TITLE: Accessibility and Universal Design: Motorization and improvement of a wheelchair

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Abstract

Using electric power wheelchairs improves the mobility, independence and autonomy of many disabled patients and elders. But for every using group there are different needs and requirements that needs to be meet, such as size, height and steering methods. Many markets offer wheelchairs in different sizes and with different steering methods so that every use group can move independently. In this paper, we show how we will meet the requirements of a specific client who’s main priority is to become more accessible in daily events. We will combine two different wheelchairs, an electric power wheelchair and a non-electric buggy and we will show how to make the control of the steering and a communication system more accessible. These solutions will solve the problem and improve the mobility of a specific user.

**Key words:** accessibility, electric power wheelchair, mobility, requirements
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**Appreciating**

This project had no budget in the beginning to accomplish its aim, but many people offer their unconditional aid, in order to have the most satisfying results for us -the team- and also for the customer-Nahuel, to improve his life and to give him the opportunity of enjoying it almost like the other children around.

First of all we want to thank Eva Marin Tordera, our first supervisor, who always kept the connection between the students and the company. She made it possible to have meetings with the company on a regular base. Her feedback on the theoretical part of the project made it possible to reflect and improve the way of presenting information.

Also thanks to Raquel Vallez for keeping contact between the project group and the Accessibility Department.

To our second supervisor JuanJose Vazquez we also want to say thanks. His help in the practical part of this project included giving advice on how to build the construction, taking correct measurements and giving ideas on how to succeed in this part of the project. It is because of him that the wheelchair is shaped the way it is now.

Next is the staff and personal of the UPC school we want to say thanks too. Santiago, mechanical engineer, welded all components of the wheelchair and gave the construction a new look. Dani, electrical engineer, is responsible for wiring and connection the steering mechanism with the electronics. Thanks to Pau Marti, tutor electrical engineering, for giving his opinion the steering mechanism and giving the project team a few ideas for this part.

Then one big thanks for the people responsible for the maintenance of the UPC school. We were able to borrow and use tools so that the project could be made inside the school facilities.

This project was very interesting an very fulfilling to give a small, young boy the opportunity to move on his own still due to his current situation. The challenging part of the project was for us a motivation to fulfil the wish of a small boy and his family.

On behalf of the group consisting of Maurits Binnema, Jan Stepputtis, Charlotte Berthomieu, Adina Marin and Ludwig Siegfrids:

Thank You All!/Muchas Gracias a todos
Introduction
This project was addressed from the term “Accessibility and Universal Design”. This term is about designing products or services to grant majority of people better access to the usage of the corresponding product or service. In this way, improvement of mates-inclusion and promoting equal opportunities in the pupils environment will be the main objective.

The project came from the ‘Escola Politècnica Superior d’Enginyeria’ in Vilanova I la Geltrú, Barcelona. In association with the primary school ‘El Margalló’ (providing special education) and the local physiotherapists in Vilanova I la Geltrú, the task was given to create more opportunities for independent actions for a certain kind of user.

1.1 Need for improvement
In our society, it is simple for the local man to move on his own and get groceries whenever he/she wants, these are considered ‘standard abilities’. But for a certain kind of people these standards are unreachable in their way of living. These people are not able to cooperate in daily society and therefore require additional assistance. Not only are these groups more dependent on others, but they will also feel left out of society due to lack of accessibility and universal design in common objects and services.

1.2 The client
For this project, our focus will be laid down on one specific user: “Meet Nahuel”. Nahuel (figure 1.1) is a thirteen year old boy who lives just outside Vilanova I la Geltrú. Originally from Argentina, Nahuel learned at young age the Catalan and Spanish language. He is known as a happy boy who always smiles and always cheers for his favourite football club “FC Barcelona”.

1.2.1 Disorder
Nahuel suffers from a special disease called ‘Dystonic, Spastic Tetra Paresis’ (in Spanish: ‘Tetrisparexia Espástica Distón’). The disorder is caused by muscle contractions which lead to twisting and repetitive movements. He is not able to fully control his own body movements.
Because of the disorder, Nahuel is taken care of from the early mornings, till the late nights. He is always put in a specialized wheelchair for big children. As shown in figure 1.1, the wheelchair has the form of an enlarged baby buggy. In association with his school, Nahuel has daily appointments with the local physiotherapists who meet with him for exercises. Nahuel has to do different kinds of exercises for muscle training, so that his muscles don’t become any weaker.

1.2.2 Capabilities
Because of his abilities, he is able to do little compared to the ‘normal’ circumstances. For now, the focus lays on what he is capable of. Focusing on his cognitive capabilities, it is known that Nahuel is able to think on his own. He is able to point out objects and reacts to emotions by smiling or frowning dependently on which/what is shown.

For his physical capabilities, it is known that the disorder takes away/lowers controlled facial and body actions such as talking. This uncertainty of movements makes Nahuel not aware of any danger by sudden movements in his direct environment. Therefore, he is being strapped with weights on his arms and legs every time he needs to sit still. But besides that, Nahuel is able to hold grip on an object for a few seconds and is also able to set little strength in some of his body-parts. For example, he should be able to use a chin-controlled, mechanic wheelchair.
2. Project objective
This project is defined in different tasks, set by the various requirements our project is based on. The main objective for the project is to create a wheelchair for Nahuel which makes him capable of moving on his own. The following tasks need be done by the end of the 3th of June to achieve this goal.
- Universal Seat Fixture
- Steering mechanism
- Wheelchair handles
- Communication ‘arms’

2.1 Task 1: Universal Seat Fixture
Earlier on, there was shown that Nahuel has always been placed in to an enlarged children’s buggy. But to deliver Nahuel a wheelchair in which he can move on his own. The top part of this buggy will be combined with a bottom half of an electrical wheelchair (with a motor). Combining these parts with each other is the cheapest and simplest way of making an effective, working wheelchair. It is important to take in count that the two parts need to be taken of any time and has to be adaptable.

2.2 Task 2: Steering mechanism
If the first part of the project is done, there can be worked on the second part. Because the clients want Nahuel to move on himself, he will need a new way to move with the muscle strength he has and with using the motor on the wheelchair. The wheelchair with steering mechanism will be only used in indoor environments such as school and at home.

2.3 Task 3: Wheelchair handles
If the two wheelchair parts are going to be combined, than there will be no place for the original handles of the electrical wheelchair. The motor of the wheelchair will not always be full and need recharging every six hours, so someone needs to be able to push the combined wheelchair whenever possible. The plan is to adjust the original handles (from the electrical
wheelchair) in size and heights. The goal is to deliver handles which are ergonomically friendly to use for the ‘pusher’.

2.4 Task 4: Communication ‘arms’
This is considered a side task, but is still important for the clients. Nahuel is being taught to use a new communication system which involves a tablet, clicking devices next to Nahuel’s cheeks to control the interface, and the bars that hold the clicking devices. These bars are called the arms of the system. Because the clients experience trouble with the arms, the task consists of adjusting the length of the arms. The arms take quite a lot of space and it takes time to adjust the arms into the right position. It is important for this task to keep the distance between the cheeks and the clicking devices.

2.5 Requirements
For this project and the involving tasks that have to be done, it is important to meet the requirements, set by the clients/company, to finish the project with a good mark. The main objective for the company is to realize a real usable product which enables Nahuel to move independently. The final product (wheelchair) has to fit the requirements for wheelchair usage with engine, considered safety rules for example.

The supervisors of the project team expect quite the same, but still focus more on the documentation and working process of the project team. The supervisors expect collaboration between the team mates, professionally working mentality of the project team and weekly documentation to reflect the working process.

Because of the client’s abilities, the requirements for this group are very specific. The controls of the wheelchair has to be adjusted to his ability, the wheelchair must be safe for usage (for example, stop whenever there is danger ahead), the wheelchair needs to meet “normal’, electrical wheelchair requirements and the wheelchair has to allow the boy to participate more in the daily community.
2.6 Budget

This project is started without a budget to work with. From the start it is made clear that the company will not be responsible for any purchases that will be made for the project tasks. The company itself will provide for the two different wheelchair parts from the valuable price around 4.000-5.000 euros each. The students will be allowed to cut and adjust everything on the bottom part of the wheelchair. This enables the students to give readjustments to the wheelchair.

