ERASMUS INTENSIVE PROGRAMME

SMART HOME DESIGN FOR WHEELCHAIR ACCESSIBILITY

Team: Game DV (Team 2)

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The University of Applied Science in Zwickau, Germany arranged an intensive programme about Smart Home Solutions in Finland. In Jyvaskyla six groups of students came together from different countries. All students were divided into 6 internationally mixed teams, in which every nationality was represented. Together we combined our forces concerning the creation of a concrete smart home.

Our group has the following members: David Hatzel from Germany, Veera Laukka from Finland, Ada Moisescu from Romania, Giulia Piffer from Italy, Eline Talen from the Netherlands and Marco Weyns from Belgium.

We have a lot of differences: age, gender, habits, studies, way of thinking, life vision and knowledge. But we have one very important thing in common: we are willing to learn from each other. This is our asset.

On Wednesday 6 march, 2014 we got a concrete assignment. Our mission: rebuilding a townhouse into a wheelchair accessible home.
Every day we stand up in the morning, we are climbing stairs, take stuff from shelves, clean our body and so on. Normally this is nothing special for us, but when you are paralyzed in your lower body and when you are obligated to use a wheelchair, all these things can become problematic.

This report deals with Roseanne; she is a fictive woman who had to use a wheelchair after a car accident. She lives with her husband and her six years old daughter in a small town house which is not wheelchair accessible. Our main goal in this report is to make a concept for rebuilding the house, so that Roseanne can access all the floors and rooms and do the household as good as she can.

Our report contains some solutions for Roseanne, for example possibility’s to access the whole house, a smart home kitchen, a wheelchair suitable bath and garden and also a security and health concept. Accessibility means the possibility to access every part of the house by building an elevator make the doors/hall more wide and so on. In the smart home kitchen Roseanne can cook for her family, all the cabinets are electrically moveable so she can reach them. Also the sink and the stove are inductive to avoid burning. Moreover she has a waterproof wheelchair for the shower where she can drive into, a height adjustable sink and moveable grip bars next to the toilet for a simple transfer. The garden was also modified. As a result she can access her garden and she is able to take care of her flowers which are integrated in a wheelchair accessible flowerbed.

This is only a brief impression of our total concept. This report contains a detailed description of it.
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The report is about finding solutions for wheelchair users (here: caused by a spinal cord injury) who want to live their life as independent as possible.

Before you can start thinking about modifications, it is absolutely necessary to have knowledge about spinal cord injuries and wheelchair use.

These two main aspects about wheelchair accessibility are described with more details in this chapter.

SPINAL CORD INJURY

A spinal cord injury (SCI) refers to any injury to the spinal cord that is caused by trauma instead of disease. [1] Depending on where the spinal cord and nerve roots are damaged, the symptoms can vary widely, from pain to paralysis to incontinence. [2][3] Spinal cord injuries are described at various levels of "incomplete", which can vary from having no effect on the patient to a "complete" injury which means a total loss of function.

Figure 1. Anatomy of spinal cord and vertebra

Traumatic spinal cord injury is classified into five categories on the ASIA Impairment Scale:

- **A** indicates a "complete" spinal cord injury where no motor or sensory function is preserved in the sacral segments S4-S5.
- **B** indicates an "incomplete" spinal cord injury where sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5. This is typically a transient phase and if the person recovers any motor function below the neurological level, that person essentially becomes a motor incomplete, i.e. ASIA C or D.
- **C** indicates an "incomplete" spinal cord injury where motor function is preserved below the neurological level and more than half of key muscles below the neurological level have a muscle grade of less than 3, which indicates active movement with full range of motion against gravity.
- **D** indicates an "incomplete" spinal cord injury where motor function is preserved below the neurological level and at least half of the key muscles below the neurological level have a muscle grade of 3 or more.
- **E** indicates "normal" where motor and sensory scores are normal. Note that it is possible to have spinal cord injury and neurological deficits with completely normal motor and sensory scores. [4]
Signs recorded by a physician and symptoms experienced by a patient will vary depending on where the spine is injured and the extent of the injury. These are all determined by the area of the body that the injured area of the spine innervates.

A severe injury may also cause problems in parts of the spine below the injured area. In a "complete" spinal injury, all functions below the injured area are lost. In an "incomplete" injury, some or all of the functions below the injured area may be unaffected. If the patient has the ability to contract the anal sphincter voluntarily or to feel a pinprick or touch around the anus, the injury is considered to be incomplete. The nerves in this area are connected to the very lowest region of the spine, the sacral region, and retaining sensation and function in these parts of the body indicates that the spinal cord is only partially damaged. An incomplete spinal cord injury involves preservation of motor or sensory function below the level of injury in the spinal cord.[5] This includes a phenomenon known as sacral sparing which involves the preservation of cutaneous sensation in the sacral dermatomes, even though sensation is impaired in the thoracic and lumbar dermatomes below the level of the lesion.[6] Sacral sparing may also include the preservation of motor function (voluntary external anal sphincter contraction) in the lowest sacral segments.[5] Sacral sparing has been attributed to the idea that the sacral spinal pathways are not as likely as the other spinal pathways to become compressed after injury. The sparing of the sacral spinal pathways can be attributed to the lamination of fibers within the spinal cord. [6]

**LUMBOSACRAL SPECIFIED INFORMATION**

The effects of injuries to the lumbar or sacral regions of the spinal cord are decreased control of the legs and hips, urinary system, and anus.

