	__
2º Oper.	Lixar topos	__
3º Oper.	__	__
4º Oper.	__	__
5º Oper.	__	__
6º Oper.	__	__
7º Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	30/04/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_tubo costas esq 40x40mm			Versão Nº



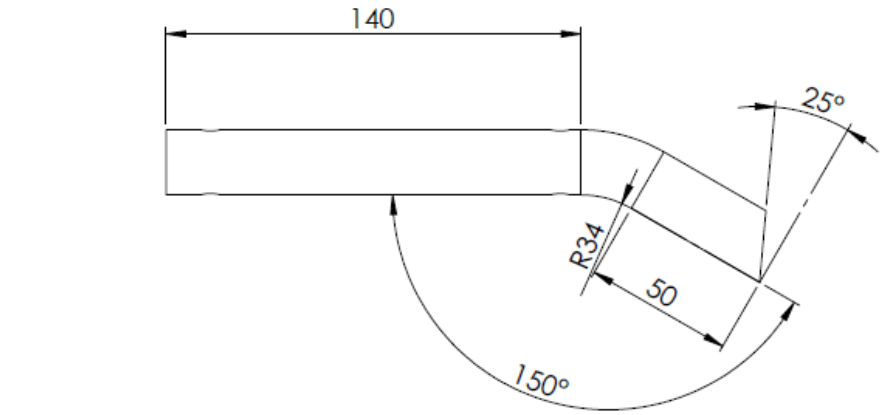
Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 40 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

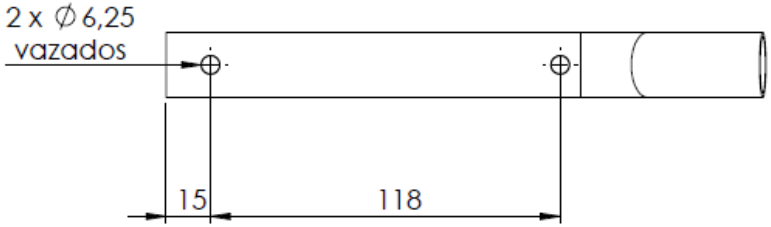
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	04/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	04/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: tubo apoio cabeça prototipo			Versão N°



Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 310 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_ tubo interior apoio pes 22mm			Versão Nº



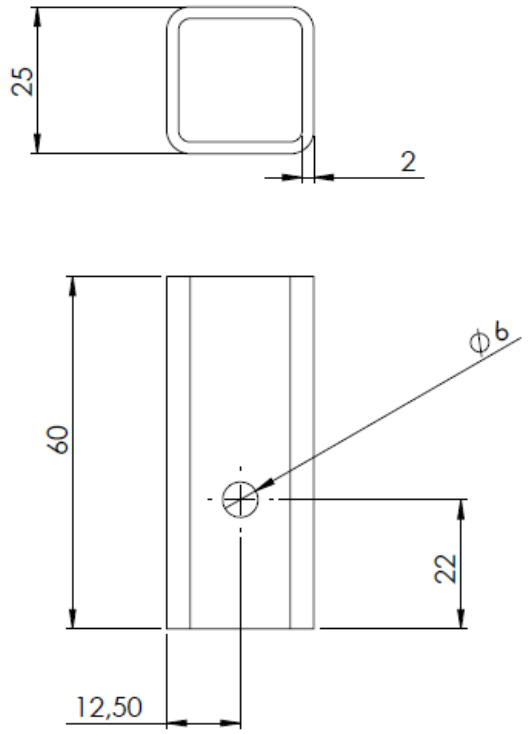


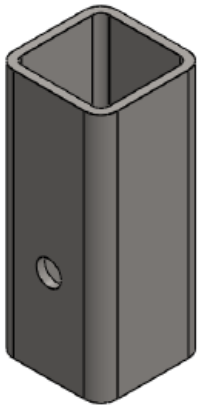
Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1º Dobra	140	150		34
2º Dobra				
3º Dobra				
4º Dobra				
5º Dobra				
6º Dobra				

Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1º Oper.	Cortar 214 mm de tubo	—
2º Oper.	Dobrar conforme tabela	—
3º Oper.	Furar conforme desenho	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º		D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2		PROJ.			Data: 08/03/2018
Configuration:		DESENH.	04/05/2021	Filipa Fernandes	Substitui: Versão nº 1
Default<As Machined>		VERIFIC.	04/05/2021		Substituído por: João Silva
Produto: —		Tipo de desenho: —			
Código:	Designação: V12_tubo ajuste altura prototipo				Versão Nº

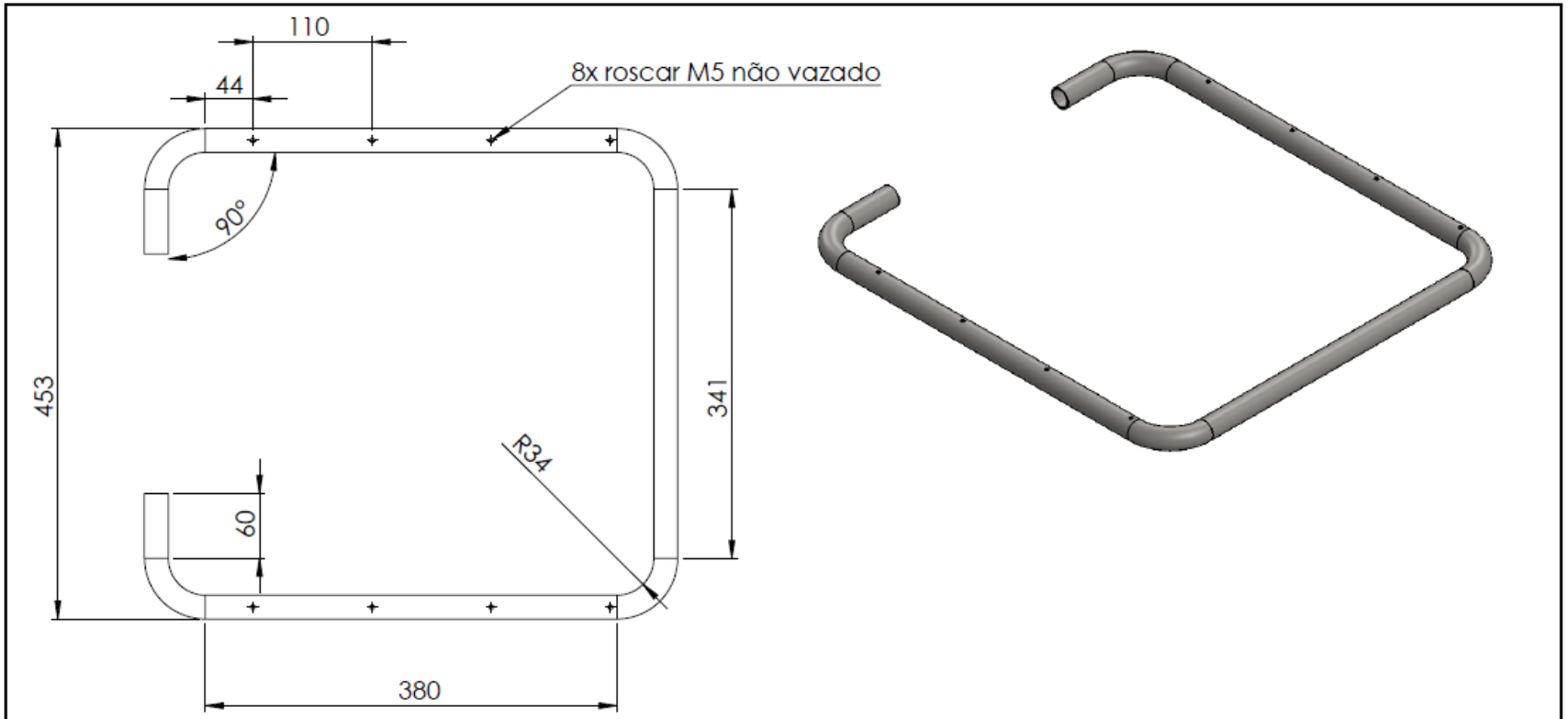
ORTHOS XXI european inclusive solutions





Tubo:	Tubo quadrado aço 25 x 2 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 60 mm de tubo	—
2ª Oper.	Lixar topos	—
3ª Oper.	—	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo apoio arco 25x25mm			Versão Nº



Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1ª Dobra	60	90		34
2ª Dobra	380	90		34
3ª Dobra	341	90		34
4ª Dobra	380	90		34
5ª Dobra				
6ª Dobra				

Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 1504 mm de tubo	—
2ª Oper.	Dobrar conforme tabela	—
3ª Oper.	Furar conforme desenho	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