In case of a student project, the UPC school will provide for all the constructing equipment necessary for building or adjusting mechanical structures. All the materials that will be used for constructing, will be first purchased by the students themselves, but will later be refunded by the school. Most materials used for the wheelchair construction are already property of the school or from the staff themselves. Next thing is the staff that helped with building and constructing components on the wheelchair.

Appendix 4 listed all the used materials and human resources used for the project with their prices. The prices for the materials and for the human resources are not accurate.
3. Universal Seat Fixture
The main task for the project is to make a usable wheelchair for Nahuel. The main idea was to combine parts of two different wheelchairs. The top half consist of the buggy he is using on a daily base, the bottom half is from an electrical wheelchair. To use the electrical wheelchair it has to be modified to meet the requirements.

3.1 Wheelchairs
The buggy which Nahuel is using is from the German company ‘Thomas Hilfen’, figure 3.1. This wheelchair is ergonomically stable for both the user and the pusher of the wheelchair. The seat will be used into the new construction due to it is ergonomically seat.

The other wheelchair is the ‘Power-Picco’ from ‘Meyra’, figure 3.2 this wheelchair is designed for children to move on their own, using the joystick. This wheelchair is purchased together with a battery. The company has no need for this wheelchair anymore and it is open for any construction. The lower part will be used for the new construction. The benefit here is the stability of the wheelchair.

3.2 Processing
The end goal is to connect the two wheelchair parts and create a stable wheelchair, figure 3.3, in which the seating part can be dismounted at any time desired.

On the bottom of the seat, there is a construction (figure 3.4) which allows the user to dismount the seat off the original construction. It is important to create a new way to use this mechanism for connecting the two wheelchair parts. This subject was also applied in the midterm defence with the focus on choosing the cheapest and easiest solution to connect the two
wheelchair parts.

Figure 3.5 shows the drawing, with the measurements of the chosen option that will be implemented on the electric wheelchair. In appendix 2 there is more information about the different drawings and options.

The solution seemed quite simple, placing irons bars onto the lower part of the (electrical) wheelchair, figure 3.6. At first the bars seemed to be easy to made and still stable and strong enough to hold the seat. After testing this construction, it seemed that it was indeed a good solution for connecting the two parts together.

As shown in figure 3.7, it is possible to see that the construction (from figure 3.4) fits perfectly on the bars. At first, there was been thought of placing the bars by making holes in the yellow wheelchair and attach the bars with screws. But after some thinking, it was
made clear that simply welding the bars would be more time saving and also cheaper.

The place where the bars have to be weld are marked and spotted for the mechanic. After the wheelchair has been left by the mechanic, the bars were welded on the wheelchair (figure 3.8). To test if the bars could hold the weight of the boy and the seat from the buggy and to see if the bars were welded at the right position, the two wheelchair parts were connected together and the boy was placed in the wheelchair. It showed that the wheelchair is able to hold the boy and the weight of the seat also were the bars welded at the right position.

There were only a few problems with the bottom wheelchair part as it was now. First, the handles of the (electrical) wheelchair couldn’t fit on the construction as it was originally. And second, the armrest from the electric wheelchair was not going to fit on the original construction either. But these problems will be discussed in their fitting chapters. The last problem was that the top part of the wheelchair would move horizontally. That was because there was nothing placed on the bars that would make the top wheelchair part stop moving horizontally. To give a proper solution to this problem, there were different methods tried.

Figures 3.9 and 3.10 show different methods that would stop the top part of the wheelchair to move horizontally. A cut would be made in the plastic (3.9) and foam (3.10) and it would be placed on the rear bar. After a comparison, the soft foam material had been chosen due to the fact that you could glue the parts tight on the bars, also it is cheaper to replace and the chance that this material gives a little bit of suspension between the top and bottom part of the wheelchair.
To surprise Nahuel, we also wanted to give the bottom part of the wheelchair some nice colours. Since Nahuel is such a huge fan of “FC Barcelona”, the wheelchair will be coloured in blue colours with red stripes. But the problem with the painting job was that it would take different layers of paint and a lot of time to paint this construction in these colours. And because the seating part is black itself and black looks less notable it is chosen to paint this part black. In figure 3.11 the end product of the seat fixture is shown (together with all the other components).

3.3 Materials
For this part there is a lot of material used for the different components. In this chapter the wheelchair construction will be discussed only. In appendix 4 all the materials and the human resources are listed and described with the full prices. To remove all the ‘useless’ parts of the electric wheelchair and get from figure 3.2 to figure 3.11, the parts were removed by the project group with the use of a screwdriver and an hour effort.

To make a new construction for the wheelchair so that both wheelchair parts could connect with each other, two iron bars of around 400 mm with the value of € 7,20 were used for the construction. Next material is the foam used in figure 3.10 to stop the seating part of moving horizontally and keep it in its place. Each of those pieces is 35 mm and has a value of € 1.50 (bought as a one meter piece). The bars were from the staff and the foam is newly purchased. And the technical support (including the welding) took two to three hours for this part.
4. Steering Mechanism
Nahuel is not able to move on his own, it is therefore the task to apply a steering system on the wheelchair so that he would be able to move independently. The focus lays on the possibility for steering, the connection with the engine to provide power for the mechanism and the design of the chin-control mechanism.

4.1 Chin Control
The midterm defence was focused on choosing the right steering mechanism, out of many possibilities, that would fit the capabilities of the boy. The conclusion was to choose for the Chin-Control steering mechanism, out of different systems which require different use approaches. Because of its low cost expense, the less technical barriers, the intuitive steering, the fitting approach and it is overall safe for Nahuel to use it. Appendix 3 contains the valid information, from the midterm report, in which the different systems are put together to choose the best steering mechanism for Nahuel.

As shown in figure 4.1, the chin-control works with a joystick attached on the wheelchair and placed right under the chin of the user. To move forward, the user has to push the stick forward with his/her chin. For going right, the user has to move the stick to the right, etcetera.

To see if Nahuel would be able to use any chin-controlled device, a few similar constructions has been tested on the boy. Therefore he only had to move in different directions with the object in front of him. The test showed that the boy would be able to move around the chin controlled in different directions, but only if the control would be round shaped. With the use of any vertical object (for example a pen) he wasn’t able to fully move the pen in the required directions because of the difficulty controlling a pen. With any round object, he could easily move in any direction that has been told him. Like shown in figure 4.2 the round object was a few centimetres and attached onto the box.
4.2 Sketching

Considering the low budget and the possibility of using the old motor and battery of the electrical wheelchair there has been made a few sketches on how to design the chin control and where to place all the components.

As shown in figures 4.2 and 4.3, the boy will be sitting in a similar position during the usage of the steering mechanism.

There has to be taken in count that the boy will use a head pot attached to the chair, to make his head stay right and makes him capable of using the controlling mechanism. Next is the fact that the original joystick box of the electrical wheelchair is placed on the arm seat on the right side of the wheelchair user. This component will be used and slightly customized to fit the new mechanism.

Sketch 1

Sketch 1, figure 4.4 shows that the original joystick controller will be placed in its original state and that the chin control will be wired all the way up to the users chin.

The advantages of applying this idea is that the box will not be in an inconvenient position for the user and that it doesn’t take too much time to (re-)install the device. The disadvantage is however that, how longer the distance is between the box and the chin control, the more pressure the user has to build to move the object.

Sketch 2

Sketch 2, figure 4.5 show that the original joystick box will be placed in front of the wheelchair user and that the chin control will be attached on the box.

The advantage of this idea is the fact that it takes away the other disadvantage mentioned earlier. The disadvantage is however that the box is very heavy and therefore will not be hold easily by a few iron bars.
**Chosen sketch**

The final decision is sketch 1 (figure 4.4). The weight of the box would not be possible to be carried by only a few bars. It will take more materials and maybe more time to build this concept, but this would be more practical for Nahuel. The box won’t be in the way of the boy and won’t hinder his sight.

However, an electrical engineer at the UPC school has taken a look on the box and declared that this solution will not provide a sustainable solution for a longer period of time. He suggested that the use of radio transmissions so that the steering would be wireless and the boy wouldn’t have trouble with wires and can focus on the steering mechanism.

**4.3 Processing**

The best solution would be opening the box and enlarge the wires with the steering mechanic all the way up to the chin of Nahuel. This would for now be the cheapest and easiest way to give a proper solution for the given problem.

Figure 4.6 shows the inside of the old joystick box. The ideas is to place the box on its original place and make the wires (the colourful wires on the top), with the steering mechanism attached, longer until it comes near the chin of Nahuel.