Bowel and bladder function is regulated by the sacral region of the spine. In that regard, it is very common to experience dysfunction of the bowel and bladder, including infections of the bladder and anal incontinence, after traumatic injury.

Sexual function is also associated with the sacral spinal segments, and is often affected after injury. [6]
Figure 2. Overview of the innervated body parts [7]

Figure 3. Overview of different spinal cord injuries [8]
We do not know the exact number of wheelchair users in Europe.

Aldersea estimated that there were 710,170 wheelchair users in England while the Audit Commission reported the total number of wheelchair users for the UK to be only about 640,000. With England’s population being around 50 million and the UK being around 61 million, this would put the percentage of wheelchair users between 1.0-1.4%.

On the other hand a French study published in 2008 by Vignier put the estimate of French Wheelchair users at 0.62% (361,500 wheelchair users).

A Dutch Study has estimated the number of wheelchair users to be almost 1% of the population.

If one assumes a population of 500 million in the European Union and 1% of the European population being wheelchair users, this would bring the number of wheelchair users in the European Union to approximately 5 million. [9]

About 1,275,000 persons of the wheelchair population had a traumatic spinal cord injury.

**Figure 4. Causes of spinal cord injuries [10]**
MAIN PROBLEM

A young couple with a six year old daughter lives in a new townhouse. The mother had a car accident which resulted in a spinal cord injury. As a result she is now wheelchair-bound for the rest of her life. They would love to rebuild their townhouse into a cozy, intelligent and wheelchair accessible home.

In the assignment there are several things which we should keep in mind:

“The woman would like to cook by herself and do the household alone as well. The house has three floors and a cellar. The main entrance has three stairs. The entrance hall is about 2m wide and 4m long. At the end of the entrance hall there are the stairs to the cellar and a door to the living area. There is also the kitchen on the ground floor. Its entrance can be found by going right in the living room. The entrance to the terrace and garden is on the opposite side of the house. The terrace and garden are as wide as the house. The terrace’s length is about two meters. As a result the length of the garden is about eight meters. The stairs leading to the first and the second floor are located at one side of the living room (same side as entrance). The first floor contains: the sleeping room, the children’s room and the main bathroom with bathtub and shower. The second floor has a small bathroom with shower, an office and a guest room. There are inclined walls because of the building’s roof. A storage, a washing machine, a dryer and fitness area can be found in the cellar.”

We received an architectural plan from the ground and first floor. This was just an example. Based on this impression we developed initial architectural plans for the cellar, ground floor, first floor and second floor.

Figure 5. Basement initial plan

Figure 6. Ground floor initial plan
This assignment results in a main problem:

Rebuild their house so that the woman can go everywhere without any help. The home should be totally wheelchair accessible.
Roseanne is an unfortunate woman who had a terrible accident 1 year ago. Now she is in a wheelchair because her lower body became paralyzed due to a complete spinal cord injury. She is a very optimistic woman and wants to do as much as possible on her own. She is very young and loves technology. She loves the concept of home automation to make her life as easy as possible. She has lived with her husband Herb Smith in a townhouse for 2 years. Together they have a 6 year old daughter Ella. The family does not have pets. She is paralyzed from her first lumbar vertebra down. As a result she is totally incontinent. She can't move her legs nor feel them. This means that she is classified in the A-category of the ASIA Impairment Scale. Last week the family won a nice sum of money at the lottery. As a result they are now of rebuilding their beloved townhouse. They do not want to move into a bigger house because they already bought this house two years ago. Roseanne likes to cook, do the household and take care of her child as she used to do. From the moment her daughter was born, she stopped working as an engineer and became a full time house mother. Her husband travels a lot for work so she wants to do everything on her own.
One of the main goals of our report is to design Roseanne’s house so that she can access each room in a very easy way. Therefore we identified the problems the current townhouse has, in terms of accessibility.

As you can see in our plans, we have made some little but important adjustments in Roseanne’s house.

Figure 5.1 Basement modified plan

Figure 6.1 Ground floor modified plan

Figure 7.1 First floor modified plan
The first problem Roseanne must face when she is arriving home is climbing the entrance stairs. There are 3 steps at the entrance door and very little space due to the fact that being in a townhouse means living very closely to your neighbours. For that matter, we have chosen a very simple and flexible solution provided by a Belgian company named Comfortlift. They manufacture a combination of staircase and elevator named FlexStep. It can be used both for indoor and outdoor applications. [11]
FlexStep Compact system is a very suitable choice for Roseanne because it will help redesign the entrance stairs in such a way that she will be able to use it in a wheelchair, without the necessity of rebuilding the outside environment. The 3 steps will be replaced with a lift and a staircase combined in the same product. The FlexStep system will be activated in order to transform the stairs in a lift, and also the other way around by pushing a button. The lift is available in 4 platform widths: 700mm, 800mm, 900mm and 1000mm. Lift travels up to 1250mm. [12] Current stairs have a width of 1 m, therefore the fourth platform will fit perfectly.

We did not choose a ramp or a more traditional solutions mainly due to space considerations but also because FlexStep will look like normal stairs and will not change the outdoor environment very much. Due to the fact that we are redesigning a townhouse there are many aspects that must be taken into account, like the fact that there is no platform between the stairs and the entrance door. Therefore, building a ramp would have imposed the necessity of taking more space from the sidewalk which might have raised urban planning problems or considerable bureaucratic efforts.