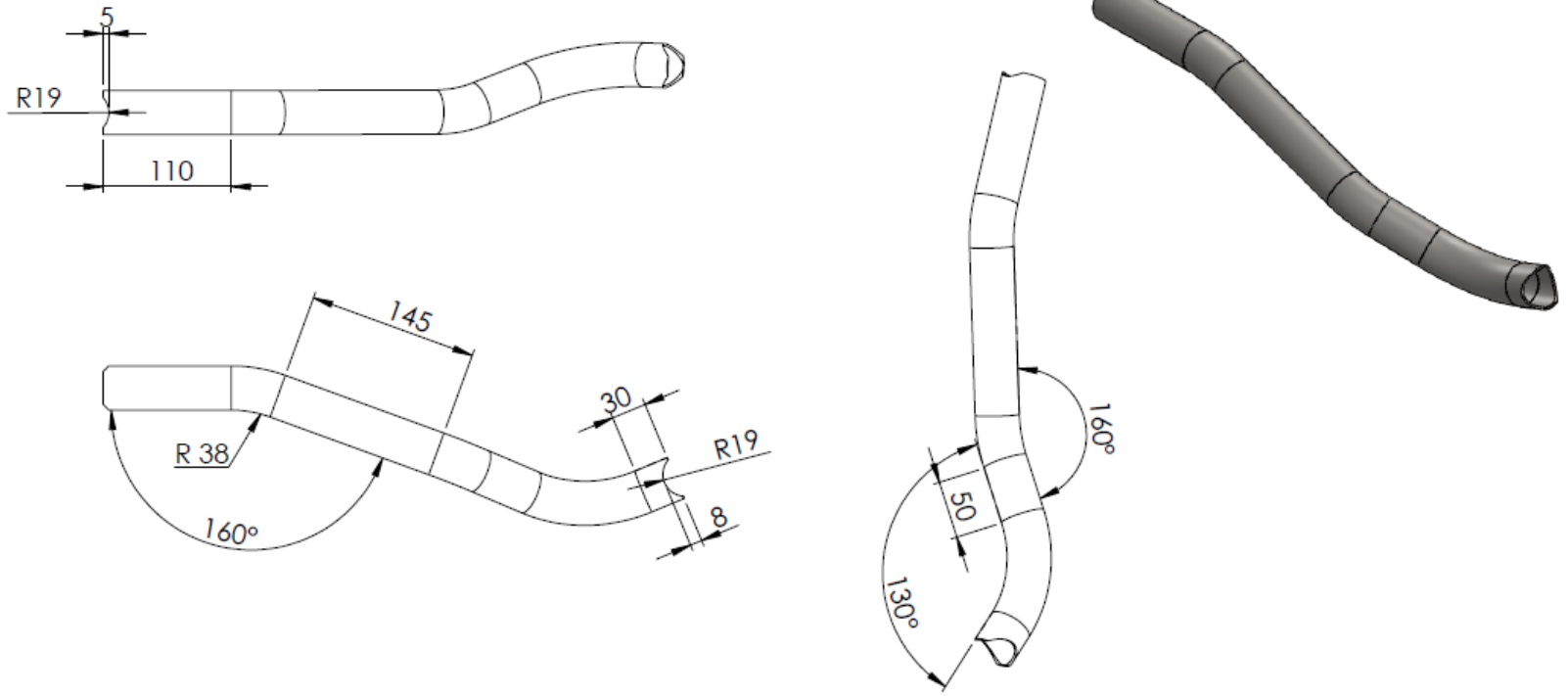
Tolerâncias
Comp. +/-1mm
Diam. +/-0,1mm
Ang. +/-1°

Observações

ORTHOS XXI european inclusive solutions

	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

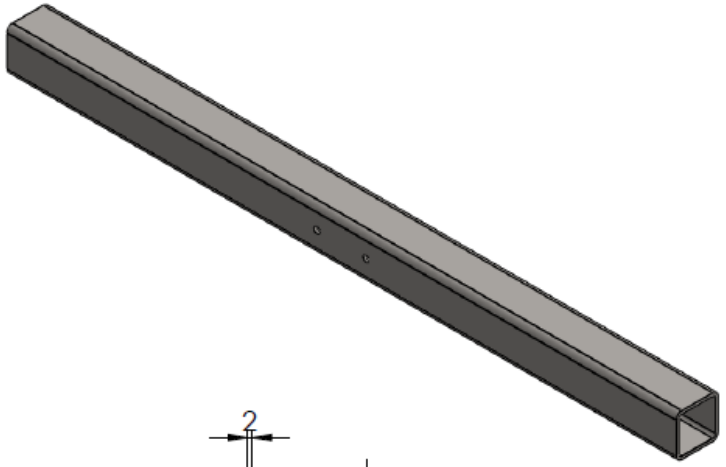
Código:	Designação:	Versão Nº
	V12_tubo assento 22mm	

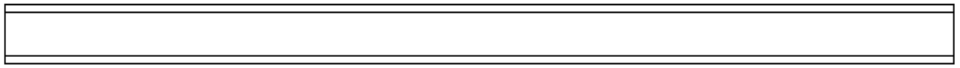


Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1ª Dobra	110	160	0	38
2ª Dobra	145	160	81	38
3ª Dobra	50	130	60	38
4ª Dobra				
5ª Dobra				
6ª Dobra				

Tubo:	Tubo redondo aço 38 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 519 mm de tubo	—
2º Oper.	Dobrar conforme tabela	—
3º Oper.	Furar conforme desenho	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

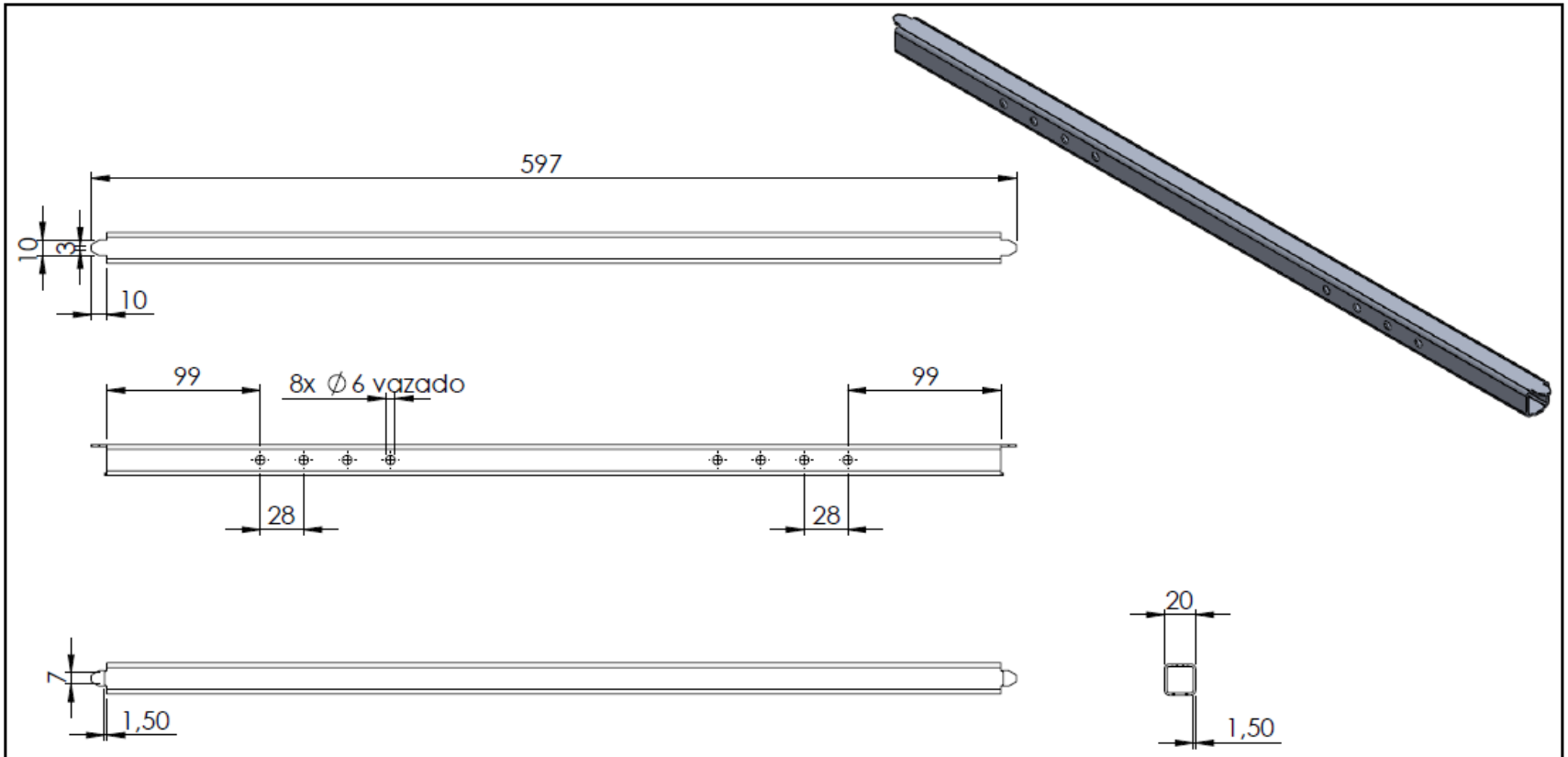
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: Júlio Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo base rodas tras 38 mm			Versão N°





Tubo:	Tubo quadrado aço 30 x 2 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 478 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

