ENGINEERING GOOD STUDENT CHAPTER TECHNOLOGY DEVELOPMENT PROGRAMME

SOLUTIONS FOR WHEELCHAIR OVERCOMING DOORSTEPS (SWOD)

(June 2016 - January 2017)

Felicia Tay Hui Ming

Ken Teo Bo Hao

Khang Pham Minh

Thanh Lam Chi

Yue Linn, Chong

[CONTENT PAGE]

[CONTENT PAGE]

[ABSTRACT]

[ACKNOWLEDGEMENTS]

[INTRODUCTION]
- Context
- Design Criteria
- Problem Statement
- Scope

[BACKGROUND RESEARCH]
- Market research of commercial products
- Patent Search of Similar Products

[DESIGN CONCEPT & MANUFACTURING]
- Ideation
- Proposed design
  - Summary of concept
  - Assessment of Concept
  - Wheelchair Attachments
  - Outdoor Unit
    - Ramp Channels
    - Guiding Mechanisms
    - Transitional Slope
    - Inbuilt Staircase
    - Frame
  - Indoor Unit
    - Methods of installation, mounting and storage of prototype.
    - Force Calculations for Indoor Unit

[PROTOTYPE ASSESSMENT]
- Testing Iterations
- Actual Wheelchair User Testing

[FUTURE DEVELOPMENTS]
- Outdoor Unit
  - Ramp Tracks
  - In-Built Stairs
  - Safety Railings
  - Guiding Rails
- Indoor Unit

- Electronics
  - Micro Control Unit
  - Sensor
  - Automated System
- Data range of variable data
- Hooking stations
- Certification considerations

[CONCLUSION]

[APPENDIX]
- Appendix A: Compilation of relevant building codes
  - Fire Code 2013
  - Building and Construction Authority (BCA) regulations
  - Regulations with regards to Renovations of HDBs
- Appendix B: Design concepts from ideation phase
  - Design 1: Folding ramp
    - Working mechanism
    - Modifications
  - Design 2: Hydraulic platform
  - Design 3: Fold up ramp (similar to Design 2)
  - Design 4: Varying Climbing Slope
- Appendix C: Tipping Angle Calculations
- Appendix D: Preparation for Prototyping
  - A list materials and machining processes needed for manufacturing
- Appendix E: Assuming a Door Sweeper Mechanism

[REFERENCES]

[ABSTRACT]

Wheelchair users in older Housing and Development Board (HDB) flats have are hindered from accessing their homes due to the presence of several steps at their front door. Hence, this project aims to enable wheelchair users to overcome these doorsteps independently. Reviews of current market and patented solutions was done and the compilation of their assessments is included in this report. From the solutions reviewed, none fully satisfied the criteria required for this project, leading the team to propose an alternative solution. The team proposes the use of a winch to pull the wheelchair and its user up a ramp, which is positioned strategically on top of existing stairs. Detailed designs of the proposed concept is elaborated in this report. A prototype was made to prove the concept and results of the testing is reported. Based on the prototype tests, some future developments are suggested.

[ACKNOWLEDGEMENTS]

The team would like to acknowledge the support from Engineering Good Student Chapter (EGSC). We would like to thank the Young Change Makers grant for their support in funding our project. The team would also like to express deep gratification towards Mr Ivan Tan from Serving People with Disabilities (SPD) for his continuous encouragement and assistance.

The team would also like to express our heartfelt thanks to our mentors, Mr Deng and Mr Mano for their input and efforts.

Furthermore, the team would like to thank the input from the internal EGSC panel and all who assisted in the project for their time and input.

[INTRODUCTION]

Context

Some older HDB flats have 3 or 4 steps in front of the front door. Such steps cannot be overcome using regular wheelchairs. Approximately a few hundred wheelchair users are affected by this problem; the number expected to rise as the population of those living in older HDB flats age (Tan, personal communication, February 3, 2017).

Figure 1. Older HDB door.

Hence, this project aims to allow wheelchair users to access their homes despite the stairs.

Design Criteria

To successfully achieve the previously mentioned objective, the following has been highlighted by corresponding parties:

From user experience

A wheelchair user, Mr Mano, was interviewed and his key concerns were noted as below.

1. Minimize protruding parts of permanent add-ons.
2. Minimize weight of permanent add-ons.
3. Must ensure that users feel safe.
4. Minimise required user effort.

From engineering point of view

1. Must be durable for outdoor usage.
2. Must be reliable.
3. Must have a fail-safe in case of power failure.
4. Will the user slide-off the wheelchair or topple over?

From SPD side

1. Must allow independence of wheelchair user.
2. Cannot block other users from using the stairs.
3. Must not intrude into the common corridor in compliance with relevant regulations and codes on emergency evacuation. See Appendix A for relevant codes.
4. Must bring in the wheelchair in addition to its user. The user should not be transferred out of the wheelchair.
5. Must guarantee the safety of the user.
6. Must not require great strength or flexibility of user to operate.
7. Commercial solution should be around the range of $750 - $1000.