Another possible solution would have been the portable access ramp. They can be found easily on ebay, with prices ranging from 70$ to 300$. [13] The main problem with this solution is the fact that is very uncomfortable
and cannot be used independently. There are also no bars which makes it more suitable for car transfers use or for smaller altitude gaps (like one step).

A wheelchair platform lift is also a possible solution to create a barrier free entrance for Roseanne. Even though it may be a cheaper alternative, it would obstruct the staircase space in the current home plan due to the fact that the current stairs have 1 m width. Therefore the platform lift is more suitable for stairs of width greater than 1.2 m. [15]

Figure 12. Wheelchair platform lift [14]

Moreover, installing a platform lift would also create the stigma of disability around Roseanne’s life and that is a major thing we should avoid when designing a smart home.

The second problem that we faced when redesigning Roseanne’s home was the width of the doors. Even though European Regulations state that the minimum opening of an external wheelchair accessible door should be 800mm [16], we designed a 1m door for the entrance because it will fit in more easily with the FlexStep system and also improve the mobility of Roseanne. For the inside doors we provided a width of 900mm replacing the previous ones that had 800mm. Moreover, some of the doors will open more than 90 degrees and some will be replaced with sliding doors. (see Appendix 4)
Moreover, to increase accessibility we have redesigned the house in a way that each hallway is wider with 10 cm (from 1.1 m to 1.2 m). Even though this is not a required solution, it could add more comfort and increase accessibility in many situations.

Another important barrier that Roseanne encounters every day is the opening and closing of the doors and windows. As many other people with limitations, she is unable to use doors and windows due to the physical effort required. Therefore, the most proper solution we found was to automate the doors and windows so that they can be controlled remotely in a flexible and intuitive way.

Stephen L. Garvin refers to automatic doors as an integrated system that combines an operator (the device that physically opens the door), an activator (the device that supplies the signal to open or close the door), control unit, electric lock and safety and security devices. They can operate in different ways depending on the level of control or assistance needed. These include Push&Go, Power Assist, Fully Automated, and Battery Operated. In a domestic context, such as Roseanne’s situation, the most doors are swing types (hinged doors).
The entrance door on the other hand, opens inward. Sliding doors can also be equipped with automatic control. [19]

The same Garvin describes a window operating system as a combination of an operator (chain, scissor, stay or jacket operator), activator, control unit and safety and security devices. [19]

There are many companies that offer solutions for automatic doors and windows like Dorma [20], Geze [21] or Door Spring Suppliers. They mostly use an electromechanical swing drive for barrier free interior single leaf doors. Sliding doors can also be automated and can blend perfectly into any building’s architecture. They can be controlled from a remote panel, a wireless sensor [23] or a push button. Moreover, considering there is a 6 year old child in the house they can be locked or may even be activated by a pet, if necessary, later. [23]

![Figure 16. Swing door drive ECturn](image16)

Figure 16. Swing door drive ECturn [21]

![Figure 17. Inside automatic sliding door](image17)

Figure 17. Inside automatic sliding door [26]

Windows can be automated in the same way. An electrical device (actuator) is placed on the leading edge of a window to open and close it to various degrees as required. These actuators come in two basic types – chain and linear. Chain actuators have the advantage that are more compact and operate by pushing a one-way folding chain out from a flush motorized housing fitted to the frame. In areas where windows are much larger, linear actuators, based on a fixed screw and motor principle may be used. [24]
Being remote-controlled, automated windows provide a barrier-free, easy and convenient operating comfort especially for those with reduced mobility, as Roseanne. They can also be equipped with weather stations that ensure the automatic closing of the windows in case of wind and rain. Window drives need a very fast installation and can be connected to conventional 230-volt network. [21][27]

Moreover, in order to improve Roseanne’s life and reduce the need of mobility, a curtain control system can be installed for every window in the house. [25] For example, programming the curtains in the child’s room to unfold automatically when is time to wake up for school will eliminate the necessity of her being present in Ella’s room every morning.

Light control will also bring a lot of benefits especially when she needs to go to the cellar. Other than that, monitoring the lights from a control panel can be very efficient from an energetic point of view while controlling them from distance will be more than helpful in a four-floor house. [28]

Another problem that Roseanne is facing, probably the most important one, is the indoor stairs. For that matter we consider that the best solution would be to install a home elevator. There are many solutions offered by companies like Garaventa Lift (Elvoron Home Elevator) [30] or Comfortlift (The Movis) [29].

The Movis is especially designed for vertical transport of people in a wheelchair. It takes minimum architectural requirements and does not need a separate machine room. It can be built in its own steel structure and used in private homes up to 5 levels, which make it very suitable for the four-floor townhouse of Roseanne. The Movis elevator is driven by a hydraulic motor. [29]
Solutions offered by Garaventa Lift include home elevators with either hydraulic drive or in-line drive. For the hydraulic drive elevator it is necessary to have a small area outside the elevator to accommodate the controller and the hydraulic pump unit. This area can be adjacent to the elevator hoist-way or in a remote location. On the other hand, the in-line drive elevator does not require any machine room, making it a popular choice when space is a prime consideration. Although for the controller it is recommended to choose a location outside the hoist-way for easier service access, all the drive components can be mounted within it. [30]
In case of power outage the elevator can be lowered either manually or using a battery powered lowering. Although usually elevators with hydraulic drive system are provided with batteries for lowering it in case of emergencies, also the manual operation is easier than for the in-line drive, for those with limited strength and mobility. [30]

We think that an elevator is the best solution for Roseanne’s mobility between floors mainly because she would need to access very frequently the cellar (fitness room, storage) and both the first (bedroom, child’s room) and second floor (her office). A stair lift (Figure 21), for example, would raise another problem such as transfers and space around the winding stairs. A platform lift like the one presented in Figure 12 (at the beginning) would also cause space-problems and obstruct the stairs. Also the home environment would be less cozy than we would like to design it for Roseanne.