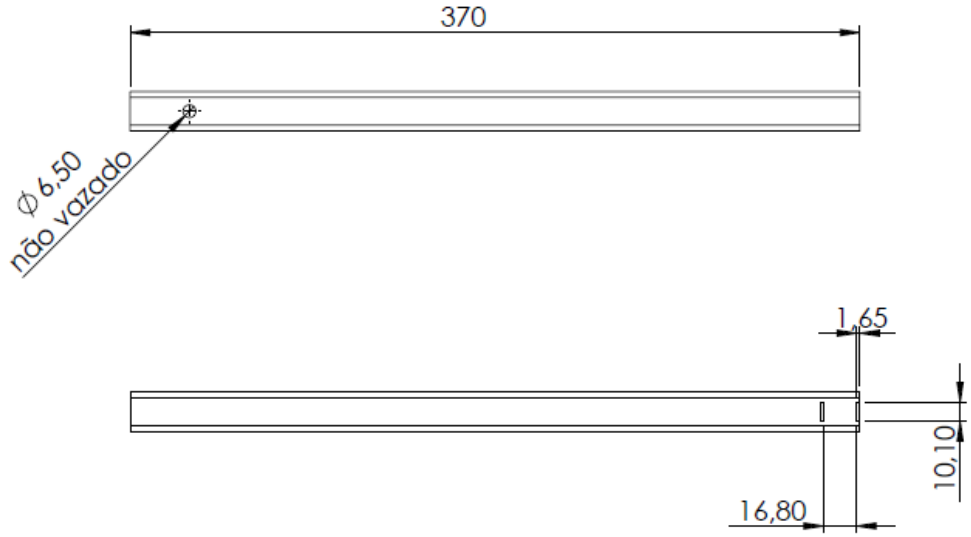
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituido por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_tubo comprido rgrua 30x30mm			Versão Nº

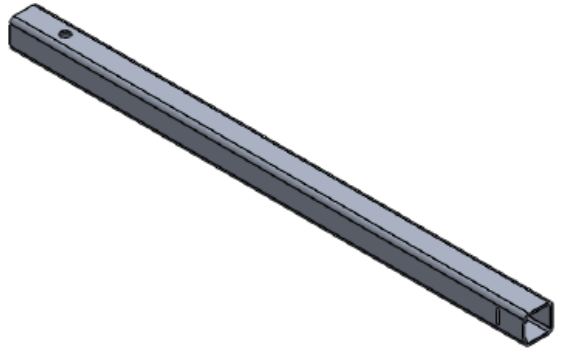


Tubo:	Tubo quadrado aço 20 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 597 mm de tubo	—
2ª Oper.	Lixar topos	—
3ª Oper.	—	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°		D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3.		PROJ.			Data: 06/05/2018
Configuration:		DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
Default<As Machined>		VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —		Tipo de desenho: —			
Código:	Designação: V12_tubo horizontal joelhos 20mm				Versão N°

ORTHOS XXI european inclusive solutions



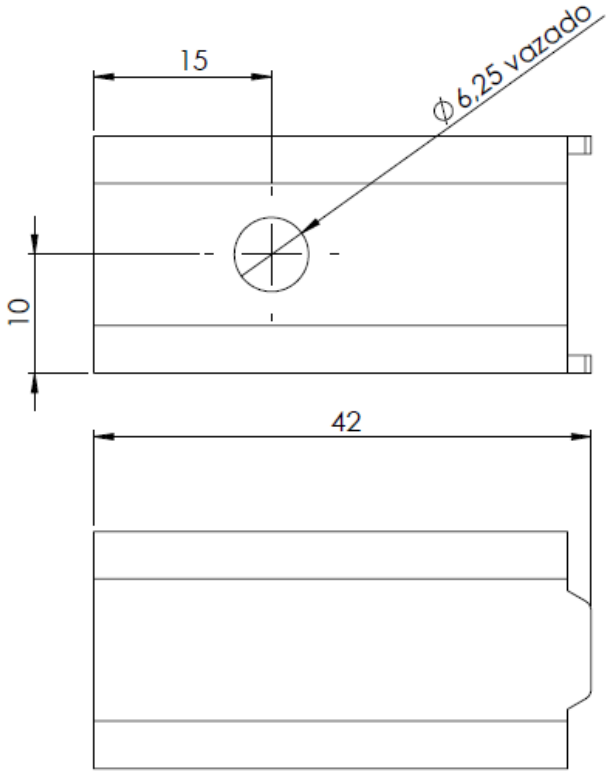


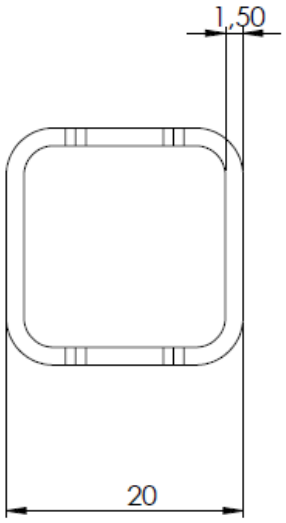
Tubo:	Tubo quadrado aço 20 x 1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 370 mm de tubo	__
2ª Oper.	Lixar topos	__
3ª Oper.	__	__
4ª Oper.	__	__
5ª Oper.	__	__
6ª Oper.	__	__
7ª Oper.	__	__

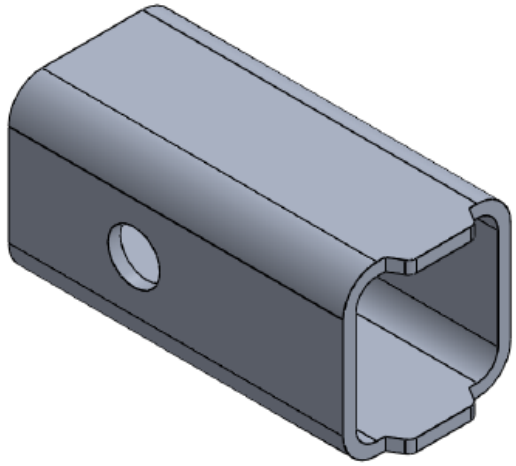
Tolerâncias	Observações			
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 06/03/2018
Configuration:	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
Default<As Machined>	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			

Código:	Designação:	Versão N°
	V12_tubo lig joelhos-estrutura 20mm	

ORTHOS XXI european inclusive solutions

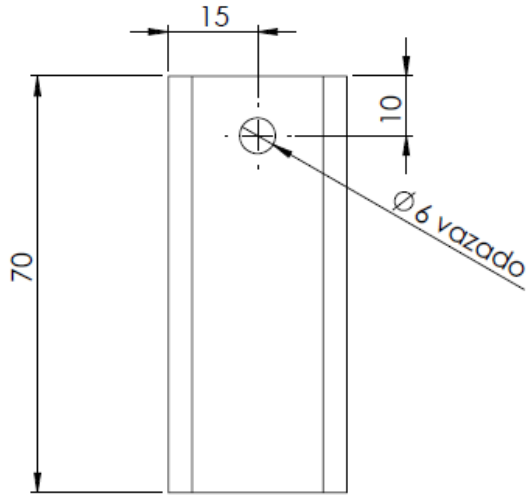


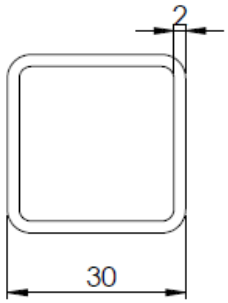


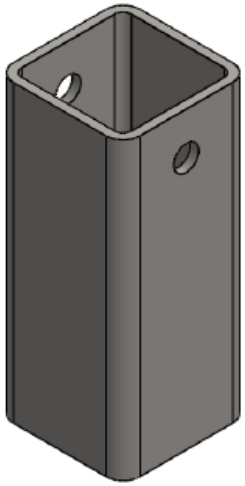


Tubo:	Tubo redondo aço 20 x 1,5 mm	Ferramenta/ Máquina
1º Oper.	Cortar 42 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo longitudinal joelhos 20mm			Versão Nº

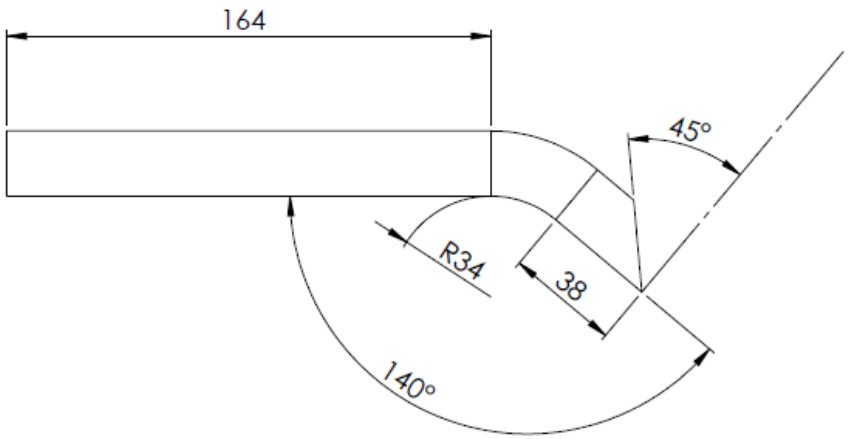


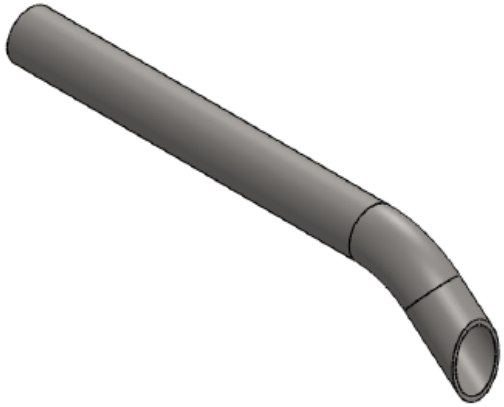




Tubo:	Tubo quadrado aço 20 x 2 mm	Ferramenta/ Máquina
1º Oper.	Cortar 70 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	03/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	03/05/2021		Substituído por: Júlio Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo meio grua 30x30mm			Versão Nº