With the help of an electrical engineer, it was able to cut the wires and attach a string of wires to it (as shown in figure 4.7). Now the string was about one meter longer than original, this would give more opportunities to try different methods.

To test if this method would actual work, the steering mechanism was attached to an aluminium bar, used as an extension holder. This progress is shown in figure 4.8 the bar would be hold closely to the test person’s chin to see if this
method worked. It showed that this method was indeed working and would give a proper and cheap solution for Nahuel.

At first, the idea was to use the aluminium bar as an extension holder for the steering mechanism (from figure 4.8). This would be cheaper to use and also easier to construct. But the problem could be that this material would not be firm enough for the pressure of the chin and maybe not easy to bend.

After deep considerations the best solution for the extension holder was to make it in bronze/metal pipe (figure 4.9). Next thing the mechanic mentioned was where this bar would be placed on the wheelchair. Considering the box will be placed on its original spot (on the right side), it seemed obvious that the bar would be placed on the other side of the wheelchair so that the two parts won’t be in the way of each other. Figure 4.10 shows the solution for this problem, there is an iron bar, called the attaching bar, welded on the left side of the wheelchair. Next thing there are holes drilled in the iron bar on the top and side view of the bar. The hole through the vertical side is to put the metal bar in, while the hole on the horizontal side is much smaller and designed to lock the metal bar with a screw (so the position of the joystick will be fixed). Figure 4.11 shows how this looks like (without cutting the metal bar yet).

After cutting the metal bar, there has also been made a few changes necessary for fitting the steering mechanic on the bar. The mechanism is ‘glued’ on the side on the top to a special made construction, as shown in figure 4.12. The bar is shaped in the form of this mechanic and this prevent the mechanism from falling of the bar while using it. There has
also been made a hole on the bottom side of the bar (as shown in the figure) with a PVC tube attached to it. This tube is made to direct the wires from the mechanism all the way to the box.

While thinking about the box, there was a problem that was stumbled up on. The box and the bar are on different sides of the wheelchair and this will cause the wires to get in the way while using it or prevent other constructions from working if it’s not tested properly. Next problem is that the wires would prevent the top part of the wheelchair from getting detached easily from the other construction, simply because the wires are not loose.

This problem would be fixed by installing a plug (figure 4.13 and 4.14) in the box, so that the wires could be disconnected with the box at any time desired. As shown in figure 4.14, the plug is installed into the box with a metal plate attached on the box to keep the plug in its place. It is tested a little while later and the picture shows as well that the box would connect to the battery and charge.

Now the mechanism is placed on a firm and stable place, the next thing is the material to control the steering mechanism with. As told earlier the materials have to be rather soft and stable enough for Nahuel to use. Figure 4.15 shows a few soft materials. The oval-shaped material would be more ideal to use if Nahuel wants to move his chin in different directions. This material is softer for the chin and the shape give Nahuel better opportunities to control the mechanism.

Figures 4.16, 4.17 and 4.18 show the end product for this chapter (with painting). Figure 4.16 shows that the bar is cut to a certain degree. Next to it is the ‘glued’ mechanic with the plush ball on it. The tube is to direct the wire into the pipe. Figure 4.17 shows the whole bar with the wire, 1 meter exceeding from the pipe, and the plug at the end to connect with the box. Figure 4.18 shows the overall connection with the wire plugged in the box.
4.4 Materials

This part has used the most materials to build and construct the steering mechanism. In appendix 4 all the materials and the human resources are listed and described with the full prices. The connection bar costs around €14,00 without the cutting. The attaching bar costs € 10,- for the full used bar. The different balls for knowing which one is the most possible for Nahuel to use are together € 10,-. The screw to lock the bar is around € 1,50, the PVC tube costs € 2,25 in its current shape and the plug is worth € 8,-. The extension for the wires is 2000 mm longer and the extension cost € 4,-. All the technical support like welding, bending, painting, wires extending and electrical support took at least 5 hours to put together. Most of the materials were already property of the school, only the ball is purchased by the students themselves.
5. Handles
The purpose of the project is to make Nahuel capable of moving on his own. But it should also be made possible for someone else to push the wheelchair forward. The goal for this task is to create a new possibility to use the handles (figure 5.1) from the former electrical wheelchair. The requirement is that the handles have to be dismountable in any time desired.

As shown in figure 5.2, the handles are quite small for normal usage and need to be enlarged in order to be usable for people of ‘normal’ lengths. This situation creates pain in the user spine after a long period of time. To avoid such a similar situation, this aspect has to be taken in count.

5.1 Sketching
The problem is stated that the original handles will not fit on the newer construction of the wheelchair (figure 5.3). In this way there are a few sketches below to give a proper solution to the problem.

**Sketch 1**
This first sketch, figure 5.4, shows that the handles will be placed in special made rings. These rings will be attached on the back of the wheelchair seat and allows the bars to be removed at any time necessary and switch heights, depending on the user. Once the handles are placed in the rings, the user can determine the length by twisting the spring.

One of the advantages of this solution is that the handles can be dismounted at any time, and that every independent user can lower or higher the handles (depending on the lengths). The disadvantages of this solution are that it takes more material to build the rings,
made for the handles. It is also requires more damage to the original seat and it is not sure if that will be allowed by the company.

Sketch 2

Sketch 2, figure 5.5, is a given solution holding the backseat intact. The idea is that the handles will be enlarged and set on a ‘normal’ level of height. The end of the handles will be placed inside the slot on the downside of the electrical wheelchair. The handles will be put in the same way as normal, but the enlarged part of the handles will be shaped slightly different to make sure that the bars and handles fit together.

The advantages of this solution are that it doesn’t require many materials to make the handles bigger than original. This solution doesn’t damage the wheelchair and is safe to remove at any time. The disadvantages are that the handles will be put on a standard size applied for use of different groups. It is also more difficult for the pusher to push the wheelchair forwards because the shape doesn’t fit the requirements for ‘normal’ wheelchair usage.

Sketch 3

This sketch, figure 5.6, is slightly a combination of previous sketches. The idea is to create a certain kind of mechanic. The mechanic will be specially made and will be placed on the slot in downside of the electrical wheelchair. The mechanic deviates to the right/left of the wheelchair. The handles will be enlarged as well and put in the slot of the mechanic.

The advantages of this mechanic are that the handles can be removed at any time and that the wheelchair stays intact. The disadvantage is that more material has to be used to create this mechanic. And due to the low budget it is uncertain if this mechanic is worth to be built.
**Chosen sketch**

Considering all the up- and downsides of the different solutions, the third sketch (the mechanic) will be chosen to solve the given problem. The low budget has to be taken in count and the fact that it will be difficult to make, it is sure that this solution gives the user/pusher more hold onto the moving of the wheelchair.

**5.2 Processing**

To build the handles like the sketch show, there has to be made a drawing first of the construction and the shape the handles will be like. Figure 5.7 shows the drawing of the aim that the handles have to be like. What has to be done is to enlarge the current handles, and make the same construction drawn on the bottom.

![Figure 5.7 - Drawing handles](image)

Figure 5.7 shows the basis of the construction. This metal piece will be cut into two pieces horizontally and vertically (from the top and from the side). This will give two useful pieces to use a basis. Next thing is making three holes (expanding current holes) in each base. One hole to fit the expanded handle in, one hole to fit a little bar in to connect with the...
electrical wheelchair, and one hole on the side to screw the handle tight and make sure the handles won’t go off easily from the base.

Figure 5.9 shows this construction, and figure 5.10 shows this construction fitting inside the wheelchair. The handle at the end of the construction and a screw that fasten the handle and in the other side of the mechanism there is a small pipe that goes in to the original handle hole. As shown it is clear that the construction is designed to put the handles directing outside its former position. This is made to make sure the top part of the wheelchair will not conflict with the handles, like told earlier.

The first problem with the handles was that they were not too large and causes almost every user to bend over. To fix this problem, the solution seemed simple: ‘enlarge the bars’. The bars had to be enlarged by 200 mm (see figure 5.11) and this would be fixed by welding bars from this size to the handles. The handles with the diameter of 18 mm would fit in the bars of 20 mm diameters. After welding, it was clear that these bars were not able to fit in the base that has been made earlier. To fix this, there were two solutions: make bigger holes in the base or sharpen a part of the bars so that it would fit in the base. The second option was chosen because it would involve less action and it would be easier to sharpen the bars. After a while it seemed that the bars would fit perfectly into the bas and figure 5.12 (without the paint) shows the end product for this stage.
A little while later, there was a problem with the construction of the handles. First was the fact that the handles didn’t have the same size. After thinking adjusting the handles would fix the problem didn’t work, it showed that one of the bases was in a different position than the other. Cutting and readjusting the base had solved the problem and the product is now ready to use.

