MEDICAL REHABILITATION DEVICES AT THE UNIVERSITY OF MINHO: DESIGN EXAMPLE

Eurico Seabra
Luis F. Silva
Paulo Flores
Mário Lima
Gustavo A. Vieira
Pedro Araújo
University of Minho, Mechanical Engineering Department, Campus of Azurém, 4800-058 Guimarães, Portugal
{eseabra, lffsilva, pflores, mlima}@dem.uminho.pt; {a30104, id2774}@alunos.uminho.pt

Abstract. *The main focus of the present work is to demonstrate how the fundamental concepts associated with Competence-Based Education are applied in Biomechanical project teaching within the MSc in Biomedical Engineering at the University of Minho, in Portugal. With the present aproach, the key factor is that the mainl role in the learning process is now centered in the student. It has been established by cognitive theories that knowledge acquired and applied in a realistic problem solving context is expected to be remembered and used properly when needed later. In fact, the traditional approach to teaching based on 'chalk and talk' style attempts to transmit knowledge from teachers to a passive recipient. However, over the last years, there is a growing awareness among engineering educators that while this style of instruction is suitable for teaching engineering analysis, it has some limitations when it comes to nurturing creativity, synthesis and engineering design, where different possible solutions have to be tested. This paper summarizes the research and parallel teaching activities related to the design of medical rehabilitation devices in order to increase the quality of life of individuals, as well as the added value of the end products in this domain. The teaching activities are being carried out at the School of Engineering of the University of Minho, involving senior researchers from the Department of Mechanical Engineering and MSc graduation students from the Integrated Master course in Biomedical Engineering – specialization area of Biomaterials, Rehabilitation and Biomechanics. The design and development of medical rehabilitation devices demands the integration of different background knowledge and scientific areas, with expertise in methods and mechanical engineering design to the use of, for example, advanced numerical simulation techniques. The establishment of a solid work basis and the collaboration between the several working groups is also a goal and motivation for the students involved. In short, this work deals with the analysis of the most relevant projects developed within in the scope of the course Design of Medical and Rehabilitation Devices. Finally, one demonstrative example of application related to the conceptual design of aid devices to help in the mobility of handicapped people, is used to present and discuss the main procedures, methodologies and assumptions adopted throughout this work.*

Keywords*: Competency-based education; Biomechanical project; Medical rehabilitation devices; Case study*

1. OBJECTIVES

The objective of this research work is the design of a technical walking aid device, usually known as "walker", to help individual's locomotion with reduced mobility. In the sequence of this process, it is of paramount importance that the solution would be focused on the requirement for keeping a good posture of the backs during locomotion. This technical aid device was designed for children below 10 years old, considering a height range from 55 to 88 cm and a maximum applied load of 500 N.

2. INTRODUCTION

The aid to the fellow human being, the help to the weaker, the possibility of making the difference with simple actions, are all good reasons that act upon thousands of people everyday. The "walker" supplies a wider support base than other locomotion aid devices, surrounding the user by three sides and supporting on the ground in four or more points. The increase of the support base that the "walker" will provide has advantages such as an increased stability, safety's feeling and an involving sensation to the user (Barreto, 2008; Health and Home, 2010). Being used by individuals that cannot make total load in one or the two lower limbs, that they possess unbalanced locomotion movement, pain and debilitating fatigue, the "walker" is usually used associated with neurological diseases (for instance, brain stokes) and osteoarticulation diseases (for example, osteoporosis and alterations in the metatarsophalangeal articulations) (Health and Home, 2010).

The basic "walker" has two main functions: it can be used to operate as a support product in a definitive way, and on the other hand, it can be used for reeducation purposes. Besides to promote a safe deambulation and to relieve the tension in the articulations, it also works as a locomotion stimulator for convalescence, which could be used in postoperative situations, such as femoral neck fractures (Barreto, 2008; Health and Home, 2010).

The user should be trained in order to use the "walker" properly in the several activities of daily life (for example, meals and bathroom activities). It is also very important to avoid that the user adopts wrong postures (which can later cause difficulties in the adaptation to other technical aid devices), maintaining the gravity centre inside of the support base so that it doesn't tumble to the front nor put very far away the device from the body when moving forward. To improve the locomotion action it is necessary to learn the correct position of the feet, in order to centre the body in the support base of the device. When the "walker" is put a step ahead, the user advances a step to approach (for instance: "walker", right foot, left foot). This sequence repeats or it can vary to execute a more natural march (for instance: "walker", left foot, right foot, "walker", right foot, left foot) (Barreto, 2008; Health and Home, 2010).

Having in mind the purpose of this work, it was initially performed a comprehensive market analysis regarding the several types of "walker" with the identification of the advantages and disadvantages/limitations of their operation, as well as the pathologies in which this kind of devices can be used to improve the quality of children's life. In this case, the essential need, besides maintaining a correct posture of the backs, is to provide increased stability to allow human locomotion to be the most autonomous possible. With these data the objectives were established through an objectives tree, and the functions that should be present in the device to develop were represented in a diagram of functions (Cross, 1994).