From EGSC side

1. Must be capped under $1, 500 for the whole project.

In short, the following criteria must be met by our proposed solution:

1. Independent operation. User must be able to operate the solution without help of others.
2. Safe
    a. Solution must be durable and reliable.
    b. Solution must have an alternative backup plan for emergencies or in unexpected cases.
    c. Solution must guarantee the safety of the wheelchair user.

3. User friendly
    a. Solution must not require great strength or flexibility to operate.
    b. Solution containing permanent wheelchair add ons must ensure said add ons are not unnecessarily protruding parts or heavy.
    c. Solution must have as few steps to operate as possible, and automate steps where possible.
    d. Solution must allow stair climbers means of access into the flat.
    e. Solution must give the user a sense of security when in operation.
4. Minimal monetary cost to implement solution.
5. Meet BCA code, and HDB and town council requirements. See Appendix A for elaboration of relevant codes.

Problem Statement

In summary, this project aims to develop a solution to overcome the doorstep obstacles independently in a safe, affordable and easy way while complying to the relevant building codes.

Scope

This problem assumes that the door is automated. The project will not consider the complexities of users needing to open or lock the doors.

The proposed solution excludes electric scooter users. Specifically, users of scooters with the base near to the ground would not be considered. Wheelchairs with low hanging parts are also not suitable for the proposed solution.

The project will focus on satisfying the problem statement within the following specifications. The proposed solution may not be directly applicable to working conditions beyond the given scope.

Table 1

Specifications required of HDB corridors and doorsteps

Minimum width of doorsteps	Angle of inclination of doorsteps	Distance from last step to the nearest wall	Total weight range of wheelchair and user	Wheelchair wheels thickness	Total height of stairs
0.9m	<33 deg	>2m	<200kg	>10 cm	<0.5m

[BACKGROUND RESEARCH]

Prior to designing our system, we looked at solutions currently in the market to solve our problem. From this we found that there are no current solutions which fits the criteria highlighted in the previous chapter. The following is a breakdown of our findings and the advantages and disadvantages of each system.

Market research of commercial products

Figure 2. The Convertable.

Name: Convertable (Seth, 2013)
Cost: None , currently still being designed
How it works: The Convertible is a flight of functional stairs that changes into a ramp for wheelchairs. By simply pushing a lever, the flight of steps shifts and become a slope.
Pros: The device has been designed for a low construction cost, easy installation, and minimal maintenance. Can be used both by the wheelchair and non-wheelchair users.
Cons: Inclination of slope is too steep to be self propelled. Also as it is only still a design, the actual product would be a lot thicker due to mechanisms underneath.

Figure 3. Telescopic ramp.

Name: Telescopic Ramp (DNR Wheels, n.d)
Cost: US $250
How it works: The Telescopic ramp comes in a set of two individual ramps with non-skid treads. The ramps are arranged at the width of the wheelchair.
Pros: Portable and lightweight. People can walk between the gaps.
Cons: Unsafe to use to overcome 3 steps. Not meant to be a permanent fixture thus need people to set it up every time. Takes up a lot of space.

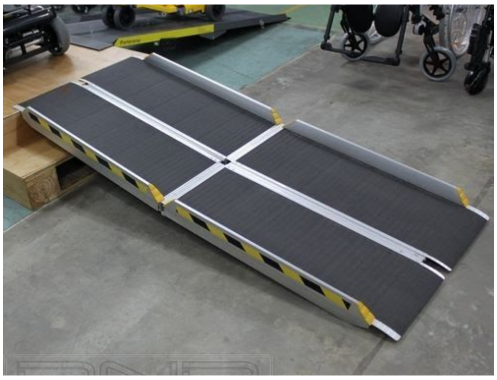


Figure 4. Tri-fold Aluminium Medical Ramp.

Name: Tri-fold Aluminium Medical Ramp (DNR Wheels, n.d)

Cost: US $480

How it works: The Tri-fold Aluminium Medical Ramp is n foldable and simply just needs to be placed over the require obstacles to be overcome.

Pros: Portable and can be transported easily. Compact, for easy storing with little space requirement

Cons: Not meant to be a permanent fixture thus need people to set it up every time. Takes up a lot of space.

Figure 5. Multilift Vertical Lift.

Name: Multilift Vertical Lift (Inc, n.d.)

Cost: US 1,000+

How it works: The Multilift is a vertical platform lift, designed for low-rise travel indoors or out. There is also an Emergency stop button on car, underpan obstruction sensors, non-skid platform, manual lowering crank, side panels, automatic access ramps, slack cable switch.

Pros: Hardy, easy to use and it's safe for a single user to use.

Cons: Expensive, and overkill for overcoming just three steps. Takes up too much space

Figure 6. Walk & Roll Stairs.

Name: Walk & Roll Stairs (W, 2013)

Cost: Undefined

How it works: The wall and roll stairs allows wheelchair users to be dragged up or push down the steps due to the alternating steps.

Pros: Allows co-sharing of step and ramps.