5.3 Materials
In appendix 4 all the materials and the human resources are listed and described with the full prices. This part has only used a few materials that needed to be used new. The base of the construction is made of steel and has a value of € 10,–, the bar that has been used for enlarging the handles is made of steel as well and its 200 mm enlargement is worth € 5,20 and the screw to loch the handles has a value of € 1,50. All the material for this component was already property of the school or staff.

Then cutting of the handles and the steel block, the sharpening of the handles and the hole making in the base is worth of three hours’ work of human resources.

6. Communication ‘arms’
Being taught to use the communication system (figure 6.1), Nahuel can use this system and the associated component on a basic level. It is necessary for the company to shorten the arms of this system in order to use the fully working system in any environment, both crowded and calm environments. For now it takes at least ten minutes to build up the whole system and put the arms in the right direction. The goal is to shorten the arms and reduce the time used to build up the system and to keep in mind save the same distance between the cheeks and the clicking devices.
6.1 The arms
Figure 6.2 sketches the situation as known now and figure 6.3 sketches the desired situation, what the end goal is for this task.

Like told earlier, the arms will be shortened. This will mean that the components of the arms will be taken apart and that some parts will not be used anymore and that the remaining parts will be put together. Figure shows which components will be necessary for shortening the arms. Component 1 is the holder which needs to be placed on the wheelchair. Component 2 is the part with the clicking device, which is very important to use and needs to be kept intact.

6.2 Processing
It seemed simple: to take apart the arms and use only the parts that would be useful. At first it seemed that all the components of the arms would fit together, regardless of purpose, and that it would be easy and simple to construct the arms just like figure 6.4 shows.
But after a while it seemed that this task would be a lot more difficult than predicted. All the components would only fit the other components which they fit originally. It would take procedures to make the components fitting. These procedures will be time taking and expensive if isn’t done right. Because this is a student’s project with a deadline to aim on and with no budget, it is not possible to focus on all the different tasks. If this task had to be done within the small remaining time, it would be possible to break the arms and it wouldn’t be possible to replace these objects easily.

6.3 Recommendation
That is why the focus isn’t on this task any more, but on the others. But there still is a recommendation to be done for the company. Figure 6.5 shows the drawing of the arms and how it should look like.

Our recommendation for the company is to hire a mechanical engineer to make all the different components of the arms fitting. ‘Fitting’ means to make it possible to take away (so to speak) a few parts of the arms and put it together like shown in figure...

The next recommendation is to use only the holder and the clicking device of the original arms and build new arms, shorter ones, to use. Fit together all the materials and then the company will have shorter arms as desired.
6.4 Materials
If the recommendation is taken in count and there has to be built by new materials for the arms, it is important to know which materials are useful for building and constructing. The bars itself are mostly made out of iron, this makes them strong enough to last longer in the same position for a period of time. The clicking devices are made of PVC what is not a cold material and softer than iron, what makes it more user-friendly for the user. The connection of the different bars is made out of metal to keep the frame the same.

If customization is necessary for the newly construction of the arms, there can be a few materials considered to use: iron and aluminium. Iron is strong and easy to work with, but it is cold if the boy presses his skin against it. Aluminium is slightly softer and warmer, but it is more difficult to work with. It is recommended to use iron due to the fact that it is the strongest and cheapest material to work with and it can last longer if it’s kept in dry states.
7. Cost analysis

To define the cost for the project the analysis is divided in three parts: The costs for the seating system, steering system and for the push handles. To examine the costs it is important to draw up a list of all the material costs first and further draw up a list of costs for the support received by employees of the University for helping the students. The material list in appendix 4 shows all the materials used for the products in detail. The price for each material comes from the catalogue of the company “RS components” to make the price of the product comparable. The price for new components is displayed although there has been used a lot of old materials for the project. Most of the materials were provided by the school.

Further the support of different teachers has to been taken into account for not distorting the competition. Dividing the supportive groups between normal employees of the school and professors for the normal employees is this calculated with a salary of 10 €/hour and professors 15 €/hour.

Following this prerequisites the estimated costs for the whole project are approximately around € 265,-. The steering system is the most expensive product of the project, while the seating system copes with the lowest amount of money.

The costs for the steering system are about € 150,-. The expenses for the human labour make about 80% of the whole costs. The costs for the materials are very small with an amount of € 27,53.

Analysing the expenses for the push handles we can notice a similar allocation of costs. The expenses for the human labour need a budget of € 65,- and for the materials € 5,80 are needed.
The last product shows a different cost structure. In this product the percentage of material costs is higher than the average of the other products. The reason is that choosing for an easy solution, which didn’t need a lot of support from universal teachers.

Concluding the cost analysis and now focusing on the allocation of cost. A high percentage of the expenses for the products are the costs for the support of different teachers. The material costs are very small overall products with 17%. Taking into account that new products weren’t used, the material cost are even less than € 46.-. For the construction of a universal seating fixture, a new steering system and the adjustment of two handles the given solutions are very price efficient.
## Setting System

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
<th>Salary</th>
<th>Costs2</th>
<th>Final price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bars</td>
<td>215</td>
<td>2</td>
<td>4.50 €</td>
<td>1.94 €</td>
<td>Welding</td>
<td>2</td>
<td>10.00 €</td>
<td>20.00 €</td>
<td></td>
</tr>
<tr>
<td>Click-system stops</td>
<td>100</td>
<td>1</td>
<td>2.00 €</td>
<td>2.00 €</td>
<td>Mechanical support</td>
<td>1</td>
<td>15.00 €</td>
<td>15.00 €</td>
<td></td>
</tr>
<tr>
<td>Black metal spray</td>
<td>1</td>
<td>1</td>
<td>8.69 €</td>
<td>8.69 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
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<td>12.63 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35.00 €</td>
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## Steering System

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
<th>Salary</th>
<th>Costs2</th>
<th>Final price</th>
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<tr>
<td>Connection bar - iron</td>
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<td>3.00 €</td>
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<td>2</td>
<td>10.00 €</td>
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<td>Attaching system - steel</td>
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<td>4.50 €</td>
<td>Bending</td>
<td>2</td>
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<td>1</td>
<td>0.80 €</td>
<td>0.80 €</td>
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<td>Steering hall</td>
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<td>Black shrink</td>
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## Cable

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<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
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<tr>
<td>Electrical Plug</td>
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<tr>
<td>Cylindrical knob</td>
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<td>1</td>
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<td>1.32 €</td>
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<td></td>
<td></td>
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<tr>
<td>Metal sprays (white, red, blue)</td>
<td>3</td>
<td></td>
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<td>2.00 €</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td><strong>Total</strong></td>
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<td>27.53 €</td>
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<td></td>
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<td>120.00 €</td>
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## Push handles

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
<th>Salary</th>
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<tr>
<td>Iron bar</td>
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<td>2.00 €</td>
<td>0.80 €</td>
<td>Welding</td>
<td>2</td>
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<td>20.00 €</td>
<td></td>
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<tr>
<td>Aluminum block</td>
<td>100</td>
<td>1</td>
<td>5.00 €</td>
<td>5.00 €</td>
<td>Mechanical support</td>
<td>3</td>
<td>15.00 €</td>
<td>45.00 €</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>5.80 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65.00 €</td>
</tr>
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</table>
8. Final Product
The final product is the combination of the two parts of different wheelchairs. Figure 8.1 shows the bottom part of the combined wheelchair, from an electrical wheelchair, which is modified for this project. Figure 8.2 shows the seating part of the combined wheelchair.

8.1 Seat Fixture
These two components were combined with each other by constructing a seat fixture to the bottom part of the wheelchair.

The bottom of the seat part has an attachment mechanism (figure 8.3) which connects the seat with the other modified wheelchair part (figure 8.4). The seat fixture is made of two iron bars that are welded to the electric wheelchair construction. With this solution it is possible to fasten the seat from the buggy on the bottom of the electric wheelchair.