Following the objectives previously defined, the product specifications could be established. The several generated solutions where then analysed for technical feasibility in order to find the best solution to meet the objectives and comply with the specifications. Additionally, a morphologic map of solutions was organised. Next, the selection of the most appropriate conceptual solution and materials for the various components of the device was carried out, followed by stability and stress calculations. Finally, a virtual 3D prototype of the developed "walker" was obtained using software AutoCAD®. Figure 1 schematically represents the design phases that were accomplished during the development of this project.

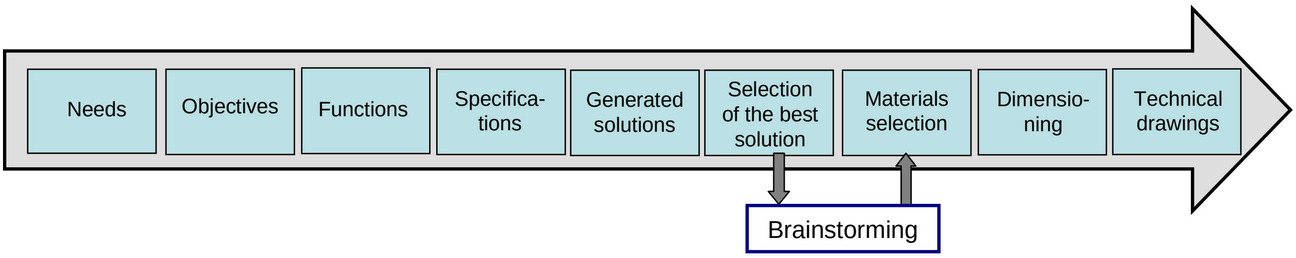


Figure 1. Development phases of the design process.

In order to briefly present the diversity of the available walking aid devices ("walkers") in the market, a detailed survey was carried out. In a broad sense, these devices can be classified in different types according to their more important characteristics of operation (Fig. 2). This classification was made according to several topics, such as, posterior or frontal, fixed or articulated, with or without wheels and the number of them. This initial study was revealed very important for the correct establishment of the specifications of the equipment under development.

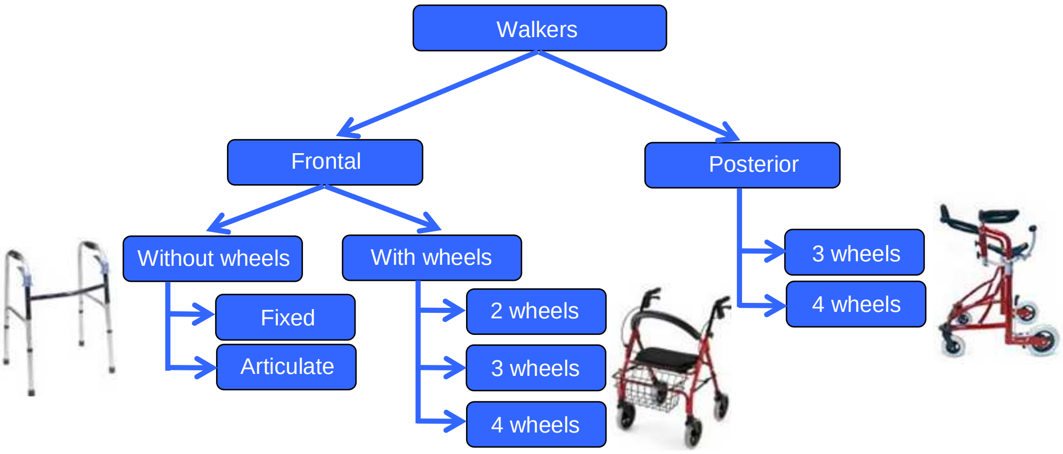


Figure 2. Classification of the "walkers" types available in the market.

The range of the acquisition cost of this type of devices is very wide (Fig. 3), and it can span from 50€ to 2500€ (PHC, 2010). In fact, quite high prices are reached, what makes this market to be very attractive from the economical point of view. According the analysis carried out, it can be concluded that all the "walkers" aid devices are regulated in height, which allows a better fit to the user. Relatively to the articulated "walkers", it must be highlighted that they have the same functionalities of the rigid "walkers", with the additional advantage of better allowing maintaining the correct posture of the backs during locomotion. For the choice criterion between the two types of devices, it can be the weight often higher of the articulated "walker", as well as the user's mental capabilities. Finally, the existence of wheels can facilitate the walking motion, but it demands a careful consideration once again between this advantage and the mental and physical capabilities of the user.

Figure 3. Cost relations of the main "walkers" types available in the market.