Cons: Have to modify steps, require a well-abled person to help assist going up and coming down.

Figure 7. BraunAbility UVL Wheelchair Lift.

Name: BraunAbility UVL Wheelchair Lift (Ride Away, n.d.)
Cost: US $700
How it works: The mobility lift can be mounted underneath a full-size wheelchair accessible vehicle. The lift is activated by the standard hand-held or remote control and, with one click of the button, the lift smoothly deploys from the underneath the vehicle. Deploying and retracting your lift in this way makes it easier to enter and exit your wheelchair accessible vehicle.
Pros: This design frees up valuable interior space and allows easier access into the vehicle for additional passengers.
Cons: Unsafe to use by oneself. Have to have free space underneath. Unable to share space with non-wheelchair users.

Figure 8. Wheelchair Stair Climber add on.

Name: Wheelchair Stair Climber add on (Mobility Toys, n.d.)
Cost: Undefined
How it works: The Wheelchair Stair Climber add on attaches on to the current existing wheelchair and allows the helper to pull or push the wheelchair safely up a flight of stairs without much force. It is able to fits onto a wide range of manual wheelchair.
Pros: Versatile, no modifications is needed.
Cons: Require a well-abled person to help assist going up and coming down. May be an overkill just to overcome 3 steps

Figure 9. Roll-A-Ramp®.

Name: Roll-A-Ramp® (Rollaramp, n.d.)

Cost: $2,000-$4,000

How it works: The Roll-A-Ramp is a ramp which is mounted on to the van floor and is much less costly than a lowered floor conversion or a lift and can be installed into many vans. They are the perfect option for those who cannot lift or want a ramp that folds in and out automatically. Ramp deploys at the touch of a button.

Pros: This design frees up valuable interior space and allows easier access into the vehicle for additional passengers.

Cons: Unable to share space with non-wheelchair users.

Patent Search of Similar Products

To ensure that none of our designs would infringement existing patents, it is important to understand also the current existing patents revolving around similar products. Below shows a some patents found which has vital design or patent claims filed. This is not an exhaustive list but it shows a variety of innovative designs and the vital claims to avoid infringing.

Patent No: US5123495 A (Littlejohn, n.d)
Publication type: Grant
Summary: The present invention provides a sensor for detecting the angle of an incline, such as a staircase, before it is reached by the wheelchair. A control signal is provided to a motor for tilting the seat to cause the seat to be tilted to a predetermined minimum safe angle before the wheelchair reaches the staircase. The minimum safe angle is an angle of tilt at which the wheelchair will not roll over if the tilting mechanism should fail to completely rotate the seat to a horizontal position and as the stairs are descended.
Claims to note: (Claim 1)

- A sensor for detecting the angle of incline of a surface before said vehicle traverses said surface;
- Means for adjusting a tilt of said seat;
- Means for sensing the tile of said seat;
- Means, responsive to said sensor and said tilt sensing agent for preventing movement of said vehicle over said incline, if said incline exceeds a predetermined steepness, until said means for adjusting has tilted said seat to a predetermined minimum angle, including a means for calculating said minimum angle, based on said detected angle, the weight of a user and the center of gravity of said vehicle, to give a change in the center of gravity of said vehicle and a user sufficient to prevent said vehicle from rolling over on said incline.

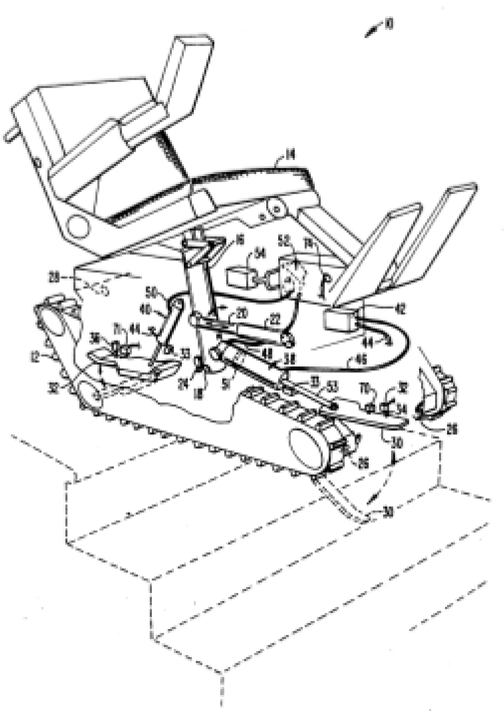


Figure 10. Patent image.