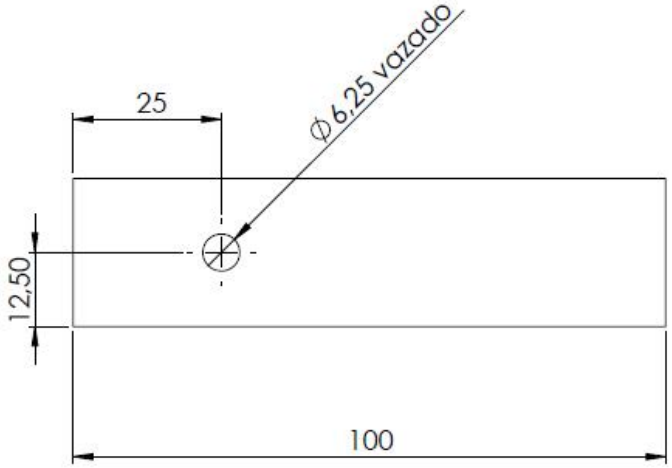


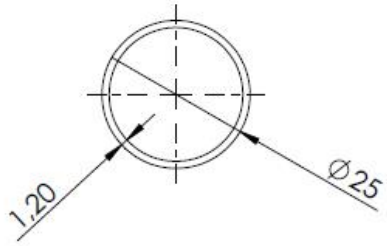


Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1º Dobra	164	140		34
2º Dobra				
3º Dobra				
4º Dobra				
5º Dobra				
6º Dobra				

Tubo:	Tubo redondo aço 22x1,5 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 233 mm de tubo	—
2ª Oper.	Dobrar conforme tabela	—
3ª Oper.	Furar conforme desenho	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

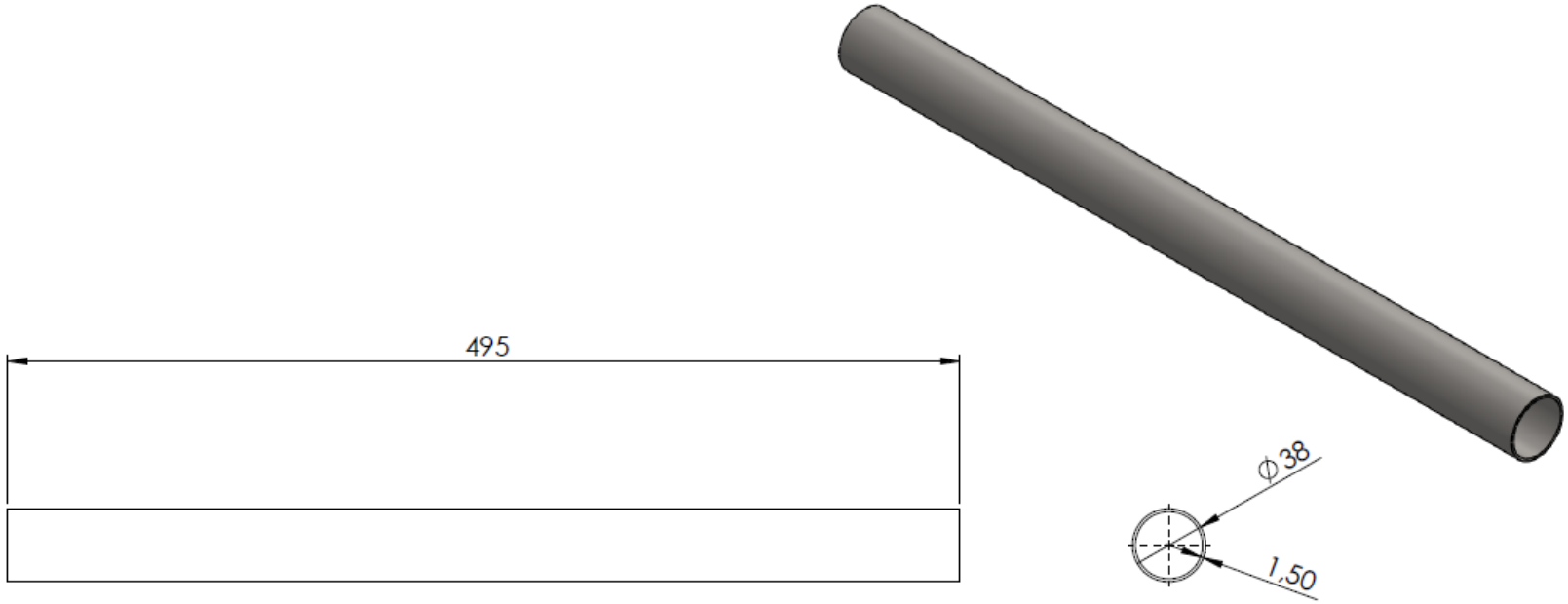
Tolerâncias	Observações				ORTHOS XXI european inclusive solutions
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º		D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2		PROJ.			Data: 08/03/2018
Configuration:		DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
Default<As Machined>		VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: —		Tipo de desenho: —			
Código:	Designação: V12_tubo punho 22mm				Versão Nº





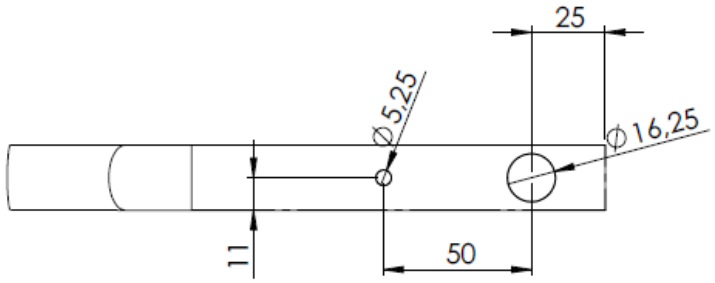
Tubo:	Tubo redondo aço 25 x 1,2 mm	Ferramenta/ Máquina
1ª Oper.	Cortar 100 mm de tubo	—
2ª Oper.	Lixar topos	—
3ª Oper.	—	—
4ª Oper.	—	—
5ª Oper.	—	—
6ª Oper.	—	—
7ª Oper.	—	—

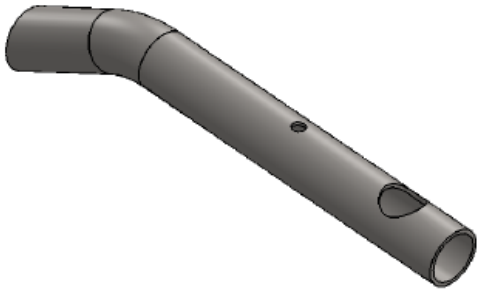
Tolerâncias	Observações				ORTHOS xxi european inclusive solutions
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2	
Escala 1:1	PROJ.			Data: 06/03/2018	
Configuration:	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1	
Default<As Machined>	VERIFIC.	02/05/2021		Substituído por: João Silva	
Produto: —	Tipo de desenho: —				
Código:	Designação: V12_tubo roda anti-queda 25 mm			Versão N°	

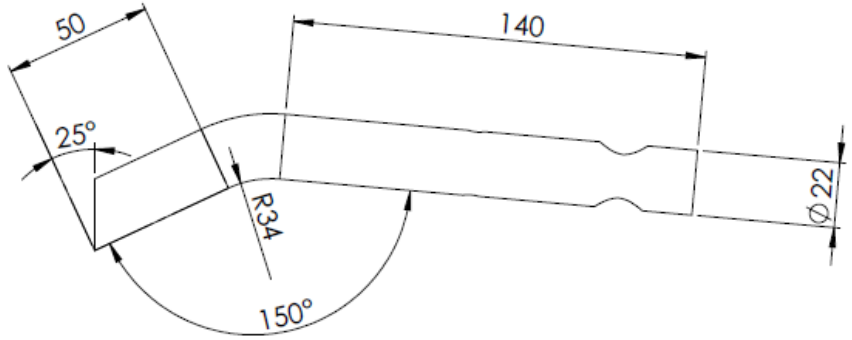


Tubo:	Tubo redondo aço 38 x 1,5 mm	Ferramenta/ Máquina
1º Oper.	Cortar 495 mm de tubo	—
2º Oper.	Lixar topos	—
3º Oper.	—	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:3	PROJ.			Data: 06/03/2018
Configuration: Default<As Machined>	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_tubo uniao central 38mm			Versão Nº