3. CONCEPTUAL DESIGN OF THE NEW "WALKER" AID DEVICE

To achieve the proposal goal of this paper related with the presentation of a design example of a medical rehabilitation devices at the University of Minho, this section 3 presents and discusses the overall methodology that was used in the development of the conceptual design of a new "walker" aid device. This process design was performed divided in the following six main topics: section 3.1 presents the objectives considered in the design of the medical device; section 3.2 depicts the main functions that the device should be capable to execute in order to accomplish its global task; section 3.3 presents the main specifications associated with the design process that were established; section 3.4 discusses and analyses several generated concepts for the "walker" that were created after a brainstorming process in order to select the best conceptual solution, for that, it is also presented in this section, the process used to obtain the overall utility value of each concept; section 3.5 presents the virtual computational model 3D in order to allow a better visualization and understanding of the operation mode of the new device; finally, section 3.6 presents and discusses the finite elements analysis performed with the purpose of verifying the mechanical performance of the tubular structure of the developed "walker".

3.1. Establishment of the objectives

Figure 4 shows the objectives tree that has been considered in the development of the new "walker" design, which clarifies the objectives to be reached in order to accomplish its functions in the most useful possible way. This tree presents the objectives and the corresponding lateral relations, as well as the hierarchies between objectives and sub-objectives.

3.2. Establishment of functions

In the development of any design process it is extremely important to define the functions that the device should be capable to execute, in order to clarify and to define the orientation that the work tasks should proceed. Besides, it is possible to notice the level of the problem, defining a conceptual "limit" to the turn of the previously established functions (Cross, 1994).

Initially, it was defined a global function the most general possible, and later that function was divided in more specific sub-functions. The global function should be seen as a "black box"", that converts certain inputs in outputs. The sub-functions were represented by a block diagram that links them through inputs and outputs, establishing a relation amongst them. Thus, once the global function is rendered, all of the sub-functions have to be executed (Cross, 1994). The established diagram of functions for this design is presented in the figure 5. It can be observed that the patient's locomotion was defined as global auxiliary function. In other words, to consider a seating patient (input), to get up and walk for himself to other place (output) through a displacement distance. This general function can be analyzed as a group of several sub-functions: first the user has to get up leaning on the "walker", and second, is moving forward and walking. During the movement, at the end of a certain displacement, it is necessary that the "walker" stops, using, for instance, a braking system, giving support to the patient; finally, the device should help the user to return to a seating position.

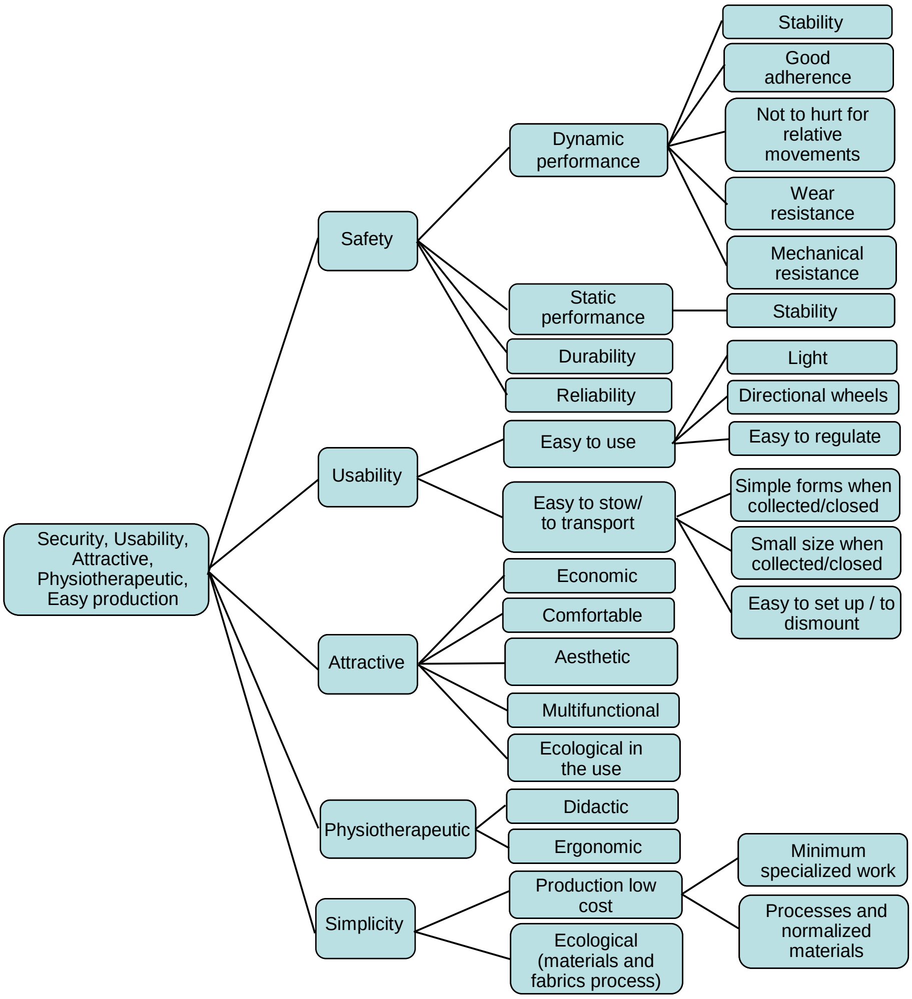


Figure 4. Schematic representation of the objectives and sub objectives defined for the “walker” design.