Legality: Expired since 29 Aug 2000 due to failure to pay

Patent No: WO2013067623 A1(Fry, n.d.)
Publication type: Application
Summary: An apparatus that permits a wheelchair to traverse stairs. A carriage platform supporting the wheelchair is housed in an inclined ways assembly and moves by means of a rotated threaded rod supported in the ways and traveling nuts fixed to the carriage; a debarkation ramp hinged to the carriage, spans the distance and elevation difference between the carriage and the desired landing point.
Claims to note:

- (Claim 1) In transporting a wheelchair up or down a set of stairs
  - A motive arrangement for selectively moving the wheelchair platform along the length of the ways assembly between a top position in which a wheelchair may move substantially directly between the wheelchair platform and the top of the stairs and a bottom position;
  - A ramp having a proximal end and a distal end, the proximal end hingedly attached to the wheelchair platform and the distal end having a ground engagement feature, wherein contact between the ground engagement feature and the ground as the wheelchair platform moves towards the bottom position, causes the ramp to pivot away from the ways assembly so as to provide a wheelchair path of travel between the wheelchair platform and the ground when the wheelchair platform is in the bottom position, and movement of the wheelchair platform towards the top position permits the ramp to pivot towards the ways assembly.
- (Claim 2)The apparatus of claim 1 wherein the motive arrangement comprises a threaded rod rotatably mounted to the ways assembly and a primary traveling nut threadedly engaging the threaded rod attached to a traveling member, wherein rotation of the threaded rod causes the traveling member to move along the length of the ways assembly.
- (Claim 5)The apparatus of claim 2, wherein the ways assembly comprises two opposed side walls, wherein each sidewall has a longitudinally extending channel; and wherein the wheelchair platform comprises: a plate having a proximal edge and a distal edge, and attached in the vicinity of the proximal edge to the traveling member and hingedly attached at the distal edge to the ramp; and two rollers, each roller engaging a respective channel, wherein the wheelchair platform is supported by the traveling member and the channels.
- (Claim 13) The apparatus of claim 1 , wherein the ramp is hingedly attached to the wheelchair platform by a hinge having a reversibly retractable hinge pin whereby a user may detach the ramp from the wheelchair platform by manual withdrawal of the hinge pin and may attach the ramp to the wheelchair platform by manual insertion of the hinge pin.

Legality: Valid, From 8 May 2014 onwards, it is patented in Europe (EP), Germany (DE), Canada (CA) and United states (US).
Patent No: US6957716 B1 (Norris, n.d)
Publication type: Grant
Summary: An emergency stairway escape apparatus permitting wheelchairs to egress a multi-story building via a stairway comprises a ramp platform of sufficient width to cover at least half of each stair tread and of sufficient length to span from an upper landing to a lower landing of said stairway. A latch is mounted to an outward wall for impinging the ramp platform in a stowed position and releasing the ramp platform to a deployed position. A plurality of hinges are used for affixing an edge of the ramp platform to the outward wall and permit an arcuate release of the ramp platform to a deployed position. A motion retarding reel is mounted to an upper landing wall, the reel comprising high strength cable outwardly dischargeable in a linear manner and self-retracting, the cable comprising a hook attachable to a wheelchair, the reel controlling ascent and descent along the ramp platform.

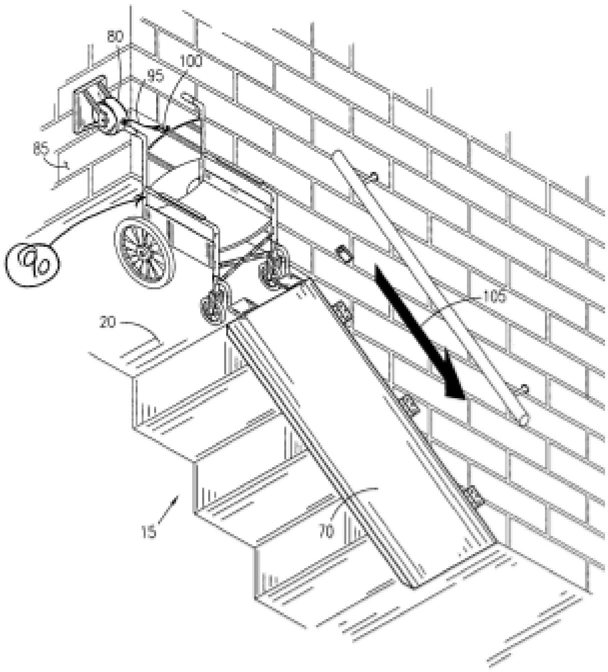


Figure 11. Picture taken from patent US6957716 B1.

Claims to note:

- (Claim 1)
    - A latch mounted to an outward wall of the stairway for impinging said ramp platform in a stowed position and releasing said ramp platform to a deployed position;
    - A motion retarding reel mounted to an upper landing wall of the stairway, said reel comprising high strength cable outwardly dischargeable in a linear manner and self-retracting, said cable comprising a hook attachable to a wheelchair, said reel controlling ascent and descent along said ramp platform.