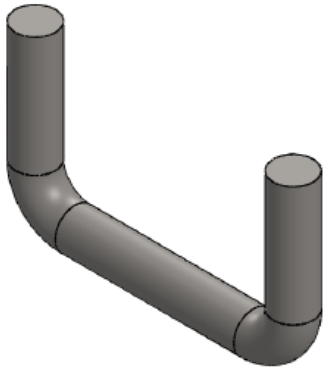
Dobragem Tubos				
	Comprim.	Ângulo	Rotação	Raio
1º Dobra	50	150		34
2º Dobra				
3º Dobra				
4º Dobra				
5º Dobra				
6º Dobra				

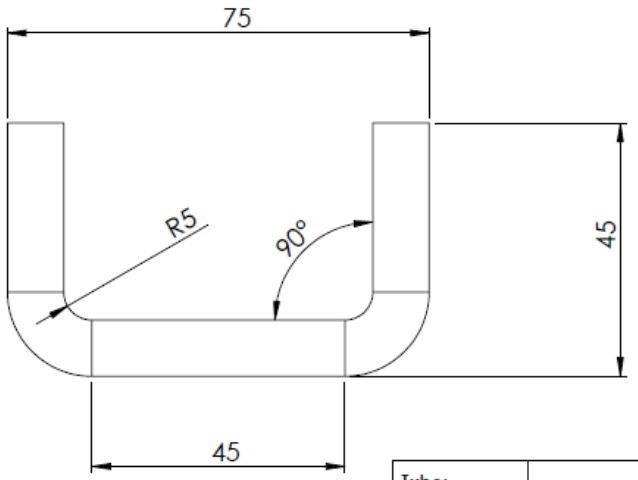
Tubo:	Tubo redondo aço 22 x 1,5 mm	Ferramenta/ Máquina
1º Oper.	Cortar 214mm de tubo	—
2º Oper.	Dobrar conforme tabela	—
3º Oper.	Furar conforme desenho	—
4º Oper.	—	—
5º Oper.	—	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias	Observações			ORTHOS XXI european inclusive solutions
Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:2	PROJ.			Data: 08/03/2018
Configuration:	DESENH.	01/05/2021	Filipa Fernandes	Substituí: Versão nº 1
Default<As Machined>	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

Código:	Designação:	Versão N°
	V12_tubo ajuste altura esq	

- Turnery parts – bushes and rods

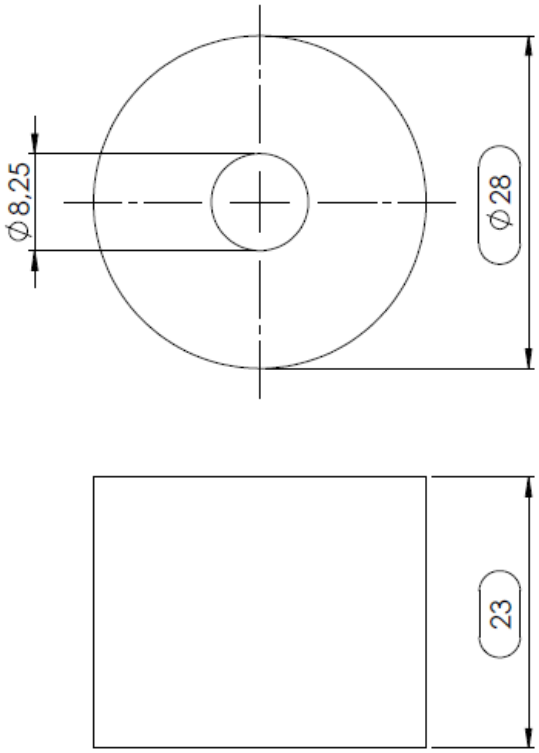


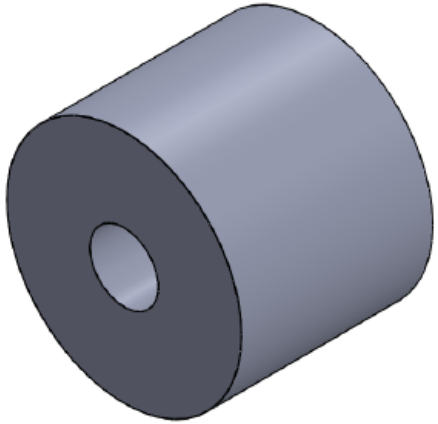


		Aut.	Man.
Tubo:	—		
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default<As Machined>	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

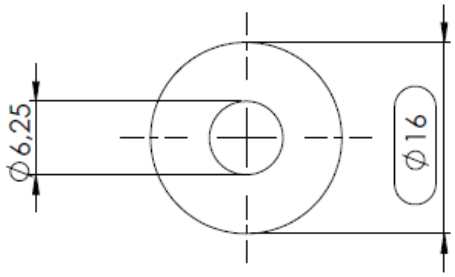
Código:	Designação:	Nº
	V12_argola prender arnes	

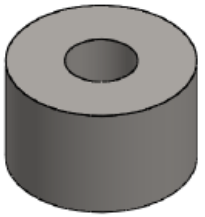


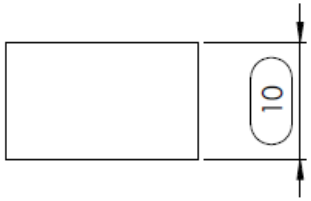


Tubo:	—	Aut.	Man.
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 06/03/2018
Configuration: Default	DESENH.	30/04/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_casquilho alheta costas 28x23mm			Nº

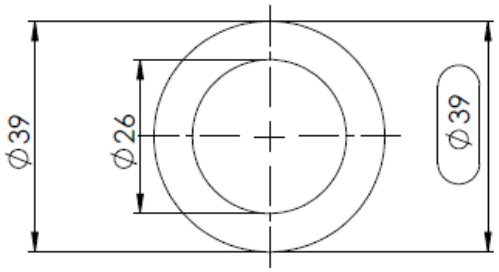


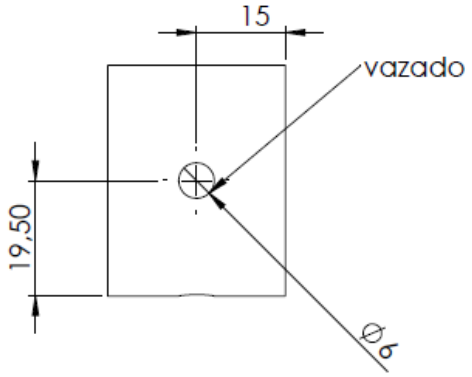


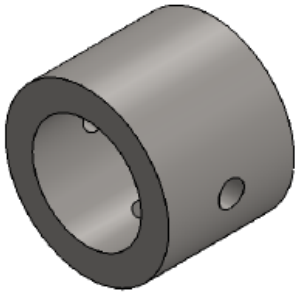


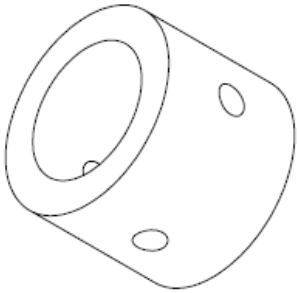
Tubo:	—	Aut.	Man.
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

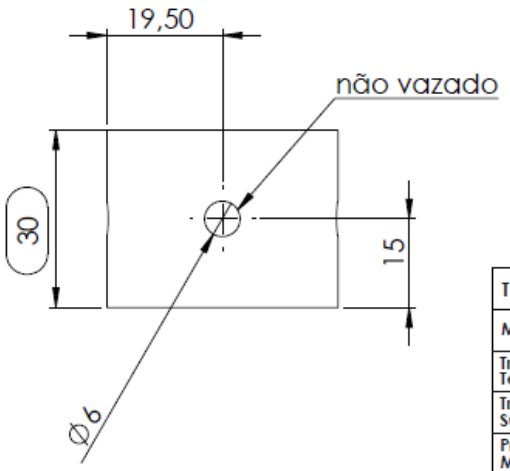
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	30/04/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	30/04/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_casquilho apoio braços esq			Nº







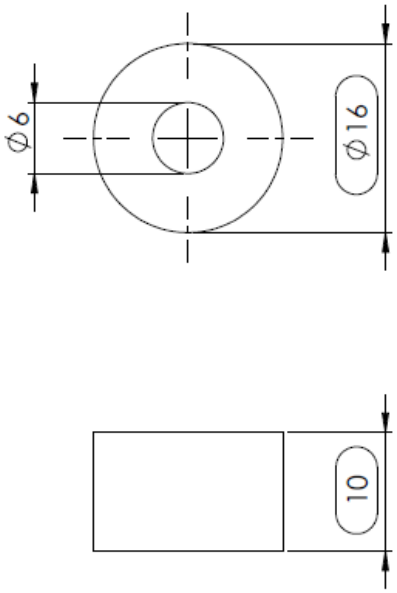


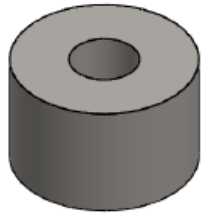


Tubo:	—	Aut.	Man.
Material	—	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	18/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	18/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