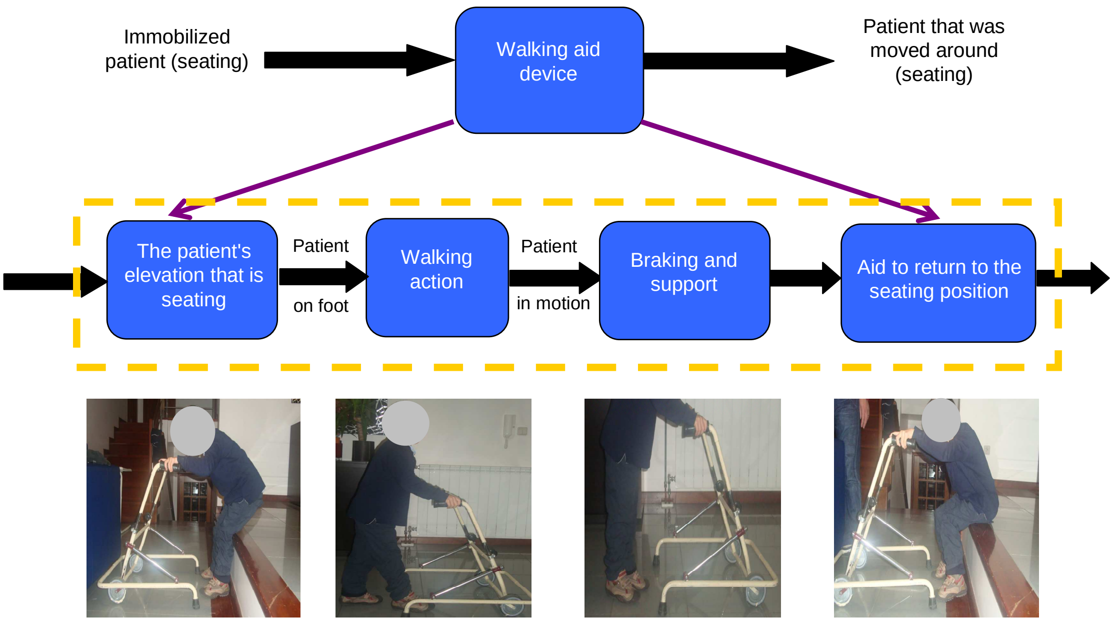


Figure 5. Functional diagram with presentation of illustrative photos of the several associated sub-functions.

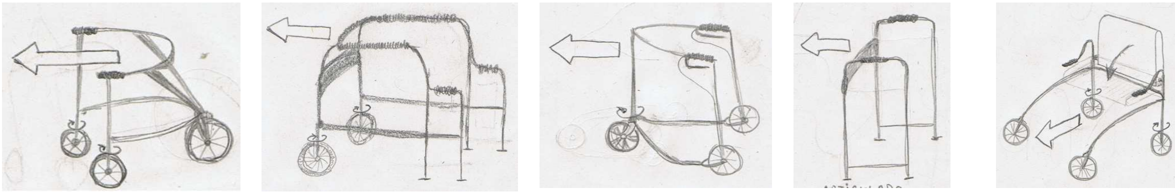
3.3. Establishment of the requirements

The main specifications associated with the design process were established, namely:

1. Antiskid rubber tips: extremely important for the user safety operation, preventing the unwanted sliding of the device;
2. Material of the support of the hands with good adherence and comfort: it is essential a good adherence between the patient's hands and the support so that to avoid the hands sliding off and the patient being without support, due to the “walker” spontaneous displacement. Besides, once a “walker” is an instrument frequently used, it is necessary the hands support to be comfortable;
3. Appropriate joints between parts, not to cripple the user: all components must be well linked to prevent certain accidents, for example treading of the patient hands;
4. Rounded edges: the edges of parts must be smooth, no cutting edges;
5. Base/floor supports to give stability, 4 or more: in a “walker” aid device the number of base supports (wheels and/or fixed rubber tips) can vary normally between 3, 4 and 6. Consequently, this number determines the stability and safety level of the device. In this design, as a higher stability is demanded, the number of base supports must be at least 4;
6. No directional wheels: between stability and mobility, the stability criterion was considered preferable;
7. Distance between fixed rubber tips and/or wheels: very relevant parameter in the dimensioning of the device; appropriate distances will provide higher stability and mechanical resistance;
8. Tubular structure (internal and external diameter of the tubes) and linking elements: a “walker” structure is usually made of some linked main parts with a tubular structure. In the developed “walker”, the linking elements are of two types: one allows the rotation movement and the other the height variation. In the first case iron braces have been used (“bicycle-saddle type”) and in the second case elements similar to those used in the “Canadian crutches” have been used.
9. Materials to be low weight, resistant, ecological: all selected materials to manufacture the “walker” must meet requirements such as low weight, in order to facilitate the patient’s locomotion, as well as the transport of the device when disassembled. Furthermore, materials must be resistant to atmospheric agents and still to be ecological;
10. Suface finishing of the parts: General finishing of the parts must be smooth for comfort and aesthetics. Special sufaces to give good adherence to the hands, as well as the base/floor supports (wheels or rubber tips);
11. Wheels (types/dimensions): These elements are extremely important, allowing easiness of movement. The wheels of the developed “walker” are rubber covered and have 100 mm diameter.
12. Braking system: very important element to allow the patient to safely stop the “walker”, remaining in a vertical position, or to support himself to get up or to seat.
13. Height regulation: the possibility to adjusting the height of the “walker” until certain level, is an advantage: In a period of time when the patient will be in a growth phase means to be able to use the device for a longer period of time. The height to be adjustable also means that the same “walker” could be used for several patients.
14. Total height (between the floor and the hand supports): the height of the “walker” must be so that the elbows make a flexion of 15-30º during use, to facilitate the locomotion and to prevent posture problems. The literature search showed that height should be in the range 49-82 cm (Crocodile, 2010);
15. Small dimensions when retracted: the “walker” dimensions when retracted must be as small as possible to facilitate transport and storage;
16. Simplicity of component parts: the parts must be simple, so that when the “walker” is disassembled its geometry must be simple, also to facilitate the transport and storage;
17. Standard components: to decrease the manufacture costs, avoiding the manufacture of new parts;
18. Typical materials: to reduce manufacturing costs common materials will be used;
19. Current manufacturing processes, allowing reduction of costs. Examples of these processes are: welding, plastic conformation, turning, milling and drilling operations.
20. Ergonomic structure: the “walker” must be conceived on the basis of anthropometric data;
21. Attractive design: being a device to be used by the patient for many hours a day, it is important to be aesthetic pleasant, so that the user feels visually comfortable and motivated to use it;
22. Incorporation of a retractable chair: this would be a very useful “extra” for the patient to sit down, whenever he fells tired;

3.4. Analysis of generated concepts

Figure 6 shows alternative conceptual solutions for the “walker” that satisfy the functions requested for the device that were generated after a brainstorming process.



Concept 1 Posterior "walker" with 3 wheels

Concept 2 Frontal "walker" with 2 wheels and 2 rising stages

Concept 3 Frontal "walker" with 3 wheels

Concept 4 Frontal articulated "walker"

Concept 5 Posterior "walker" with 4 wheels and with backs

Figure 6. Conceptual sketches of the generated alternative solutions.

Having arrived to 5 alternative concepts, all presenting advantages and disadvantages relatively to the others, it was necessary to obtain the overall utility value of each concept to select the best. For this purpose, it was established the weight of the five objectives considered for the computation of the utility value, namely: safety, usability, attractiveness, physiotherapeutic and simplicity (listed by order of importance). On the other hand, each one of the referred five objectives was classified between 1 to 5, corresponding: 1- inadequate, 2 - weak, 3 - satisfactory, 4 - good and 5 - excellent. Table 1 depicts the method used for computing the overall utility value of the five generated concepts.

Table 1. Value analysis of the five alternative concepts for "walker" aid device.

Objective	Weight	Parameter	Concept 1		Concept 2		Concept 3		Concept 4		Concept 5	
			Score	Value	Score	Value	Score	Value	Score	Value	Score	Value
Safety	0.333	Number of accidents	4	1.333	5	1.667	4	1.333	3	1.000	4	1.333
Usability	0.200	Simplicity of use and transport	5	1.000	4	0.800	5	1.000	4	0.800	4	0.800
Attractiveness	0.067	Number of extras	4	0.267	4	0.267	4	0.267	3	0.200	5	0.333
Physiothe-rapeutic	0.267	Number of didactic functions	4	1.067	5	1.333	4	1.067	5	1.333	4	1.067
Simplicity	0.133	Simplicity in production	3	0.400	4	0.533	3	0.400	5	0.667	2	0.267
Overall utility value				4.067		4.600		4.067		4.000		3.800

Based on the data listed in Table 1, analyzing the safety objective, concept 1 offers support in the backs, which is very important due to the reason that usually the child presents bigger posterior disequilibrium. However, during locomotion it is important to take into account that the child can lose balance due to bad support of the feet and due to the impulse necessary to walk, and in this case this "walker" does not give any sustainability in the front side, having the risk to fall down. This is the reason for the classification "good" instead of "excellent". On the other hand, the concept 2 does not have this drawback due to the reason of being of the front type, conferring stability to the front part. Also, it is used in this concept a first stage to help the user to raise and to return to the seated position which offers to the device two additional posterior supports adding posterior stability. This justifies the classification "excellent".