Another thing worth mentioning is that we have designed Roseanne’s house in such a way that there are no thresholds when passing from one room to another. Moreover, between the terrace, the garden and the house there is no level difference. In order to make the garden more wheelchair-accessible we placed tiles onto the ground so that she can go further into the garden (see Appendix 4).

**ADL (ACTIVITIES OF DAILY LIVING)**

**GROUND FLOOR**

There are several rooms on this floor and each of these rooms will analysed accordingly, in order to make them suitable for Roseanne's daily activities.

**THE KITCHEN**

An important part of every house is the kitchen, the place where the family gathers together and cook their meals. For Roseanne it is also an important part, because she wants to cook for her family on her own. In order to fulfil these needs, we have to design a concept for the kitchen that will increase the accessibility, the flexibility and with that, Roseanne’s independence.
During the brainstorming we had many ideas for the kitchen (see Appendix 1). The countertop should be under driveable, adjustable in height and should have an integrated sink. The cabinets could be movable, with an automatic up and down and back to forth system. Another idea was to make automatic drawers too, and sliding doors for the lower cabinets. She should have an inductive stove adjustable in height located near the sink.

In the mind map (see Appendix 2) you can find the above ideas and some more. After our visit in the Smart Home Lab and the presentation of the kitchen, all of us were convinced that this is the perfect kitchen for Roseanne.

The kitchen is made for a wheelchair driver with a normal wheelchair. The upper cabinets are adjustable in height and can be moved towards you, so Roseanne can reach all shelves. She can move them from the remote control, but also by pressing the buttons on the cupboard. Moreover, there is a Lock button so that they can be fixed in a certain way, making them less likely to be changed by Ella. The moveable cabinets are on the left wall on the kitchen only, so on the window side of the kitchen is enough space on the countertop for a coffee machine or something else. If there is something under the cabinets while they are moving, a resistance sensor detects it and stops the moving, so that you can remove the object and continue. The countertop is adjustable in height too and has an integrated sink and a stove. Moreover, the cabinets on the corner are provided with a system of rotatable shelves.

The kitchen is provided with an induction stove, therefore the safety measures are assured because induction plates create no heat by themselves. Also, the oven is mounted on the wall and the door can be slide into, in order to allow wheelchair access. (Figure 22) Lower cabinets can also be moved back to the wall, so that Roseanne has enough space under the countertop to drive and work much more comfortable. The machinery, like the dish washing machine, the fridge and the lower cabinets too can be opened by pulling, so Roseanne can comfortable drive next to it and put objects in the cabinets, the fridge and fill the dish washing machine without too much stooping. [32]
THE LIVING ROOM

The living room was no big focus for us during the brainstorm because there is enough space for Roseanne if they move or remove some furniture that may be unnecessary while the husband is gone. The important thing is that Roseanne can reach the dining table and prepare it for dinner. She must also have space next to the sofa to spend the evenings there with her family.

The kitchen is open to the living room, so Roseanne can simply move around and bring the cooked meals on a tray to the big dining table. The dining table is also electrically height adjustable (Figure 23) and moved against the wall so that Roseanne’s wheelchair could fit perfectly. We also had to remove one of the seats near the sofa to make space in front of the television.

![Electrically height adjustable dining table](image)

**Figure 23. Electrically height adjustable dining table [34]**

THE GARDEN

Roseanne loves the sun and her garden, so it was very important that she can access it and do some gardening or spend time in the sunlight.

From the living room she can reach the terrace and the garden by passing by the big sliding glass door. The terrace and the garden are at the same level, so she does not have to pass a ramp or a threshold. Roseanne can use the wheelchair in the garden too due to the fact that we extended the tiles area. Therefore the path is wheelchair-suitable and big enough (see Appendix 4). The flowerbeds (Figure 25) are not too large so she can simply drive between them, they are high enough to be under driveable, so she does not have to stoop too much and can do some work in the garden like cutting flowers for the house. The automatic irrigation for the rest of the garden seemed to be the best solution to keep a green environment without any efforts in accessibility.
When you go downstairs or use the elevator you reach the cellar of the house where you find the storage room, washing machine, dryer, ironing table and a fitness area.

The main problem we have seen in this part of the house during the brainstorming was the accessibility, but that problem was solved by installing an elevator. It is also important for Roseanne to manage the household like washing the dirty clothes, drying them, do some activities in the fitness area, use the ironing table or take some stuff from the storage room. The solutions that we found for the cellar are in the following paragraphs.

The shelves in the storage room are not particularly modified, because she can put the things she needs more often in the lower shelves and other stored objects that only her husband needs, for example, can be put on the upper ones.