Legality: Expired since 15 Dec 2009 due to failure to pay

Patent No: US4528711 A (Packer, n.d.)
Publication type: Grant
Summary: A lightweight portable wheelchair ramp comprising a pair of ramps detachably secured to one another in a compact, portable configuration. Each ramp is telescopically extensible with oppositely disposed non-slip surface engaging flanges and can be adjustably locked to the length required. A pair of alignment and spacer brackets secure the ramps together in spaced parallel relation during operation. The ramps can be detached from one another, collapsed and secured together for ease of transport.
Claims to note:

- (Claim 1) A portable self-contained wheel chair ramp comprising a pair of ramps, each of said ramps having first and second elongated telescopically engaged support members that are cross sectionally U-shaped, inturned and downturned continuously extending flanges on each of said first support members arranged to overlie portions of each of said second support members, longitudinally extending angularly disposed support flanges on the ends of each of said ramps, a pair of transversely positioned elongated spacer brackets, the ends of which are respectively attached to said support flanges whereby said pairs of ramps are uniformly transversely spaced with respect to one another.

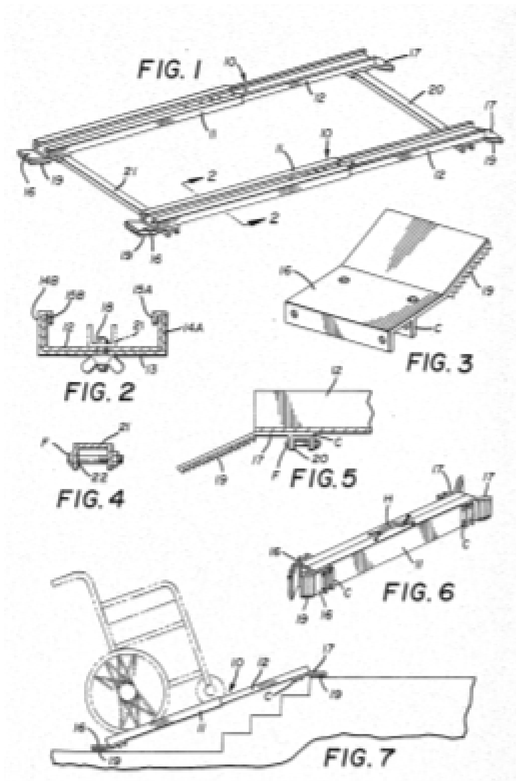


Figure 12. Image from patent US4528711 A.

Legality: Expired since 5 Oct 1993 due to failure to pay

[DESIGN CONCEPT & MANUFACTURING]

Ideation

From the evaluation of current solutions compiled in the previous chapter, no current solution is suitable for the specific problem of enabling wheelchair users to overcome doorsteps in older HDBs. Hence, the team looked towards developing a solution of our own to satisfy all the criteria listed as required in the Introduction.

Our team have came up with many designs which are similar to the vertical lift discussed in the market research. We considered alternative concepts of actuation which would be cheaper, involving hydraulics, motors and so on. To overcome the spatial limitations of the narrow corridor and to be compliant of BCA codes, we suggested means to store the device vertically, on the ceiling or tuck it along the wall. Refer to Appendix B for a more detailed elaboration of seemingly promising past design considerations.

However, such systems are too complex and concentrate stresses at isolated points. Thus, a more sturdy and reliable method is suggested instead.

Proposed design

Summary of concept

The proposed solution is to have a winch pull up or slowly release a rope attached to the wheelchair with the user on it. The wheelchair will be on a ramp, which consists of two C-channels (one channel for the left front and back wheels, and another on the right). The ramp is positioned on top of the existing doorsteps such that the stairs exposed in between the channels can still be used.