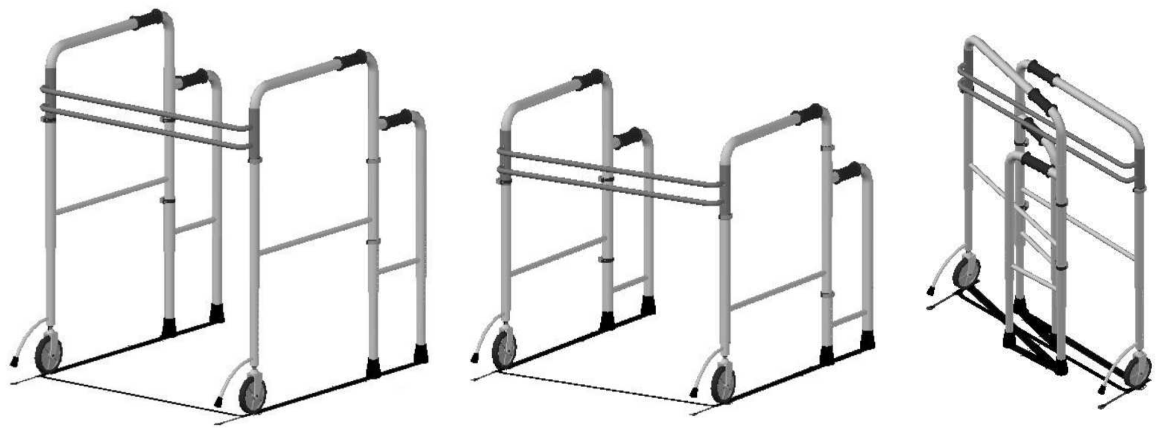
Concept 3 promotes a support in the frontal side, but does not give stability in the posterior part, also having the fall backwards possibility. This justifies the classification "good". Regarding concept 4, beyond being the one that provides greater motion freedom due to being articulated, allows the integration of the two basic types of the locomotion. However given its lack of equilibrium and stability, it can be unstable in its normal use. This justifies the classification "satisfactory". Finally, regarding concept 5, given the existence of 4 wheels (2 in the front and 2 in the rear), achieved a classification "good". Relatively to the objective of usability, the classification of "excellent" was given to concepts 1 and 3 due to the existence of three wheels allowing weight reduction, facilitating mobility and probably its transport and storage.

In what concerns the attractiveness objective a "very good" classification was given to concept 5 due to the existence of 4 wheels, two directional in the rear to allow a more easy displacement of the "walker" and also have a back support structure that permit to keep a right posture, with the possibility of the back being transformed into a seat, being therefore this device multi-functional. Concept 4 given the inexistence of wheels or any other extra functionality was classified as "satisfactory". Finally, all the other concepts have been classified as "good", due to the existence of three wheels, in the case of concepts 1 and 3, or in concept 2, the existence of one intermediary stage to help the user to raise and to return for the seated position.

Regarding the therapeutical objective the classification of "excellent" was given to concepts 2 and 4; in the case of concept 2, owing to the inclusion of a intermediary stage, which helps the user to raise and to return for the seated position, and in the case of concept 4, the articulated "walker", allowing the user to increase the capacity to develop locomotion, which demands the coordination of movements of the inferior and superior members. Finally, relatively to the simplicity objective, a "satisfactory" classification was given to concepts 1 and 3 due to the existence of three wheels; on the other hand, concept 2, besides the existence of only two wheels, was classified as "good", while for concept 4, given the simplicity of the structure of the device, received "excellent". Finally, regarding concept 5, due to existence of four wheels with inclusion of a back support structure, it was classified as "weak".

3.5. Virtual computational model 3D

In order to allow a better visualization and understanding of the new device, to find and eliminate geometric errors and to permit the dimensioning of its mechanical structure using the finite elements method, it was created, using the AutoCAD® software from AutoDesk®, a 3D virtual model of conceptual "walker" previously selected (concept 2). The developed "walker" was based on a tubular aluminium structure to reduce weight and to facilitate the user's mobility. In this structure tubes with three different diameters were used, thus they could be put concentric, forming rotational joints to allow the "walker" to be retractable. Another reason for the choice of tubes with different sections was related to the "walker" need to be regulated in height, with an identical system to the one applied in the "Canadian crutches" (concentric tubes and lock pin). Figure 7 shows three-dimensional virtual models of the developed "walker" in the three more representative configurations of its operation.



a) b) c)

Figure 7. 3D virtual models of the "walker": a) maximum height, b) minimum height, c) maximum retracted.