The washing machine and the dryer are placed on a platform to get them higher so that their doors fit perfectly Roseanne’s height in the wheelchair. (Figure 26)
The ironing table comes down from the wall and is adjustable in height, so that it saves space and Roseanne and her husband Herb can work there.

In the fitness area is enough space for Roseanne, she can train her upper body there and for lower body trainings she can use the "Tek Robotik Mobilization Device", short “TRMD” (for more information please look at the health and security concept).

THE MASTER BEDROOM

The original master bedroom was quite large and equipped with a double bed, wardrobes, chairs and a desk. We brainstormed smart home solutions for the bedroom provided with light control, nightstands with reading lamps, make-up table and mirror and ergonomic wardrobe with sliding doors and an upper bar easily reachable (Figure 28). First we thought that a double bed would be suitable but because of Roseanne’s incontinence we decided that two separate beds are needed. The bed should be big enough and at least Roseanne’s should be
electrical and adjustable in height. We also designed a railing transfer system mounted on the ceiling and a patients lift between Roseanne’s bed and bathroom to ease the way to the bathroom. We also looked for alternative solutions like different kind of wheelchairs and automatic machines like TRMD (Tek Robotic Mobilization Device) system that could offer better transferring ways and keep the bedroom environment as comfortable and normal as possible for a young couple like Roseanne and Herb.

![Figure 28. Wardrobe provided with easily reachable bar](image)

After the brainstorm we decided what ideas were worth keeping for Roseanne’s smart home. We gave up the railing system in favor of the TRMD system. TRMD is very useful in Roseanne’s situation. TRMD can lift her to standing position and she is able to transfer herself easily with that machine anywhere in the house, for example to the bathroom. You can find more about TRMD in Safety and Health concept section of this report. To make the way to the bathroom as short as possible we placed another door from the bedroom to the bathroom. The new door is a sliding one which moves along rails in the ceiling. Therefore there are no rails or thresholds on the floor which could make more difficult Roseanne’s accessibility either when using TRMD or the wheelchair.

The automatic bed was a very important choice we made for Roseanne. The two separate beds chosen can be put together, like any other young couple has, but Roseanne’s bed must be provided with a plastic material that protects the mattress due to her incontinence.

Despite we had to modify a bit the area of the bedroom, it had the perfect location that fitted the elevator so that it will pass through this room. All wardrobes in the room have sliding doors. The clothes can be pulled manually towards Roseanne using a bar, or pressing a button on the remote control. In addition to the wardrobe, we also added some shelves to the bedroom. The make-up table with mirror was added too. (see Appendix 4)

**THE CHILD’S ROOM**

Six year old Ella has a large room including a bed, a desk, chairs, a sofa and a sofa table and wardrobes as usual. The room did not need many modifications but because Roseanne has to be able to keep it clean we decided to remove the table near the sofa in order to get more space for turning the wheelchair. Another thing we did in order to assure more space near Ella’s bed was to change the direction how door opens. This is very useful for Roseanne especially when putting Ella to sleep.
THE BATHROOM

The brainstorm about the main bathroom was extensive. We decided that the floor should absolutely not be slippery even when wet because the wheels of the wheelchair may slide. There should not be any kind of ramps or level difference on the floor also to avoid sliding. [40] We all agreed that the bathroom should be enlarged and include a walk in shower with bars and grips. The sink should be shallow enough for Roseanne and Ella and the hot water pipe isolated in order to keep it safe from Roseanne’s legs when she washes her hands. [41] The shower may be enlarged and get a water resistant wheelchair for Roseanne. The original bathroom had a bath tub that we thought could be either a walk in tub or even removed.

After the brainstorm we had to decide how the bathroom would look like. To get more space we enlarged it, as we all agreed. So we put a swing door to the 1st floor entrance hall and another sliding door to the bedroom.

The shower also needed some changes. The floor has no noticeable level difference between the shower and rest of the bathroom. We chose a water resistant shower chair for Roseanne in which she can transfer herself using the grips and got a shower with handheld shower head. The shower has to be enlarged from 90cm x 90cm to 100cm x 100cm to get enough space for the shower chair.

We added adjustable grips and bars in order to help Roseanne to transfer from the wheelchair to the shower chair but also to the toilet closet. The sink and toilet are adjustable in height and there is enough space under the sink so that Roseanne can use it easily while sitting in a wheelchair.

Due to the fact that in this house there are also living a husband and a child, we decided to keep the normal bath tub and provide an aiding device like a bath tub lift (Figure 29).

Figure 29. A bath tub lift fits in normal bath tub and enables bath also for disabled people. [42]

First, the bath tub lift is as high as the tub’s side and so it is very easy for Roseanne to transfer herself from the wheelchair on the lift chair (Figure 30). Then she can lower and bend the lift chair by pressing a button in the remote control. Leaving the bath is also easy because of the remote control and adjustable height.
Last but not least, we added a make-up table with an inclined mirror so that she would also care about herself as any other typical woman of her age.

**2ND FLOOR**

**THE OFFICE**

The original office was big and there were bookshelves, cabinets, and a desk with three chairs. First of all we checked up the space for the elevator. The elevator makes the office room smaller but the leftover space is enough for a normal office accessible with wheelchair.