At the first test it seemed that the seating part clicked perfectly on the bars but would move horizontally because there was too much space on the bars. A while later there was a stop sequences mounted on the fixture. After testing these sequences, it was made clear that there were no further problem. As shown in figure 8.5, the seat part is connected with the bottom part by using the seat fixture and the stop sequences. Nahuel sits in a straight right position because of the seat and he can see straight ahead due to the position of the seat fixture. This enables him to oversee his environment and to use the wheelchair safely.

To connect and remove the two parts from each other, it is important to remove the handles and the steering mechanism first before removing/connecting the seat with the seat fixture.
8.2 Handles
When the seat is fastened to the bottom wheelchair the handles are not able to fit into the current construction, as shown in figure 8.6. Therefore, it is important to make a different construction so that the handles still fit into the new wheelchair construction. Also it seemed that the handles itself were quite small and not ergonomically usable for the new construction and so had to be enlarged. As shown in figure 8.7, there was made a special construction for the handles so that they would be placed a little bit outside the wheelchair, fit in the holes and also be enlarged to be more ergonomically friendly. The handle constructions are tightened by screws and can be removed by using the hand.

Figure 8.6 - Earlier construction

Figure 8.7 - Newly handles

Figure 8.8 - Handles on wheelchair

Figure 8.9 - Handles user
While testing the handles, it was made clear that the handles first were not of equal height. Because one of the construction was crooked compared to the other it was fixed by sharpening a few edges. The handles need to be removed while removing or connecting the seat with the fixture.

8.3 Steering mechanism
Next thing is the steering mechanism. The electric wheelchair has...
originally a joystick control that would enable the user to move around, figure 8.10. But Nahuel is incapable of using this system because of his muscle disorder. But he is able to use his chin after he’s trained how to use it. Therefore there has been a chin-control implemented on the electrics of the joystick box and used for the boy to use. The chin control is the old joystick controller taken apart and with a flush ball on top of it to use it safely with the chin. The chin-control system is placed in front of the boy by a metal bar that’s holding it, figure 8.11. The bar is hold by a bar attached on the bottom wheelchair and the bar can be removed and placed by tighten it with a screw. The chin-control is wired to the box and it is able to plug the system in and out if necessary (figure 8.12). This has to be done while removing or connecting the seat from/with the seat fixture.

The boy was, during the test fase, indeed able to use the steering mechanism to move forward, right, left or even diagonal (figure 8.13). This test fase was most successful to see Nahuel move by himself. Although it might looks like Nahuel is trying to bite in the plush, but he is just trying to get grip. Nahuel could move in almost any direction, but the bar seemed too short for him. He could not move straight forward without being helped after three seconds. This could be due the fact that Nahuel has to learn how to use this mechanism with his chin, but also that the bar is not enough in his reach. This was fixed by bending the bar 20 mm more.

8.4 Painting
As shown in figure 8.14, most of the bottom part of the wheelchair is painted in black colours to make it all one colour. The colour matches with the seat and it isn’t distracting or dangerous for people in the nearby environment. The bar that holds the steering mechanism is the only component painted in red and blue colours because this part is right in front of Nahuel and his favourite
football club is in the colours red and blue “FC Barcelona.”

8.5 Wheelchair transporting
There are a few important things to remember when transporting the wheelchair in a car. In any (special) busses the wheelchair doesn’t have to be dismounted to transport it easily. But for transporting by car it is important to know that the bottom part of this wheelchair is heavy. With using everything, such as the battery and all the components, the wheelchair becomes too heavy for one person to lift the wheelchair and put it in a similar position like figure 8.16 shows.

To fit in a car, the handles and the steering mechanism have to be removed from the construction and placed on top of the construction. The old joystick box can be dismounted as well and this is highly recommended, but can be just lowered and still putted on the construction. Keep in mind that all the screws can be dangerous in the car and can damage the glass if not put away safely. To take the construction apart, it takes around 5 minutes to loosen all the components, like described above. To put it all together it might take more than 5 minutes to get all the components on the right height and position.

8.6 Sustainability
The wheelchair is a sustainable product, referring to appendix 5 for the sustainability report of this wheelchair. Most of the materials used for all the components are not purchased newly but were already property of the school or from the supervisor. This contributes to the preventing of building and shipping materials and contributes to a sustainable product.

Then is the fact that most of the materials could be reused if the boy grows too much and becomes too big for the wheelchair and the wheelchair is. The wheelchair is built for one special client, so it won’t be able to sell the wheelchair to other clients. But the
wheelchair can be taken apart and all the materials can be reused.

9. Discussion & Conclusion
When the project started, it was not clear in which way the project was headed. The variety of possibilities made it difficult to focus on fewer things. With a heading, a aim, the final product is made without almost any budget and it was still able to construct the wheelchair into a working wheelchair part for the boy to use.

Because of the lack of budget, it could be discussed if the final product would have looked a lot different than it would have now. With a budget the steering mechanism could be improved or maybe a whole different mechanism could be purchased. It also happened often that materials had been used in which you can ask yourself if these materials are sustainable enough and if it could last for a long period of time. But the materials are welded pretty solid and are able to hold the weight of the boy.

Earlier was told that an electrical engineer from the school suggested radio transmissions to make the chin control wireless. But without a budget, it has been proven to give a proper solution to this problem. The help of the staff and professors were very helpful and proved that this project, without any budget, still could be done.

During the project, there had been a lot of meetings with the supervisors, the company and Nahuel. These meetings were used to take measurements for all the constructions, take photos of Nahuel to observe him and get to know him better to know what he thinks about the project. All the taken measurements are concluding that the wheelchair fits Nahuel and also that this construction is made especially for him and cannot be used by any other user.
The project was very interesting to work on, the purpose was clear and it was nice to help a boy out and give him more autonomy. It is clear to say that the students have delivered a product that will benefit the social and physiological aspects of Nahuel. The task was given to create more opportunities for independent actions for the boy. The wheelchair will enable Nahuel to be more independent and take more control over his own steps. Nahuel is now able to take place in social events and therefore will develop a physiological benefit in which he will feel happier about his interaction with others.

We feel very satisfied that this project helped to give a little boy in this state give him more autonomy and the fact that this project was specific helped to create the chance to build a construction that fits Nahuel requirements and wishes. After months of hard work we are pretty satisfied with the end product.
10. References

Chapter 1 – Introduction


Appendix ... - Steering systems


⁴Mobility Basics. Power Wheelchairs Drive Controls. From http://mobilitybasics.ca/wheelchairs/drivecontrols.php


⁷Pačnik, G. & Benkič, K. & Brečko, B. Faculty of Electrical Engineering and Computer Science, Institute of Robotics, Maribor, Slovenia. ISIE 20/06/05. Dubrovnik, Croatia. Voice Operated


Figures Appendix … - Steering systems

Figure 0.7: Joystick Control - http://www.rollingspokes.com/Power-Chairs.page
Figure 0.8: Chin Control - http://atwiki.assistivetech.net/index.php/Alternative_wheelchair_control

Figure 0.9: Sip-n-Puff Control - http://www.orin.com/index.html

Figure 0.10: Head Control - http://atwiki.assistivetech.net/index.php/Image:Head_array.jpg

Figure 0.11: Tongue Control - http://www.popsci.com/technology/article/2012-02/medical-tongue-piercing-and-retainer-used-control-wheelchair

Figure 0.14: Brain Control - http://www.liquidweb.it/services/brain-computer-interface-framework
# Appendix 1 - Glossary

<table>
<thead>
<tr>
<th>Word</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Company</strong></td>
<td>The research centre of the ‘UPC BarcelonaTech’ called ‘Càtedra d’Accesibilitat’. ‘Càtedra d’Accesibilitat’ works together with the local physiotherapists.</td>
</tr>
<tr>
<td><strong>Contact Person</strong></td>
<td>This is Raquel Vallez. She will be the direct link to meet up with the company</td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td>This are the physiotherapists which will be the representing group for the user</td>
</tr>
<tr>
<td><strong>User</strong></td>
<td>The boy with the disorder, Nahuel, will be the user of our final product</td>
</tr>
<tr>
<td><strong>Client</strong></td>
<td>Nahuel, but also his family will be the client for who we focus on</td>
</tr>
<tr>
<td><strong>Supervisor</strong></td>
<td>Eva Marin Tordera, teacher at the ‘UPC BarcelonaTech’ and ‘Neapolis Research Group’, will give advice and steer the project whenever needed</td>
</tr>
<tr>
<td><strong>Department of Education</strong></td>
<td>Without the approval of this department, the students won’t be allowed to fulfil the project.</td>
</tr>
<tr>
<td><strong>Buggy</strong></td>
<td>Brand of ‘Tomas Hilfen’ (Germany). It looks like an enlarged children’s buggy, but is an ergonomically wheelchair. The boy uses this wheelchair on a daily base.</td>
</tr>
<tr>
<td><strong>Power-Picco</strong></td>
<td>Brand of ‘Meyra’ (Germany), model ‘Power-Picco’. This is a wheelchair charged by a motor on the bottom, controlled with a joystick.</td>
</tr>
<tr>
<td><strong>The Gridz</strong></td>
<td>A software developed by ‘Sensory Software International’. This enables the user to talk with the use of an interface</td>
</tr>
<tr>
<td><strong>Arms</strong></td>
<td>These are two iron bars, hung on the buggy, connecting ‘The Gridz’. At the end of the bars, there are two click devices attached to let the user control the device with his/her cheeks</td>
</tr>
<tr>
<td><strong>EPW</strong></td>
<td>Electric Power Wheelchair</td>
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### Project group

The project group consist of five students with different academic backgrounds.