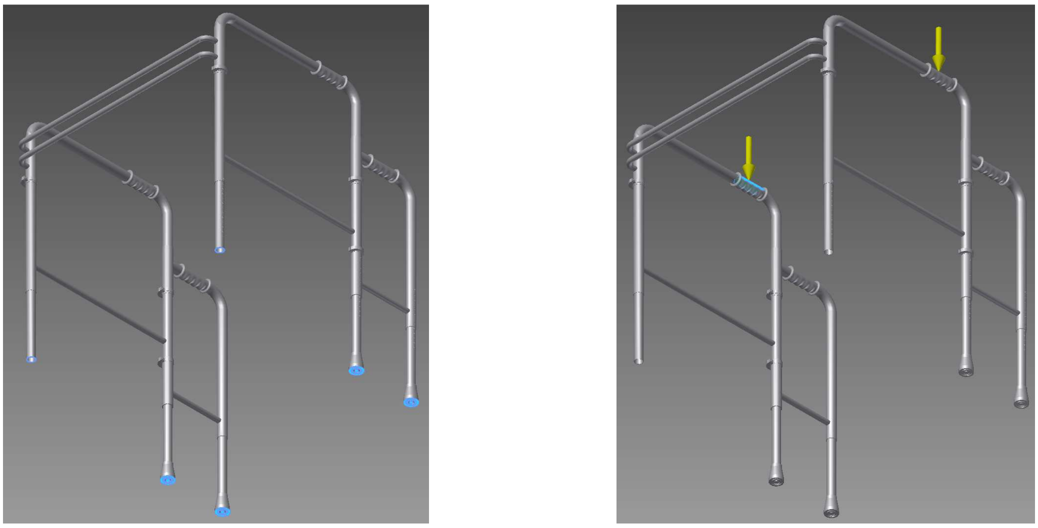
3.6. Structural analysis

With the purpose to verify the mechanical performance of the tubular structure of the "walker", a finite element analysis, using Inventor® software from Autodesk®, was carried out. For such purpose the previously developed 3D CAD model has been considered, with the necessary simplifications and appropriate boundary conditions. The main simplification was to consider the two frontals wheels (see figure 7) of the same type of the other four antiskid rubber tips already existent (see figures 7 and 8). Table 2 presents the main mechanical properties of the aluminium alloy 6061 (Al-Mg-Si), the material selected for the tubular structure of the "walker", fundamental for the performed structural analysis.

Table 2. Mechanical properties of the aluminium alloy 6061.

Mechanical properties	Value
General mass density	2.71 g/cm^3
Poisson module	0.33
Yield Strength	275 MPa
Tensile Strength	310 MPa
Young's Modulus	68.9 GPa

The main results obtained with the structural analysis performed by the Finite Elements Method (Reddy, 2005; Brenner & Scott, 2008), has been the stress-strain analysis of the "walker" structure components under maximum loads and the constraints to the tubular structure. Regarding the constrains/restrictions (see figure 8a), the six antiskid rubber tips have been considered; on other hand, regarding the applied load (see figure 8b), a force of 500 N applied in each of the two superior hand supports was considered: This corresponds to a safety factor of 2, as the specifications asked for a maximum applied load of 500 N.