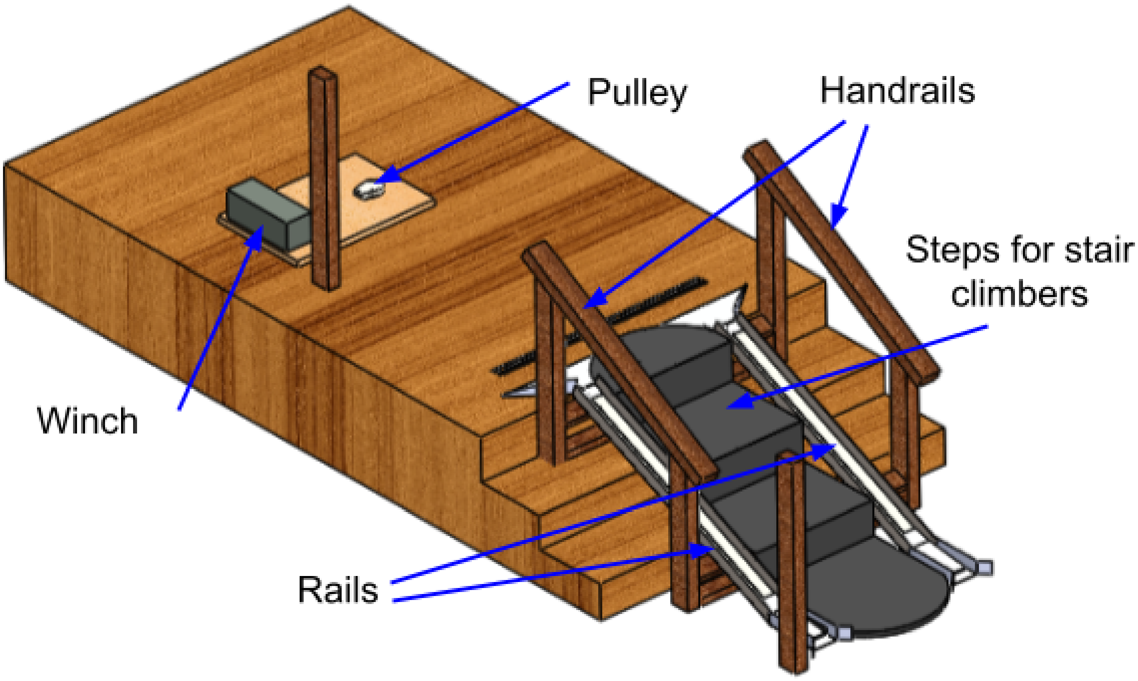


Figure 13. CAD of system.

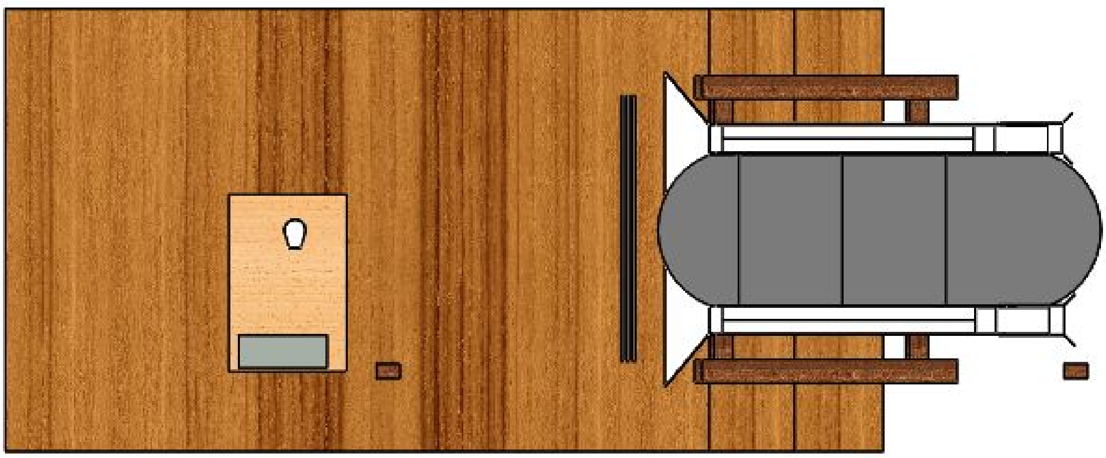


Figure 14. Top view of system.

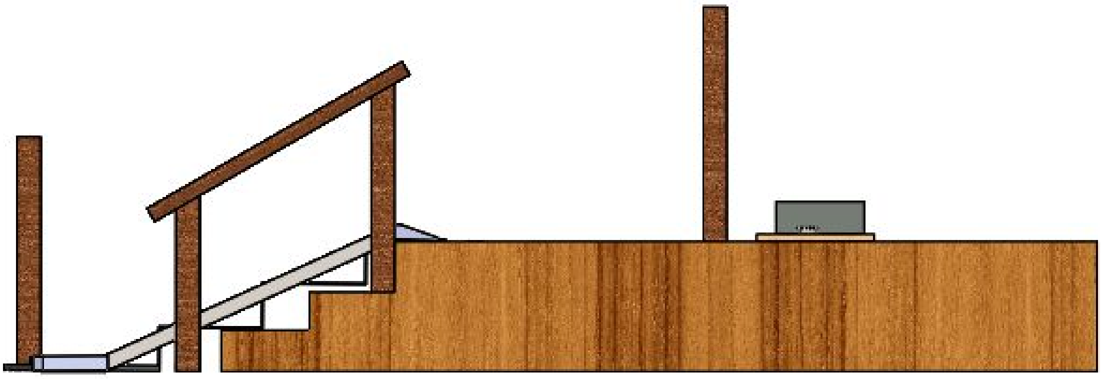


Figure 15. Side view of system.

The above CAD was manufactured and the following are pictures of the manufactured prototype used for testing.

Figure 16. Setup of prototype in Enabling Village testing.


Figure 17. Setup for testing at Enabling Village.


Figure 18. Partial team testing at Enabling Village.

The flow of procedure when using the system for going up into the flat is illustrated as below. The opposite process of going down is the reverse of the going up process.

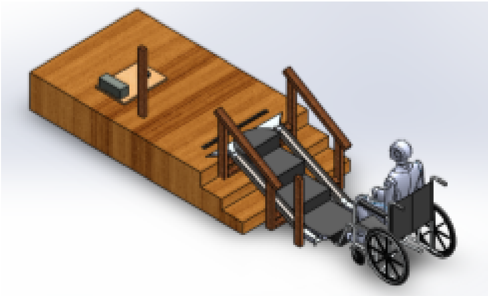


Figure 19. Alignment of wheelchair to ramp.

The wheelchair user positions himself in front of the ramp.