<table>
<thead>
<tr>
<th>Names</th>
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<tbody>
<tr>
<td>Jan Stepputtis</td>
<td>Business Informatics</td>
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<tr>
<td>Maurits Binnema</td>
<td>Human Technology</td>
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<tr>
<td>Adina Marin</td>
<td>Economic Engineering in the Mechanical Field</td>
</tr>
<tr>
<td>Ludwig Siegfrids</td>
<td>Industrial Engineering and Management</td>
</tr>
<tr>
<td>Charlotte Berthomieu</td>
<td>Packaging Engineering</td>
</tr>
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</table>
Appendix 2 - Seat Fixture drawings

The first idea is to imitate the fixture as shown in figure 0.1, in order to make the changing of the structure fast and easy.

The attachment system of the buggy, shown in figure 0.2, shows four hooks in every corner. It would be appropriate to create the same bars system for the other wheelchair.

At first, the idea was to put the system posed and attached by a piston ring clamp on the structure. However, the problem was the stability if the chair is too elevated and if we add the weight of Nahuel, the seat would be not be stable enough.

Secondly, the idea was to put the bar system at the same height of the wheelchair structure, always attached by a piston ring clamp. However, with the weight of the seat and of Nahuel, the bars can turn and sink into the structure.

However, thinking about the cheapest and easiest way to sustain it. The idea was to use two angle profile steel with screws, placed on the structure of the wheelchair to hang our attachment system. This construction will be strong and easy to do.


**Materials**

The designs are decided, but now the materials have to be chosen. The material has to have some certain characteristics. The material has to be sustainable so it can handle the weight from the boy and the seat also it have to be easy to work with. The part that it has to be light is not a main characteristic because the bar is not that big and will not change the midpoint of the wheelchair. There are a few possibilities: iron, plastic and aluminium.

Iron is a strong material that will keep the seat steady and iron is easy to work with when it is going to be weld to the wheelchair. Aluminium to work with is difficult when it has to be weld to the wheelchair but it is strong enough for the wheelchair. Plastic was also one option but were excluded. The pressure to the plastic bars by the weight of the boy and the seat is too much for the plastic bars. Due to the weight and the sustainability iron seems to be the best solution.

![Figure: seat fixture drawing](image-url)
Appendix 3 - Steering systems

Power wheelchairs are known since the 1950s. Since then the power wheelchair demand is increasing rapidly. Motorized wheelchair controls by analog or digital microprocessor based controls. The usages of microcontrollers from the INTEL 8000 or Motorola 6800 family are very common.¹

Microcontrollers provide a flexible control and the place to settle various devices. The most common device is the joystick to steer a power wheelchair. A survey in 2000 detected that 81 percent of the power wheelchair users use the joystick control. Further 9 percent move with head or chin control while sip-n-puff has 6 percent.

In 2000, the computer-aided techniques were not developed as far as they are now. That explains the less use of these techniques. States of the art are very different computer aided techniques to steer wheelchairs such as brain, eye gaze, tongue and voice control. In the following part, we give a short overview over eight common EPW control techniques. After the comparison, we list the advantages and disadvantages of the adequate systems for our client.²

<table>
<thead>
<tr>
<th>Power wheelchair control interfaces used in 2000⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percent of patients using</strong></td>
</tr>
<tr>
<td>Joystick</td>
</tr>
<tr>
<td>Head or chin control</td>
</tr>
<tr>
<td>Sip- n- Puff</td>
</tr>
<tr>
<td>Other (eye gaze, tongue pad, head, hand. foot switch controls</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

Steering Controls

1. Joystick Control

The joystick of the joystick control system is attached on an armrest (figure 0.7). The user can operates the joystick with the hand lying on
the armrest. The movement of the wheelchair results by twisting the joystick into the direction the user wants to go. Pushing the joystick forward results in moving the EPW forward, while moving the stick to the sides turns the wheelchair and pulling the stick makes the wheelchair move backward. If the joystick does not twist in any direction the wheelchair stops or does not move.

2. Chin Control³

The chin controlled wheelchair system works with a joystick fixed under the chin of the wheelchair user. At the end of the joystick a cup is installed which enables the user to steer with the joystick like in Figure 0.8. To move the wheelchair forward the user has to push the stick forwards. To go backwards he has to pull the stick while the movement to sides results in pressing the joystick to the left or right side.
3. Sip-n-Puff Control

Sip-n-Puff (SNP) control offers the possibility to steer wheelchair by breathing into a tube. The tube is on the one side connected to the mouth and fixed at the head like in Figure 0.9 or brought to the user by a construction that is fixed to the armrest of the wheelchair and the tube is put in front of the face. Sip-n-Puff stands for sipping and puffing. Sipping is the process of inhaling in contrast to puffing which is the process of exhaling. This control system uses normally four different command types to move the wheelchair. Strong exhaling will enable the wheelchair to move forward, while strong inhaling will make the wheelchair stop. Soft and continuous sipping or puffing will make the wheelchair move left or right.

4. Head Control

The head control is implemented in the back of the users head. Figure 0.10 shows one existing head control solution. The user of this control method can steer the wheelchair by pushing his head back against the headrest. Pushing the head to the left or right side against one of the buttons shown in the picture makes the EPW move to the side. With this method, it is not possible to move the wheelchair backwards.

5. Voice Control

With this kind of wheelchair it is possible to convert voice input into movement of the wheelchair. Figure 0.11 shows the basic principle of an implemented voice controlled wheelchair. The progress starts with the voice command of a user and ends with the movement of the chair. After speaking (1) the system realizes and analyzes (2,3) the words. Some Sensors check for surroundings...
(4) and check if enough space is left (5) then all data collected get checked if there is a risk in executing the command (6). If no thread gets detected (7) the command gets transmitted and the wheelchair moves in the wanted direction (8).

6. Tongue Control

Tongue control enables disabled persons to use the tongue to steer the movement of a wheelchair. Therefore a magnet is on the users tongue. After this surgery, it is possible to use the tongue like a joystick. Moving the tongue in one area of the areas marked in green (Figure 0.12, left side) results in moving the EPW in a certain direction. A waterproof retainer (Figure 16, right side) tracks the movement of the magnet in the tongue on the roof of the mouth.

![Figure 0.12 - Tongue control](image)

7. Eye Gaze Control

The eye gaze wheelchair allows patients to control a wheelchair by using their eyes. There are many different measurement methods to parse the eyes action into wheelchair movement e.g. electro-oculography (EOG), Limbus tracking, dual-Purkinje-image (DPI), pupil tracking and infrared oculography (IROG). The picture 4/figure 0.13 shows the process from looking to moving. The user looks onto a tablet screen, which shows the different directions available to move. A camera tracks the users’ eye-movement and transmits the data to a computer.
analyzes the data. Just if the movement of the eyes were looking on a special symbol on the tablet, the computer transmits the data to a microcontroller, which steers the wheelchair with the received data.

8. Brain Control⁶

Brain control usage is a state of the art technique to steer EPWs. Figure 0.14 shows a schematic overview over brain control. It works with a sensor headset e.g. electroencephalography (EEG) put on the users head. It receives the brain activities. Brain computer interface analyze the (BCI) Control Unit, transformed by computer or tablet, and transmitted to a microcontroller, which steers an engine.