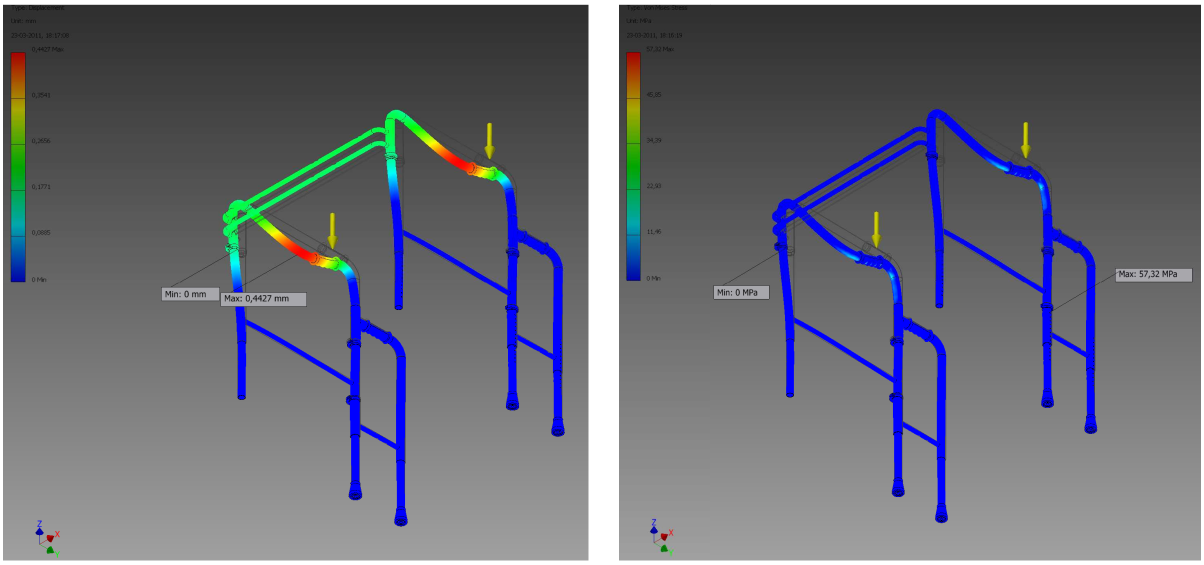


a) Constrains (the six antiskid rubber tips).

b) Load application in the two superior hands supports (more critical situation).

Figure 8. Constrains and loads in the "walker" tubular structure.

Figure 9 shows the obtained results in a graphical manner, respectively for the strain and stress obtained for the proposed tubular structure of the "walker".



a)

b)

Figure 9. Main results of the finite elements analysis: a) strain (mm) and b) stress (MPa).

Finally, it can be concluded from the analysis of figure 9a) that the maximum strain occurs near the superior hands supports (0.4427 mm), which is an acceptable value for the stability and functionality of the "walker". On the other hand, as far as the stress results is concerned, as shown in figure 9b), it can be observed that the structure is well designed, with maximum stress occurring in the adjustment tubes of "walker" height (57.32 MPa) which is about five times lesser that the yield strength of the material (275 MPa).

4. CONCLUSIONS AND FUTURE WORK

In this paper it was presented, summarized and discussed a research project undertaken at the Department of Mechanical Engineering at the University of Minho whose main goals are addressed to the investigation, design and development of an aid device, known as “walker”, to assist individuals with different locomotion pathologies of the lower limbs, to walk with a high degree of safety, while reducing the discomfort during walking.

Associated with the performed design process of the new "walker" technical aid device, it can be concluded that it is possible to develop a device that has the great advantage of promoting stability allied to mobility to the patient, above the average level of other “walkers” available in the market. In this way, it will be able to be used by children with a higher degree of motor disabilities, namely, who suffer of spastic tetraparesis with muscular hyptertone (Axe, 2008; Fradinho, 2009; Araújo, 2010), which is a type of Brain Paralysis.

Finally, as future works, it is intended in first place to perform the development of the detail design of the solution, namely select the appropriate off-the-shelf components and to elaborate the technical drawings of the parts to be manufactured. After the conclusion of this stage, a physical prototype will be made and validated in order to evaluate its performance, in real situations with childrens with some types of motor pathologies. For this purpose, a battery of systematic tests will be performed with the technical specialized support of medical doctors, occupational physiotherapists and therapists.

5. REFERENCES

Araújo, D., 2010. “Efeitos de treino em tapete rolante na marcha e funcionalidade de Crianças com PC”, Faculdade de Desporto da Universidade do Porto, Portugal

Barreto, H., 2008. “Readaptação do domicílio face à pessoa com limitação funcional”, Escola Superior de Enfermagem S. José de Cluny, Funchal, Portugal

Brenner, S. C., Scott, R,. 2008. “The Mathematical Theory of Finite Element Methods”, 3rd Edition, Springer, New York, USA

Crocodile, 2010, “Crocodiletm – English User Manual”, http://www.Spinlife.Com/Files/Snug_Seat_Crocodile_Om.Pdf, access on-line in 15 Nov. 2010.

Cross, N. 1994. “Engineering Design Methods: Strategies for Product Design”. John Wiley, Chichester, 2nd Edition.

Fradinho, M., 2009, “O contributo do desporto no sucesso escolar de alunos com deficiência motora”, Universidade Portucalense, Porto, Portugal

Machado, S., 2008, “Estudo de cariz circum-fonológico de crianças com e sem lesão Cerebral”, Escola Superior de Educação de Paula Frassinetti, Porto, Portugal.

PHC, 2010, “Meywalk Mk3 Gait Trainer, Pacific Rehab Gait Trainer, Children And Adult Size Gait Trainer”, <http://www.phc-online.com/Pacific_Rehab_Gait_Trainer_p/meywalk-mk3.htm>, access on-line on 22 Nov. 2010.

Reddy, J. N., 2005, “Solutions manual for an Introduction to the Finite Element Method”, 3rd Edition, Department of Mechanical Engineering, Texas A & M University, McGraw-Hill, New York, USA

Saúde e Lar, 2010, <http://www.saudelar.com/Edicoes/2008/Novembro/Principal.Asp?Send=05_Medicina.htm>**,** access on-line on 20 Oct. 2010.

6. RESPONSIBILITY NOTICE

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