Código:	Designação:	Nº
	V12_casquilho apoio gemeos 39x30mm	

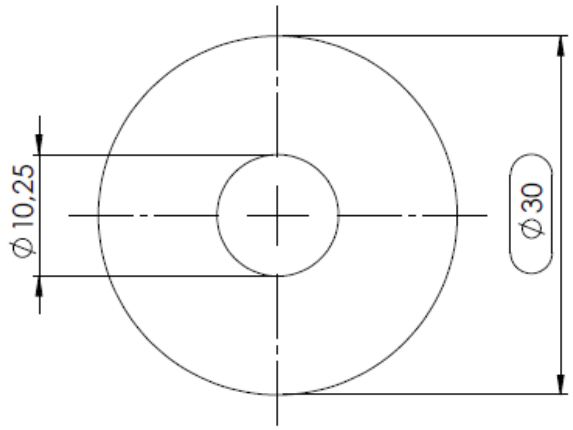


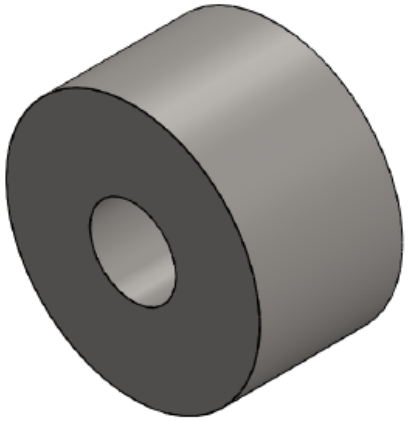


Tubo:	—	Aut.	Man.
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 06/03/2018
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: Júlio Silva
Produto: —	Tipo de desenho: —			

Código:	Designação: V12_casquilho arco 16x10 mm	Nº

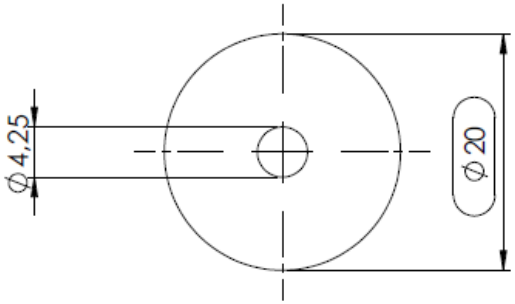


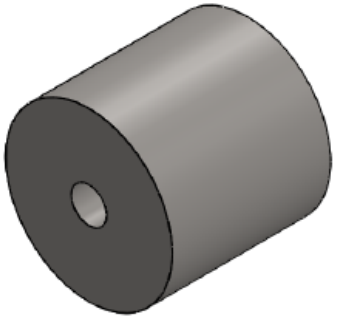


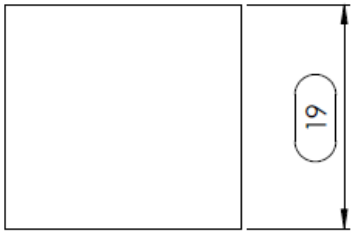
		Aut.	Man.
Tubo:	—		
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european Inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	01/05/2021		Substituido por: João Silva
Produto: —	Tipo de desenho: —			

Código:	Designação:	Nº
	V12_casquilho estrutura chapa	



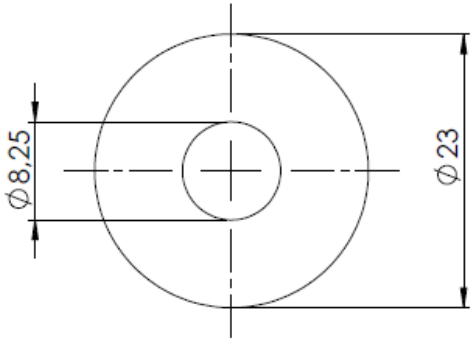


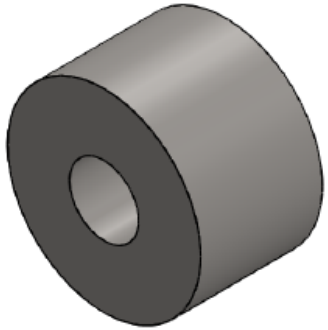


Tubo:	—	Aut.	Man.
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	01/05/2021	Filipa Fernandes	Substituí: Versão nº 1
	VERIFIC.	01/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			

Código:	Designação: V12_casquilho lig ap cabeça-tubo 20x19mm	N°



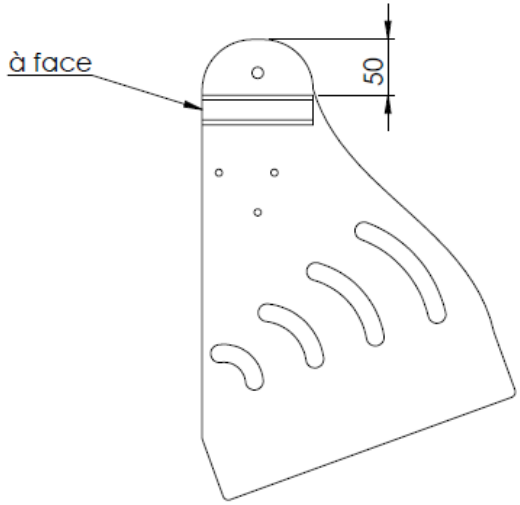


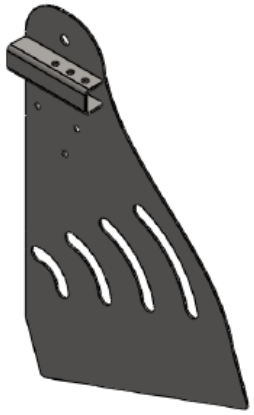
Tubo:	—	Aut.	Man.
Material	aço	—	—
Tratamento Térmico	—	—	—
Tratamento Superficie	—	—	—
Programa de Maquinagem	—	—	—
		—	—
		—	—
		—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 2:1	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituido por: João Silva
Produto: —	Tipo de desenho: —			

Código:	Designação:	N°
	V12_casquilho mola de gas 23x15 mm	

- Welding and assembly

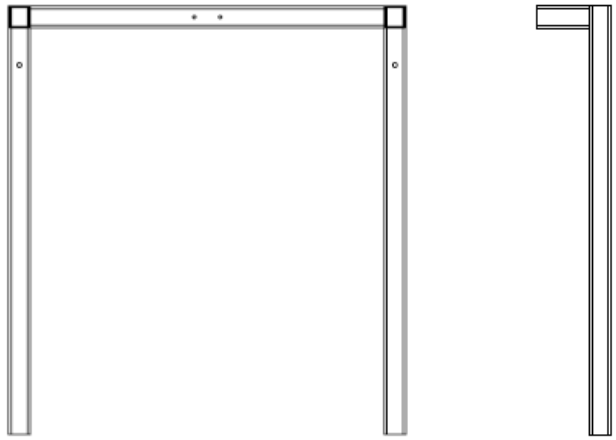


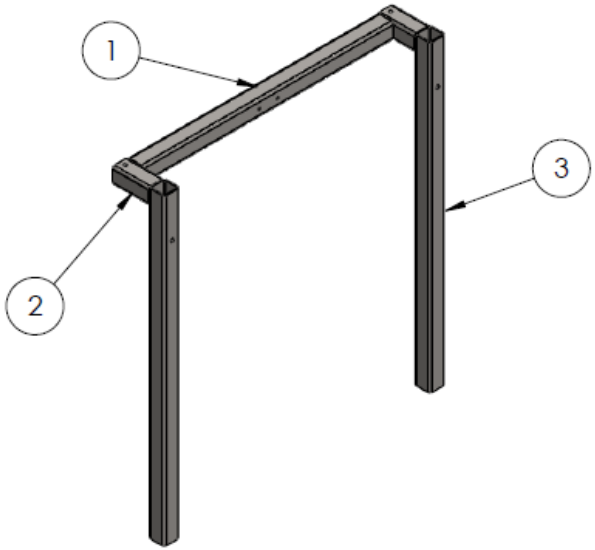


Nº	PEÇA	QTY.
1	V12_chapa lateral 4mm	1
2	V12_chapa lig joelhos-cadeira	1

Soldadura:	Peça	Ferramenta/ Máquina
1º Oper.	Soldar conforme desenho	__
2º Oper.	Limpar salpicos	__
3º Oper.	Desempenar se necessário	__
4º Oper.	Listar quantidades	__
5º Oper.	Listar cor de pintura	__
6º Oper.	__	__
7º Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 07/05/2021
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: Chapa lateral grande+joelhos			Nº