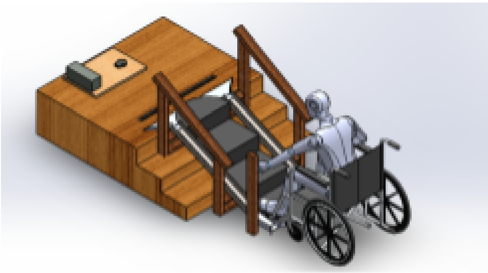


Figure 20. Retrieving hooks.

The wheelchair user retrieves hooks attached to the end of the winch rope. The user hooks the winch rope onto his wheelchair at the wheelchair attachments.

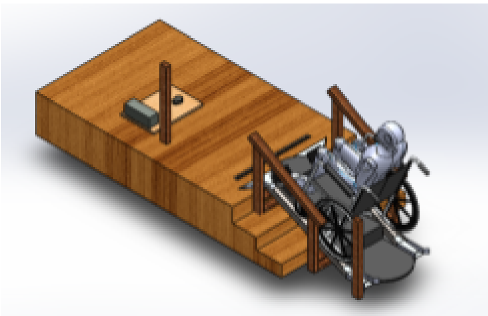


Figure 21. On the ramp.

The wheelchair user turns on the winch. The wheelchair user controls the winch as the winch pulls the wheelchair up the ramps. The process is controlled by the user using a hand-held remote controller.

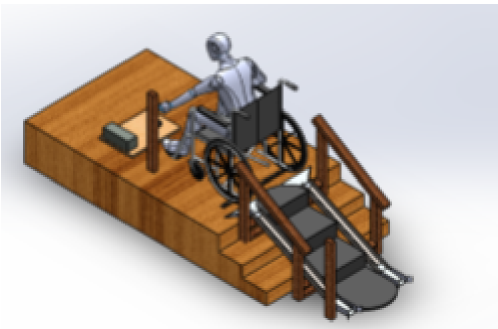


Figure 22. Placing back hooks.

The wheelchair user unhooks winch rope and stores the hooks at a designated stand.

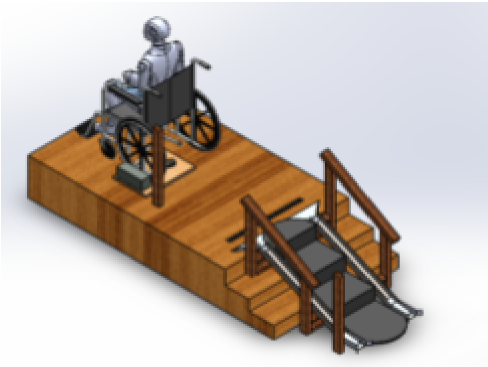


Figure 23. Moving into flat

The user can move over the system to enter his home.

Assessment of Concept

The proposed solution satisfies the following the criteria required of the solution as discussed in the Introduction.

In short, the following criteria must be met by our proposed solution:

1. Independent operation.
   The proposed system can be operated independently by wheelchair users.
2. Safety.
   a. The proposed solution uses a winch to pull the wheelchair up. The winch used has a maximum loading capacity beyond that of 907 kgs.
   b. Parts of the proposed solution which are located outdoors are made from steel or hardwood. These materials are weatherproof and suitable for outdoor use. Hence the safety of the design over time is not compromised by the outdoor conditions.
   c. Materials for key parts which undergo high stress such as the wheelchair attachments are to be made of tough materials such as stainless steel to ensure higher strength.
   d. The proposed solution will be locked into position in the case of a power outage due to the nature of the winch. The winch used will not unroll when the power is cut. In the case of sudden unexpected power outages, the user will not fall from the unexpected release of the winch. However, if there is a power outage there is no means for the user to independently go in or out of the flat safely but must rely on external help to evacuate safely.
3. User friendly.

a. The proposed solution requires the user to bend to lower than to reach just below his or her knees. No strength is required to operate the proposed solution.
b. The proposed solution minimises add ons to the wheelchair. Only a pair of small and light add ons are required.
c. The proposed solution is simple and intuitive to use. Steps can also be automated in future.
d. The proposed solution allows stair climbers means of access into the flat via the steps in between the channel.
e. However, the perceived safety from the user's perspective may be arguably compromised to a certain degree due to the steep slope of the ramp.

4. Minimal monetary cost to implement solution.

   The project managed to adhere to the budget limit of 1.5k SGD.

5. Meet BCA code and HDB requirements.

   The proposed system allows for the 1.2m clearance in the 2m corridor. See Appendix A for relevant codes specifying this constraint. No permanent modifications to the steps outside the flat is required. However, having a non temporary fixture on the corridor of the flats at all times, requires the approval from the HDB and the town council. The approvals would be done on a case by case basis by both HDB and the relevant town councils and therefore may or may not be approved depending on the circumstances of the surrounding structures.

The review of the proposed solution is compared to current market solutions in the following table. The scale ranges from 1 to 10 where the score of 1 represents the lowest satisfaction and 10 represents the highest fulfilment of the criterion.