One of the modifications was changing the normal desk to a desk that is adjustable in height by pressing the buttons on the desk or on the remote control. Around the desk we left two chairs and space to come with wheelchair and choose shelves only instead of cabinets. Roseanne likes coffee and in order to reduce the need of transfers between the office (2nd floor) to the kitchen (ground floor) that’s why we decided to place a coffee machine on the office’s shelves.

**THE SMALL BATHROOM**

We decided that the bathroom of the first floor will be the main bathroom that Roseanne will use. Therefore this bathroom does not need to include an accessible shower for Roseanne at all. Other than that, being the bathroom that guests will be using it is suitable to be provided with a typical shower cabin. We still made some changes to the toilet and the sink in order to make them adjustable and added grips that help with Roseanne’s transferring. In order to make the bathroom more accessible especially for cleaning we have also enlarged it to have enough space for turning with the wheelchair. The recommended space for turning with a wheelchair is 150cm x 150cm. [44]

**THE GUEST ROOM**

The guest room becomes a bit smaller due to the enlarging of the bathroom next to it. There were two twin beds in the original guest room but after the demolishing and adding (see Appendix 4) of the walls the shape of the room changes. If we had put a double bed instead, the room would have become too narrow for cleaning. Instead of a double bed we decided to take out one of the twin beds and place a sofa instead.

**HEALTH AND SAFETY**

**HEALTH**

It is very important that Roseanne stands up on daily basis. Even though she is paralyzed in her lower body, she should stand on her legs every day. Otherwise she will have an increased risk of developing osteoporosis, thrombosis and a bad blood circulation. If you stand up every day, you will keep up a healthy bone density. Otherwise Roseanne will have problems later on in her life like breaking bones very easily when falling. Her blood circulation will also improve. In this way the risk of forming blood cloths in her lower extremities will be
reduced. It is a known fact that Roseanne will sit a lot in her wheelchair. She will probably be faced with decubitus, caused by pressure. The wounds will heal very badly if you have a bad blood circulation. [47]

![Percentage of Graduated Compression](image)

**Figure 31. Compression hose**

![Waterproof wheelchair](image)

**Figure 32. Waterproof wheelchair**

This principal thing should be combined with wearing compression hose (lower extremities). These are similar to panty hose, and they're specifically designed to stabilize the leg tissues and help blood circulate more easily. You can pick them up at the drug store or see your doctor about ordering hose specially fitted for your legs and your individual needs. [45]
Furthermore we chose for a waterproof wheelchair with a rather short distance between the front and back axle. 80/90 % of Roseanne’s weight will rest on the back wheel which will result in a much easier and faster rotation movement while only 10 to 20% on the front wheel. This will result in higher mobility, for example shorter rotation movements or easier navigation. Because the wheelchair’s back upholstery only supports Roseanne’s lower back, Roseanne will be stimulated to actively use her hull to keep the wheelchair stable and prevent falling. [46]

We absolutely do not want Roseanne to injure herself during the transfer movements inside the house. To cope with this issue and fulfil her wish to be independent, we decided therefore to bring in another mobilisation unit: the Tek Robotic Mobilization Device (TRMD) which is a revolutionary, mobile, stable and polyvalent improved device for independently performing transfers when having an lower body paralysation. Therefore we are very eager to use the TRMD as a transferring device which can be sent towards the involved person with an infra-red based remote control. This device will most of the time be on the first floor due the fact most transfers take place there. If you want to use the TRMD on another floor, you will need to take it with you in the elevator. The reduction in fall risk will also prevent dementia symptoms caused by physical injuries. So a very important issue to cope with will be transfer movements. Mostly that will be movements from wheelchair to the toilet, bathtub, bed, shower, TRMD, personal lift and vice versa. [47]
First there is the question whether Roseanne’s wheelchair will be safe enough to use in our Smart Home. As we already explained there will be no height differences in the house. This means there are no small thresholds to cope with. Therefore there will be no need to independently incline the wheelchair. If the wheelchair do falls backwards, there will be two back wheels preventing it. [48]

In the entire house there will be a Premium Hardwood Core floor with five layers. This floor is anti-slip, extremely strong and durable. This floor is very warm and comfortable to live on because it looks like an entire wooden floor, but there is this transparent aluminium oxide layer on it. In this way we have the best of both worlds: good looking and safe. [55]

While the previous description was quiet general, we can now go more specific. When Roseanne is doing transfers it’s very important that she can perform them safely to avoid further injuries. Because Roseanne wants to do everything on her own, we needed a device that fulfilled two criteria: safety and independence. The TRMD was therefore a perfect choice. Despite its narrow dimensions, Tek Robotic Mobilization Device is an exceptionally well-balanced device. It grabs the users from the balance points and prevents any misuse or unwanted movements that would result in a loss of balance. Correct standing position and balance are preserved by Tek Robotic Mobilization Device at all times. [47]
Furthermore the hot water supplies must be isolated. Otherwise Roseanne’s legs could get burnt while driving underneath the sink to wash her hands. Also the technical room in the cellar should have an isolated hot water boiler and electricity cabinet. With this isolation we avoid the risk of burning her legs without feeling it on the moment itself. Burning wounds can be very deep and therefore very dangerous.