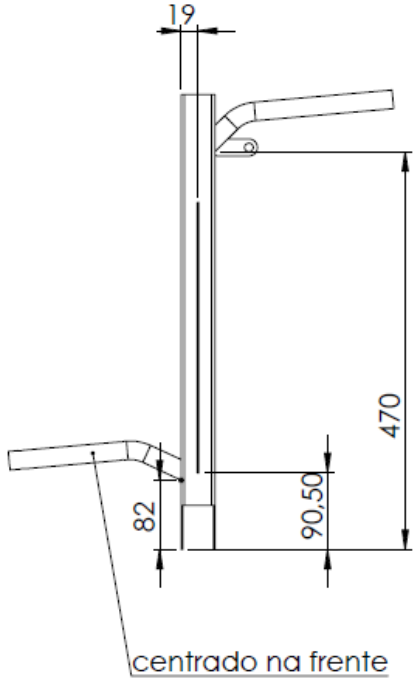


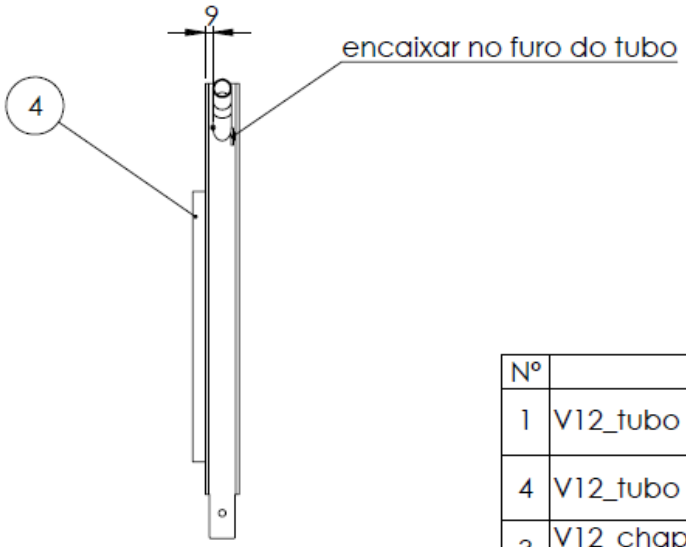


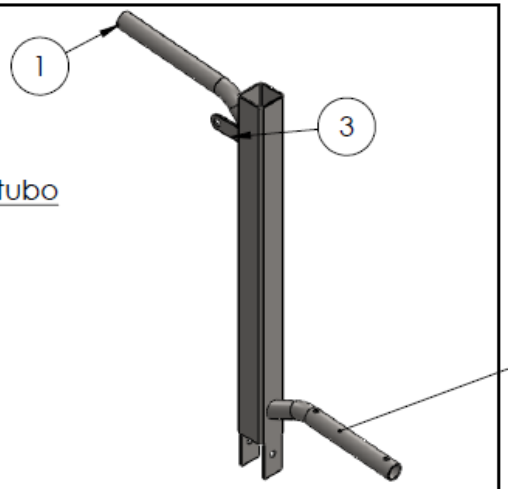
Nº	PEÇA	QTY.
1	V12_tubo comprido rgrua 30x30mm	1
2	V12_tubo meio grua 30x30mm	2
3	V12_tubo interior costas 30x30mm	1

Soldadura:	Peça	Ferramenta/ Máquina
1ª Oper.	Soldar conforme desenho	__
2ª Oper.	Limpar salpicos	__
3ª Oper.	Desempenar se necessário	__
4ª Oper.	Listar quantidades	__
5ª Oper.	Listar cor de pintura	__
6ª Oper.	__	__
7ª Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:8	PROJ.			Data: 07/05/2021
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituido por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: costas estrutura superior			Nº



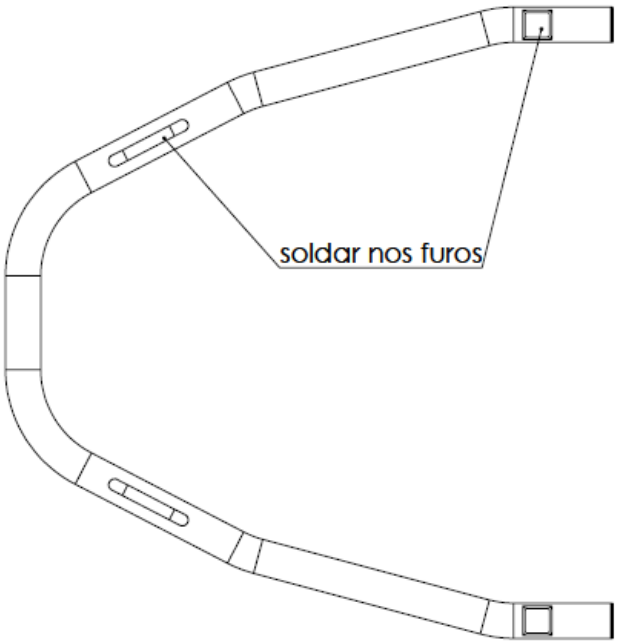


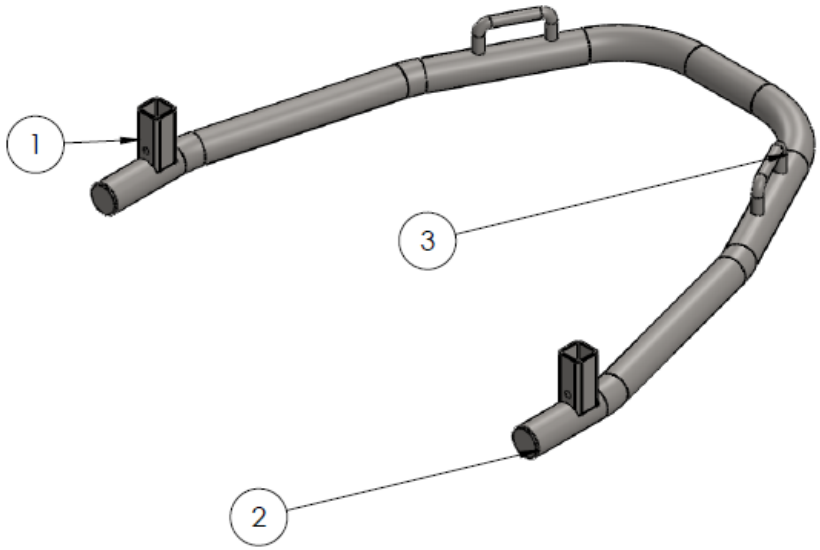


Nº	PEÇA	QTY.
1	V12_tubo punho 22mm	1
4	V12_tubo costas dir 40x40mm	1
3	V12_chapa atuador costas cima 3mm	1
4	V12_chapa correr costas 3mm	1
5	V12_tubo ajuste altura prototipo	1

Soldadura:	Peça	Ferramenta/ Máquina
1º Oper.	Soldar conforme desenho	—
2º Oper.	Limpar salpicos	—
3º Oper.	Desempenar se necessário	—
4º Oper.	Listar quantidades	—
5º Oper.	Listar cor de pintura	—
6º Oper.	—	—
7º Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:7	PROJ.			Data: 07/05/2021
Configuration: Default	DESENH.	07/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	07/05/2021		Substituido por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: lateral costas			Nº

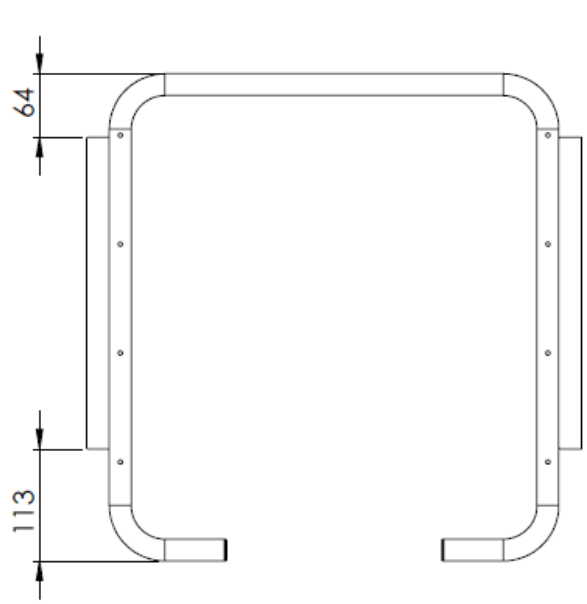


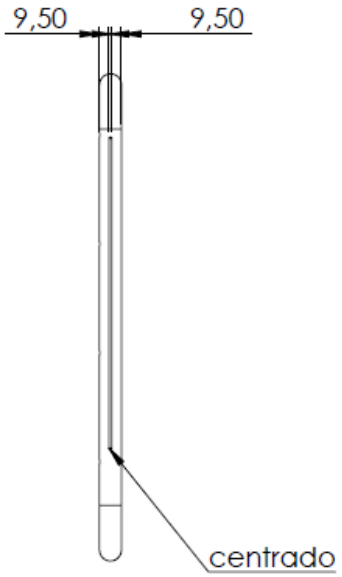


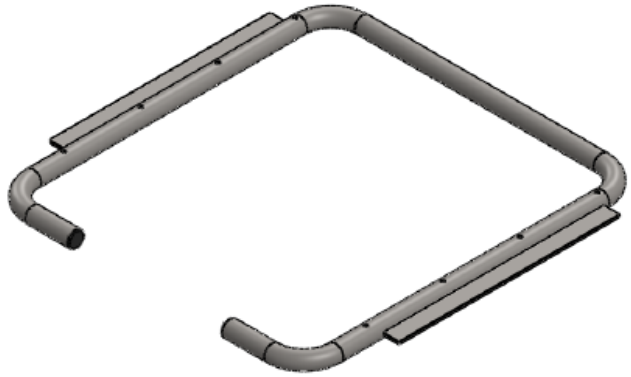
Nº	PEÇA	QTY.
1	V12_tubo apoio arco 25x25mm	2
2	V12_arco tubo 30mm	1
3	V12_argola prender arnes	2