Evaluation of Systems

To know which of these upcoming solutions are more efficient and what their possibilities for applying on the wheelchair are, is there a comparing of the controlling possibilities below and the advantages and disadvantages.

Comparing controlling possibilities

For the comparing of the controlling possibilities are ranged by different kind of factors and these factors are graded by -2, -1, +1 and +2. This will give an impression about the strength of this factor whereby -2 is really bad and +2 is really good. The controlling possibility defines by how easy it is for the boy to learn how to use the control device (Learning). If it can be placed near the boy (Placing) it will be easy control the device (Controlling). Is it cheap or expensive (Cost), if the boy can easily use the method by himself (Usability), if it is disturbing the control process (Movement), if the boy has to have a lot of grip in his body (Grip), if the device needs a lot of maintenance (Maintenance) and if it will be overall effective for the boy when he is going to use it (Effectiveness)
Below we also have set all the advantages and disadvantages of the different steering methods. These factors will be taken in count in the final selection of the steering method that will be most suitable for usage.

**Advantages and Disadvantages of controlling possibilities**

<table>
<thead>
<tr>
<th>Proper control possibilities for the client</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Steering method</strong></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Chin Contr.</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sip-n-Puff</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Interface</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Eye-Gaze</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Tongue</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Explanation scores**

*Joystick:* With its end score of -3 will not be considered for implementing in the wheelchair. It would be easy to learn for the boy and it would be the cheapest solution, but they boy is not able to use it. The joystick requires a firm grip to use it, and considered that the boy has uncontrollable movements and almost no grip in his hands; it is not safe for him to use this kind of system.

*Chin control:* The score of 6 points makes the chin control the best possibility to implement in the wheelchair. The controls are in front of the chin of the subject, which makes that the boy can move freely with his arms and feet. It requires a bit of learning but after the learning session, it would be easy to use. Because the control requires calm handlings, it is not possible for the chair to move when the boy is in panic.

*Sip-n-Puff:* This control is not a possibility for implementing in the wheelchair (score 0). This control requires a lot of learning sessions, maintenance and is not very cheap. The boy needs to learn a lot of the system like the way he has to breathe and to sit still all the time. In panic situations, this will not be safe if the boy uncontrollable breathes, and the wheelchair still moves.

*Voice:* The boy will not be able to use the control. As the situation is now, he barely can speak and only communicate with noises. To learn how to use a voice control mechanism it would take too much training to become an easy usage. This control will not implement in the wheelchair.
**Tongue**: With a score of -5 it would not be a good control to use for the wheelchair. It requires at first a special usage per person and then it takes a lot of time to get to know the system. A further point is the fact that it is not cheap and requires a lot of maintenance. Positive is that it is simple to place and that the boy can move freely with his arms and legs.

**Eye-Gaze**: It would be easy to place and maybe easy to learn, but it is mostly expensive and requires a lot of maintenance. It could be a safe method, considered that the user knows what to do in panic situations, otherwise the wheelchair will move uncontrollably. This method considers effective because the user is fully aware of its own eye movements. This technique can work in the wheelchair.

**Brain control**: It is expensive, requires many check-ups and a lot of training. On the other hand, it is effective at the end. The user can control the chair without wires and is able to control the wheelchair in every situation. Considered that it has to be implemented in the brain, it is not a very safe solution for the issue.

**Head control**: This would be a possible solution for implementing in the wheelchair. It is simple to learn and simple to place and use. It is also one of the cheapest solutions. However, the user is also likely to lose control faster when he is in panic. There is not much grip because the user can only move forwards, left or right.

**Conclusion**

After our research about the steering possibilities, we decided that we want to consider further the “Chin Control” and the “Eye Gaze Control.”

6.6 Cost analysis of the pre-selection

We chose the eye gaze and the chin control as best possibilities for our client to use. Now we have already one working EPW. The power-picco system consists of a mechanical transmission system, a controller, two motors, a battery and an operational interface. The operational interface of the power-picco is a joystick. For these components, we do not have to assume any cost.

To implement an eye gaze or a chin control system we need to change the interface.
Eye gaze control

The eye gaze control, as a whole system, is at the moment not available commercial. Therefore, we have to estimate the costs of every part. Additional to the power-picco system we need a computer and one CCD camera. The computer has to calculate the eye movement and transmit the result to the power wheelchair controller by way of USB to RS232 converter.

Our client also has a tablet computer working with Windows 7. So the whole cost of such a system emerge from the camera and a camera-fixing system. A CCD camera you can purchase from up to 200 €. The system to fix such a system at a wheelchair starts at 50 €. The biggest costs in such a systems result in the connection of all components. To build such a system we need an expert from outside the EPS group, which can work on the electronic parts. The estimation of the costs is not possible.

Chin control

For the chin control, we have to work on the chin interface. The components that we need to add to the system are mechanic parts. We are able to build these parts within our project group.

The cost result of making the chin control, which will use iron or aluminium bars for holding the chin control. The chin control itself must be soft to put the chin on, and therefore we will use materials like foam or plastic for this part. To connect the chin control with the motor, we have to use metal wires which will be hidden inside the bars, so that the user won’t get stuck in the wires or get hurt by them. For the safety, it is important to coat wires with a layer of PVC, like known in electrical cables.
### Appendix 4 - Materials list

#### Seating System

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
<th>Salary</th>
<th>Costs2</th>
<th>Final price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bars</td>
<td>215</td>
<td>2</td>
<td>4,50 €</td>
<td>1,94 €</td>
<td>Welding</td>
<td>2</td>
<td>10,00 €</td>
<td>20,00 €</td>
<td></td>
</tr>
<tr>
<td>Click-system stoppers - foam</td>
<td>100</td>
<td>1</td>
<td>2,00 €</td>
<td>2,00 €</td>
<td>Mechanical support</td>
<td>1</td>
<td>15,00 €</td>
<td>15,00 €</td>
<td></td>
</tr>
<tr>
<td>Black metal spray</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8,69 €</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>16,56 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35,00 €</td>
</tr>
</tbody>
</table>

#### Steering System

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Costs</th>
<th>Human resources</th>
<th>Hours of work</th>
<th>Salary</th>
<th>Costs2</th>
<th>Final price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection bar - iron</td>
<td>1500</td>
<td>1</td>
<td>2,00 €</td>
<td>3,00 €</td>
<td>Welding</td>
<td>2</td>
<td>10,00 €</td>
<td>20,00 €</td>
<td>23,00 €</td>
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<tr>
<td>Attaching system - steel</td>
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<td>4,50 €</td>
<td>4,50 €</td>
<td>Bending</td>
<td>2</td>
<td>10,00 €</td>
<td>20,00 €</td>
<td>24,50 €</td>
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<tr>
<td>Base board</td>
<td></td>
<td>1</td>
<td>0,80 €</td>
<td>0,80 €</td>
<td>Mechanical support</td>
<td>4</td>
<td>15,00 €</td>
<td>60,00 €</td>
<td>60,80 €</td>
</tr>
<tr>
<td>Physioterapy Steeringball</td>
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<td>1</td>
<td>7,25 €</td>
<td>7,25 €</td>
<td>Electrical support</td>
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<td>1,53 €</td>
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<td></td>
<td></td>
<td></td>
<td>0,72 €</td>
</tr>
</tbody>
</table>
## Pushhandles

<table>
<thead>
<tr>
<th>Materials</th>
<th>Length in mm</th>
<th>Quantity</th>
<th>Price for 1000 mm/piece</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron bar</td>
<td>200</td>
<td>2</td>
<td>2,00 €</td>
<td>20,80 €</td>
</tr>
<tr>
<td>Aluminum block</td>
<td>100</td>
<td>1</td>
<td>5,00 €</td>
<td>50,00 €</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>70,80 €</td>
</tr>
</tbody>
</table>
Appendix 5 - Sustainability report

Project Introduction

The project “Accessibility and Universal design” is about designing assistive tools and devices for pupils in order to improve their inclusion with mates and promote the equal opportunities at environments such as school.

This project supports a boy named Nahuel, that has a disability disease so his mobility depends of a wheelchair. He is thirteen-year-old and he has a condition called ‘Spasticity with Dystonia’. Spasticity is a feature of altered skeletal muscle performance in muscle tone involving hypertonia. Dystonia is a neurological movement disorder in which the patient cannot control his movements. Sustained muscle contractions cause twisting and repetitive movements or abnormal postures.