The FlexStep compact system at the entrance of the house is equipped with all thinkable safety features: Roll-off protection, squeezing, fault operation, malfunction, etc. If one of these safety features is activated, the FlexStep Compact will immediately stop moving and an alarm will sound. Furthermore it is very easy to use: you just switch it on lift modus and ride on the plate. From that moment the system will do everything automatically in order safety will be guaranteed. After leaving the pressure plate, the stairways will return to the default setting after one minute. As long as the wheelchair is on the plate, nothing will change. [49][50]

Our Movis has an alarm system when dysfunctioning. A signal will be send towards local fire departments from the moment the elevator mechanism fails. There is also a manual button to send this signal. The elevator floor is equipped with sensors. When the elevator measures that a person is in there for longer than half an hour, the same alarm signal will be send towards the fire departments. The pointed light at the picture will blink when the alarm call is received. Roseanne will still be able to use her cell phone because of the glass design of our elevator (there’s also a speaker and microphone in the elevator to communicate with the help services). [51]

This house is equipped with smoke and heat detectors from the Comptronic Solutions Company. These conventional smoke and heat detector systems are smart enough to detect if there is unwanted fire around. This helps you to take necessary steps to prevent life and properties. This smoke and heat detection system is of guaranteed quality and prove to be a cost effective solution of fire security and protection. [52]

Security is an important consideration when you want to increase Roseanne’s individual’s feeling of comfort and confidence especially when her husband is not at home. Automatic openers can be fitted to external doors, gates and windows which can then be controlled remotely. Of course our entrance door will be provided
with a lock and unlock system, the same goes for the windows. The doors in the house will just open and close, no locking system is required here. It is very important that everything can be opened manually (for example: doors and windows have normal handles). Also the entrance door can be locked and unlocked by key. This allows the internal/external doors and windows to be opened and closed during a power outage. [54]

![Figure 38. Security entry system](image)

Last but not least there will be a secure entry video intercom system so Roseanne can see who’s at the door. [53]
DISCUSSION AND CONCLUSION

DISCUSSION

ACCESSIBILITY

In this chapter we will have a critical look over our smart home solutions and try to find also the negative aspects or unsuitable situations that may occur.

Regarding accessibility, we have chosen many solutions that take a lot of time and effort to be implemented. Our main intervention is installing an elevator and it creates the necessity of rebuilding a great part of the house. Moreover it steals some of the little space we have in our townhouse. Widening the doors and the hallways is also a solution that is not really necessary (considering wheelchair regulations [reference]) and might arise many problems like interfering with the electrical or sanitary installations. Providing doors with hinges that open more than 90 degrees is also not a required but is a “nice to have” solution that increases the accessibility. Demolishing and rebuilding the walls is both a time and effort consuming solution that would also be needed when replacing swing doors with sliding ones.

Most of the solutions we have chosen for home automation (like doors and windows automation, curtains control, lights control and especially the elevator) can cost very much. Moreover they are not environment-friendly because they arise the problem of energy consumption.

Accessibility could be a problem in the technical room, because there isn’t the right space to turn the wheelchair. However, Rosanne can go in and out with the wheelchair or with the TRMD and she should not need to go there because she is not a technician. Also, Roseanne cannot access the shower in the bathroom on the second floor. This bathroom is accessible with the wheelchair and the WC and the sink are designed for people with limitations, but we prefer to put a regular shower with a step because this bathroom will be mainly used by guests. Moreover, she will not be able to clean the indoor staircases, because she cannot reach them.

Regarding the outdoor modifications, the tiles we put in the garden take out from the space reserved for gardening and may be dangerous for a 6 year old child that usually plays (and falls) a lot outside. FlexStep solution for the entrance stairs may require also approval from the city council or other bureaucratic licensing that take effort and time.

ADL (ACTIVITIES OF DAILY LIVING)

KITCHEN

In the kitchen there is a problem with the upper cabinets. You cannot place high devices like a coffee machine, toaster or something else under the upper cabinets because the cabinets stop moving when they recognize some objects and Roseanne cannot reach the cabinets anymore. Now Roseanne has to move devices every time she wants to move down the cabinets and that takes a lot of time. Or she can put devices only on the left side where there are not upper cabinets.

Because of inductive stove the family needs to buy new crockery which is suitable for inductive technology. In case of power outage the kitchen will not work anymore. The kitchen takes a lot of electric power because there are many devices built in the kitchen. The kitchen is not very child proof because the cabinets are adjustable and simply to handle for child too. The whole system in the kitchen is very expensive.
BATHROOM

The enlarging of the bathrooms is also expensive. We had to use the whole storage room to enlarge the main bathroom so there is no more space for storage bathroom stuff like towels or toilet paper. The shower in the second floor cannot be used by Roseanne because it is not on the same level of the floor. The small bathroom can be enlarged again if it is necessary.

MASTER BEDROOM

We have not put a railing system to transfer Rosanne from the bed to the bathroom. By the way, in case of weakness in the future, it could be added easily because the bed is located right in front of the bathroom. This solution is expensive too. The automatic bed may look like a bed in the hospital but maybe it is possible to modify it to look more modern and pleasant. Because of Roseanne’s incontinence she and her husband cannot have a normal double bed but the automatic bed can be placed next to the normal bed. The elevator takes some space in the room and so Roseanne has to deal without as many wardrobes as before. Maybe she has to abstain for some clothes in the bedroom wardrobes and put them in the storage room.

HEALTH AND SAFETY CONCEPT.