Soldadura:	Peça	Ferramenta/ Máquina
1ª Oper.	Soldar conforme desenho	—
2ª Oper.	Limpar salpicos	—
3ª Oper.	Desempenar se necessário	—
4ª Oper.	Listar quantidades	—
5ª Oper.	Listar cor de pintura	—
6ª Oper.	—	—
7ª Oper.	—	—

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 02/05/2021
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: —	Tipo de desenho: —			
Código:	Designação: V12_arco completo			Nº



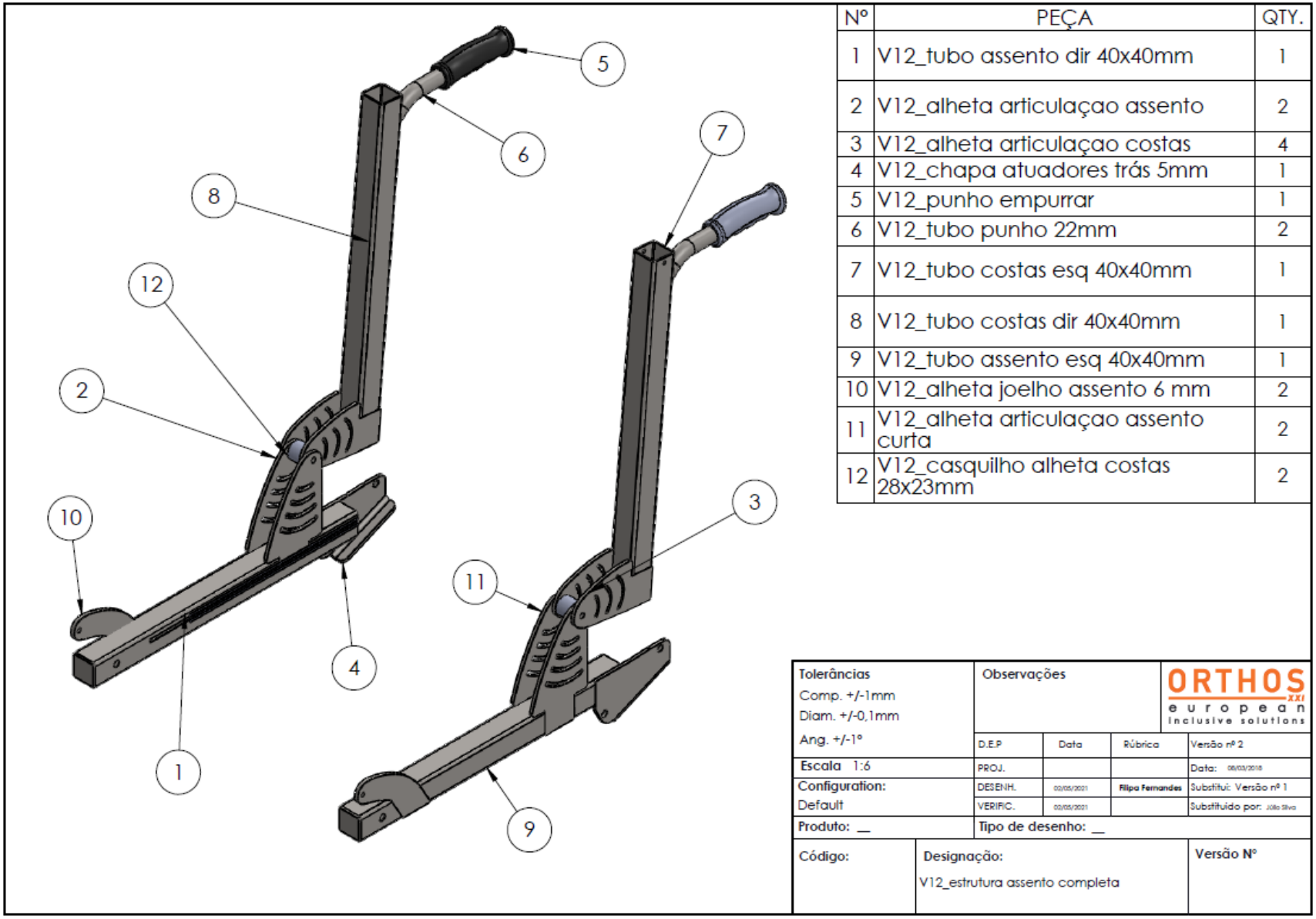




Nº	PEÇA	QTY.
1	V12_tubo assento 22mm	1
3	V12_chapa correr assento 3mm	2

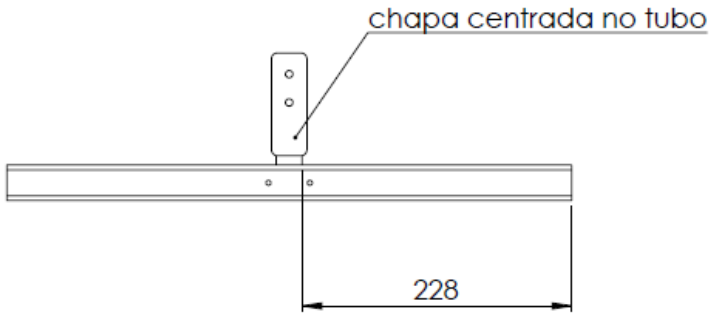
Soldadura:	Peça	Ferramenta/ Máquina
1º Oper.	Soldar conforme desenho	__
2º Oper.	Limpar salpicos	__
3º Oper.	Desempenar se necessário	__
4º Oper.	Listar quantidades	__
5º Oper.	Listar cor de pintura	__
6º Oper.	__	__
7º Oper.	__	__

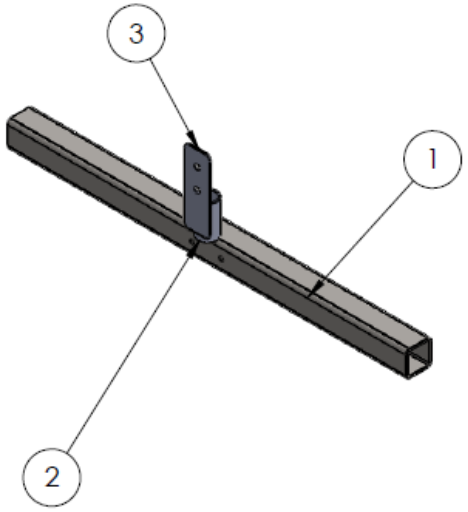
Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:6	PROJ.			Data: 04/05/2021
Configuration: Default	DESENH.	04/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	04/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_assento			Nº



Nº	PEÇA	QTY.
1	V12_tubo assento dir 40x40mm	1
2	V12_alheta articulaçao assento	2
3	V12_alheta articulaçao costas	4
4	V12_chapa atuadores trás 5mm	1
5	V12_punho empurrar	1
6	V12_tubo punho 22mm	2
7	V12_tubo costas esq 40x40mm	1
8	V12_tubo costas dir 40x40mm	1
9	V12_tubo assento esq 40x40mm	1
10	V12_alheta joelho assento 6 mm	2
11	V12_alheta articulaçao assento curta	2
12	V12_casquilho alheta costas 28x23mm	2

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1°	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:6	PROJ.			Data: 08/03/2018
Configuration: Default	DESENH.	02/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	02/05/2021		Substituído por: João Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: V12_estrutura assento completa			Versão Nº





Nº	PEÇA	QTY.
1	V12_tubo comprido rgrua 30x30mm	1
2	tubo apoio cabeça prototipo	1
3	chapa apoio cabeça prototipo	1

Soldadura:	Peça	Ferramenta/ Máquina
1ª Oper.	Soldar conforme desenho	__
2ª Oper.	Limpar salpicos	__
3ª Oper.	Desempenar se necessário	__
4ª Oper.	Listar quantidades	__
5ª Oper.	Listar cor de pintura	__
6ª Oper.	__	__
7ª Oper.	__	__

Tolerâncias Comp. +/-1mm Diam. +/-0,1mm Ang. +/-1º	Observações			ORTHOS XXI european inclusive solutions
	D.E.P	Data	Rúbrica	Versão nº 2
Escala 1:5	PROJ.			Data: 05/05/2021
Configuration: Default	DESENH.	05/05/2021	Filipa Fernandes	Substitui: Versão nº 1
	VERIFIC.	05/05/2021		Substituído por: Júlio Silva
Produto: __	Tipo de desenho: __			
Código:	Designação: Apoio de cabeça			Nº