Nahuel is capable of thinking on his own but the muscle disorder causes him to lose control about his facial and body muscles, which makes him unable to talk and control his own movements.

Presentation of the working process:
The project’s aim is to improve the wheelchair of Nahuel and give him more autonomy by making it possible to control his own wheelchair.

His current wheelchair is a buggy, a baby chair without motor (figure 0.15). The second wheelchair is a motorized wheelchair, with a joystick to steer the chair (figure 0.16). The goal of the project is to combine the both wheelchairs (figure 0.17). The project consist of three fitting tasks.
**First task: A universal seat fixture**

Nahuel can’t use the motorized wheelchair in its current state. The seat of this wheelchair is not accurate regarding the customer requirements. There is no support for his head or a safety system like a belt. The goal is to keep the seat from the buggy and adapt it to the motorized wheelchair. The parents of Nahuel want to keep the both wheelchairs: the motorized wheelchair will be used only inside the school and the buggy for outside use (it is lighter and easier to drive).

One part of the project is to build a structure that makes the seat from the buggy fit and fasten in the motorized wheelchair. (figure 0.18).

**Second task: the steering system**

Another part of the project consist of allowing Nahuel to use the steering system and giving him some autonomy; but, heaving the specified disease, he can’t neither hold the joystick nor to control his movements. The task includes finding and building a system that allows him to use without any external help. The proper solution is the ‘Chin-Control Steering System’ because the head is the only part of his body that the boy can control properly.

**Third task: the handles**

The insertion of the seat from the buggy on the motorized wheelchair makes changes to consider. The seat of the buggy is bigger than the motorized wheelchair and the handles won’t fit on this current construction (figure 0.19). The task includes building different handles by using the actual one and by adding some materials. The handles’ position was changed and they were built longer.

**Sustainability part**
The project is only for a specific client, and won’t be set out on the market. This sustainability study will be only for this prototype.

**Universal seat fixture**

<table>
<thead>
<tr>
<th>Components</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bars</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Click-system stops</td>
<td>Polycarbonate (PC)</td>
</tr>
<tr>
<td>Click-system foam</td>
<td></td>
</tr>
</tbody>
</table>

To build the universal seat fixture, steel bars were used and welded together on the seat (figure 0.20). To avoid that the seating part would move from a side to another, we added two Click-system stoppers (of tough foam).

*Diagram 1 - Energy (MJ) of the Seat Fixture*
Diagram 2 - CO2 Footprint of the Seat Fixture

Table 1 - Energy and CO2 of the Seat Fixture

<table>
<thead>
<tr>
<th>Phase</th>
<th>Energy (MJ)</th>
<th>Energy (%)</th>
<th>CO2 (kg)</th>
<th>CO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>2,888</td>
<td>99,3</td>
<td>0,195</td>
<td>99,3</td>
</tr>
<tr>
<td>Manufacture</td>
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<td>0,0</td>
<td>0,000</td>
<td>0,0</td>
</tr>
<tr>
<td>Transport</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,0</td>
</tr>
<tr>
<td>Use</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,0</td>
</tr>
<tr>
<td>Disposal</td>
<td>0,021</td>
<td>0,7</td>
<td>0,001</td>
<td>0,7</td>
</tr>
<tr>
<td>Total (for first life)</td>
<td>2,909</td>
<td>100</td>
<td>0,196</td>
<td>100</td>
</tr>
<tr>
<td>End of life potential</td>
<td>-2,672</td>
<td></td>
<td>-0,183</td>
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</tr>
</tbody>
</table>

As shown, the use of energy and CO2 is quite low

The steering system

<table>
<thead>
<tr>
<th>Components</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection bar</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Attaching system</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Base bar</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Steering ball</td>
<td>Flexible Polymer Foam (MD)</td>
</tr>
</tbody>
</table>
To construct the steering system, the idea was to take off the joystick from the initial box and put it right in front of Nahuel’s chin. For this idea, we needed a long steel bar to attach it next to the seat and to hold the mechanism. This bar would be held in an attached system and all these materials were used from the same initial bar (figure 0.21). At the end of the connection bar, there is a foam ball fixed to the joystick to make possible for Nahuel to move it. The joystick is connected with the motor and battery through the cables (figure 0.22).

Diagram 3 - Energy (MJ) of the Steering System
Diagram 4 - CO2 Footprint of the Steering System

Table 2 - Energy and CO2 of the Steering System

<table>
<thead>
<tr>
<th>Phase</th>
<th>Energy (MJ)</th>
<th>Energy (%)</th>
<th>CO2 (kg)</th>
<th>CO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
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<td>89,8</td>
<td>61,592</td>
<td>90,1</td>
</tr>
<tr>
<td>Manufacture</td>
<td>0,662</td>
<td>0,1</td>
<td>0,051</td>
<td>0,1</td>
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<tr>
<td>Transport</td>
<td>0,011</td>
<td>0,0</td>
<td>0,001</td>
<td>0,0</td>
</tr>
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<td>Use</td>
<td>117,708</td>
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<td>6,674</td>
<td>9,8</td>
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<tr>
<td>Disposal</td>
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<td>0,018</td>
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<tr>
<td>Total (for first life)</td>
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<td><strong>100</strong></td>
<td><strong>68,337</strong></td>
<td><strong>100</strong></td>
</tr>
<tr>
<td>End of life potential</td>
<td>-1050,148</td>
<td></td>
<td>-161,592</td>
<td></td>
</tr>
</tbody>
</table>

As shown, the energy is higher because it includes the electricity that is used to move the wheelchair.
**Handles**

<table>
<thead>
<tr>
<th>Components</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steelbars di 22</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Steelbars di 18</td>
<td>Medium carbon steel</td>
</tr>
<tr>
<td>Steelblock</td>
<td>Medium carbon steel</td>
</tr>
</tbody>
</table>

*Figure 90.23 - New handles base*

*Figure 0.24 - Handles*

*Diagram 5 - Energy (MJ) of the Handles*
Diagram 6 - CO2 Footprint of the Handles

Table 3 - Energy and CO2 of the Handles

<table>
<thead>
<tr>
<th>Phase</th>
<th>Energy (MJ)</th>
<th>Energy (%)</th>
<th>CO2 (kg)</th>
<th>CO2 (%)</th>
</tr>
</thead>
<tbody>
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<td>0,615</td>
<td>78,9</td>
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<tr>
<td>Transport</td>
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<td>0,0</td>
<td>0,000</td>
<td>0,0</td>
</tr>
<tr>
<td>Use</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,0</td>
</tr>
<tr>
<td>Disposal</td>
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<td>0,6</td>
</tr>
<tr>
<td>Total (for first life)</td>
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<td>-0,615</td>
<td></td>
</tr>
</tbody>
</table>

As shown, the energy used and the CO2 footprint are quite low.

Discussion of the results

These results show that the product doesn’t require a lot of energy and the CO2 footprint is quite low. With no budget for the project, all the materials were reused or nearly bought for building the new construction. Almost every component comes from the laboratory of the school or from our supervisor’s home (2 km from the school). The only costs come from the
manufacture in the factory and from the components: the building of the iron bars and other components.

Because of the fact that the components where in the most part achieved with the University’s help, we don’t know the producer of these parts, if the company it’s far away from the school or not, but each component’s weight isn’t too big; So the transport from the factory should not be too polluting and too expensive.

The product doesn’t require much energy because Nahuel’s powers are limited, so he won’t use it very often until he will manage to handle it, maybe once or twice a week until he learns to deal with the steering system. And perhaps later, he will use it more often. Electricity will be the only used energy for the wheelchair.

Furthermore, almost all the components used can be reused after (except the ball for the chin steering system). Considerate that Nahuel will use this new chair only two years because he will grow and the equipment won’t fit him anymore. After that, it will be easy to readjust the chair with other components and use the old components to build other useful components.

**Conclusion**

In conclusion, the wheelchair is a sustainable product because it doesn’t take too much energy to build it, almost all the components can be reused after and the wheelchair doesn’t consume too much electricity.

But this analysis is not representative of the sustainable analysis that is found about the wheelchairs presented in the market. This product is only made with cheap and reused components and cannot be sold or used by other people because the wheelchair is customized for our client. A real motorized wheelchair would have a bigger consumption of an energy and CO2 footprint.