HEALTH

First of all autonomy of our TRMD could become a problem: maximum three hours. If Roseanne recharges it whenever she is not using it, there will be no problem. The only thing is that you have to think about it all the time. Further on this device is very expensive: 20.000 euros is the final price. If we had a money limitation, this device wouldn’t be an option. There is also no intervention from the community in the payment. This place taking device cannot swap automatically from floor to floor. Only when the TRMD is on the same floor as you, you can send it towards you.

SAFETY

We asked ourselves the question whether it is necessary to have webcams in the cellar, bathroom, child room or not. It could be an excellent observing instrument to check the laundry in the basement from the second floor. But if we compare with a normal house mother without a paralysis we have to be honest: Roseanne only needs to take the elevator and she’s there. The cognitive functions are still very good, so there shouldn’t be more security cameras than a normal house mother would need.

SMART HOME SOLUTIONS: GENERAL FOOD FOR THOUGHT

First of all it is a fact that our smart home is equipped with a lot of electrical devices which are more prone to fail than mechanical ones. There is also a constant need for power. Having a power outage would mean a crash of our whole system. It’s a good thing we partially anticipated on this issue by making the doors, windows and curtains manually usable. We should also ask ourselves the question whether the house will be cosy when it’s filled with smart home solutions. We had a very keen eye for this remark. All of our choices were made from different views. Our floor, flex steps, automated windows and so on are all beautiful from the outside.
CONCLUSIONS

When you are in a wheelchair some normal things become very difficult, but we are sure that our Smart home solution can help Rosanne to live as normal as possible.

WE THINK THIS BECAUSE:

• She has a control panel (or use smartphone) to control all the Smart Home devices in her home;

• Thanks to the Smart kitchen she can cook just like everyone else;

• She can go everywhere and do everything she wants at home by her own;

• Even though our house is completely wheelchair accessible, you cannot see it because there is no stigma.

SOME FUTURE DIRECTIONS:

• It is possible to modify the master bedroom with a railing system to transfer her;

• She can buy a cleaning robot or lawn mower robot to help her with the household and gardening;

• In the future she can expand the control panel with more functions like controlling the coffee machine or other devices.
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APPENDIX 1: BRAINSTORM

Bathroom
- isolated hot water supply
- slide door for enough space to turn the wheelchair around
- invalid toilet
- no stair to the shower
- bars on the ceiling
- shallow sink
- ride in shower
- hand held shower head
- shower toilet
- no slippery floors
- enough grips
- rack for towel can’t be high
- wide doorways
- enough room for turning with wheelchair
- some place in front of the shower to dry up and the wheelchair
- alarm bell to someone who can help her
- two sinks
- shower accessible without steps
- no slippery tiles
- lower sink and some shelves
- walk in bathtub
- modified system under the sink
- infra red rile in ceiling
- low mirror
- low cupboard for cleaning solutions
- low bar for towel
- bench for clothes en others
- space for the wheelchair
- walk in shower
- enough space around the toilet and bathtub
- proper height

Bedroom:
- nightstands
- wardrobe with reachable bar
- cloths of the women in the lower ward
- nappy for the women
- bottom not slippery and easy to clean and ...
- light control
- Get out of the bed, bar ....
- space for wheelchair
- open and close windows easily for wheelchair, maybe electric or mechanic
- electric bed (split in two independent beds)
- automatic closet
- space to put on make-up
- reading lamp near the bed
• movable upper wardrobe bar
• railing system for patients lift
• wardrobe height
• bed you can change in height
• adjustable bed
• decent bed-frame
• upper shelves for husband
• ergonomic raised wardrobe
• enough space around bed
• dress space
• up/down bed
• double bed with separated mattress and blankets

Kitchen
• no slippery floor
• switch on/off everything
• the surface of the floor could be rough
• have a tablet for wheelchair to serve the meals
• open the window should be possible when you are in a wheelchair
• slide doors
• control panel
• environment control
• enough space between furniture
• automatic cabinets with remote controller
• space under the stove
• stove/sink adaptable in height
• extractor fan with remote controller
• cabinet comes out
• cabinets have to slide, not too heavy
• upper cabinets white up & down system
• sliding doors for cabinets
• movable cabinets
• possibility to reach the upper cabinets
• enough cabinets
• much space under the countertops
• under drivable countertops
• up and down counter top
• cabinets on countertops
• sink built in countertop
• raised machinery built in countertops
• hanging countertops
• drawers
• sink near stove
• rotative cupboard on the corner
• raised dishwasher
• dishwasher white disappearing door
• cooking plate above oven
• fridge not too high, freezer next to the fridge
• fridge raised half a meter, with sliding door
• induction heat plates they won’t gone hot
• dishwasher
• oven with disappearing door
• italian oven
• oven should be raised
APPENDIX 2: MINDMAP

The mindmap about the brainstorm
APPENDIX 3: HOUSE PLAN

The plan we made before working out the details.

House plan:

entrance:
- there are 3 steps (stairs) on the outside of entrance door
- Door
- Entrance hall
  - stairs to the cellar
  - door to the living area

Cellar:
- storage
- washing machine
- dryer
- fitness area

Living area:
- open entrance to het kitchen
- entrance to terrace and garden
- stairs to the 1e floor

1e floor:
- 2 bedrooms
- 1 bathroom with bathtub and shower
- stairs to the 2e floor

2e floor:
- small bathroom with shower
- guest room
- office
- the walls are inclined
APPENDIX 4: PLANS

Previous plans from the basement to the attic.
Current plans of the house:
Comparison addition - demolition