Table 2

Comparison between proposed solution and commercial solutions

	Independent operation	Safety	User friendly	Cost	Meet BCA code and HDB requirements.	Total
Proposed Design	10	6	8	10	7	44
Telescopic Ramp	1	8	9	10	5	33
Multilift Vertical Lift	10	10	8	2	1	31

Walk & Roll Stairs	2	7	3	3	2	17
Wheelchair Stair climber	10	7	5	2	10	34

From the table above, the proposed solution best fits the necessary criteria of the project. A prototype was fabricated to test and prove the working concept proposed.

The prototype can be divided to 3 main parts, the wheelchair attachment, the indoor unit and the outdoor unit. To manufacture the physical prototype, the spending sheet can be found in Appendix D.

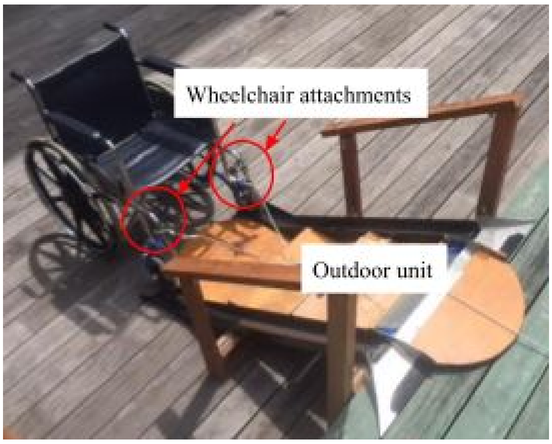


Figure 24. Outdoor unit and wheelchair attachments. Set up at Enabling Village testing with the wheelchair attachments and the outdoor unit indicated.

Figure 25. Indoor Unit. Set up at Enabling Village testing with the indoor unit indicated with a blue box.

Wheelchair Attachments

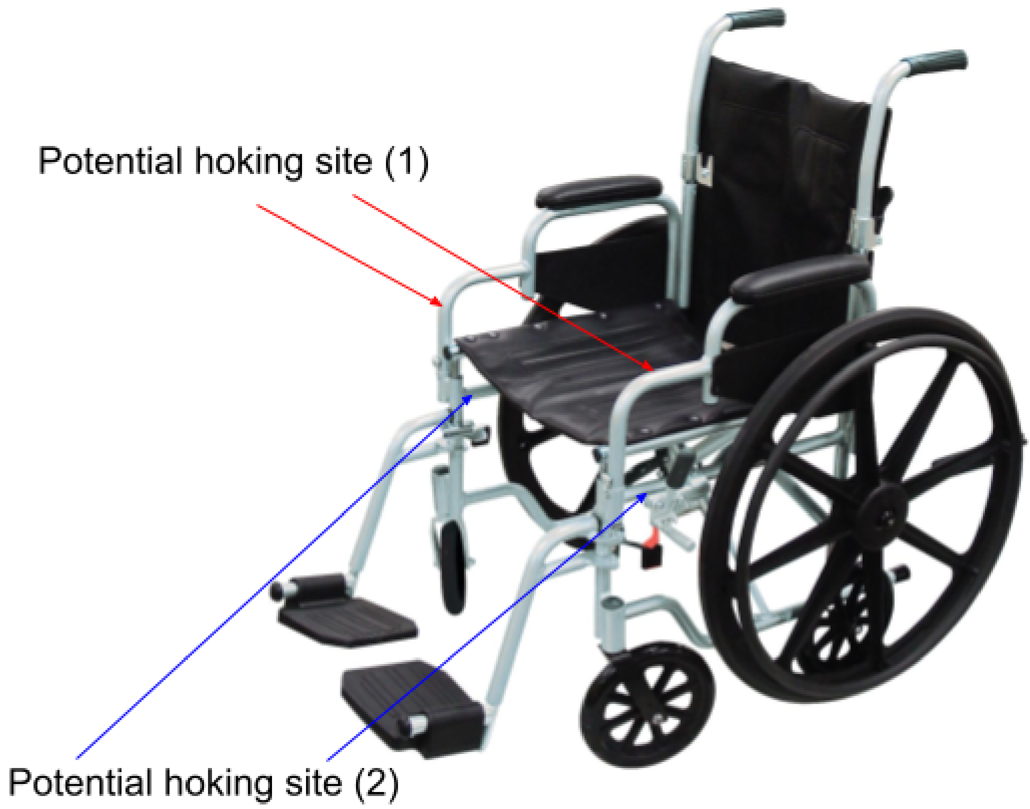


Figure 26. Clamp mounting sites.

Figure 27. Clamp.

The wheelchair attachments refer to the 2 truss clamps installed either onto the pole below the seat of the wheelchair or at the armrest as shown in Figure 27. These 2 clamps will provide hooking points.

The two hooks that are attached to the winch will be hooked onto the wheelchair attachments. When the winch turns on, the wheelchair will be pulled up or released down the ramp.

Outdoor Unit

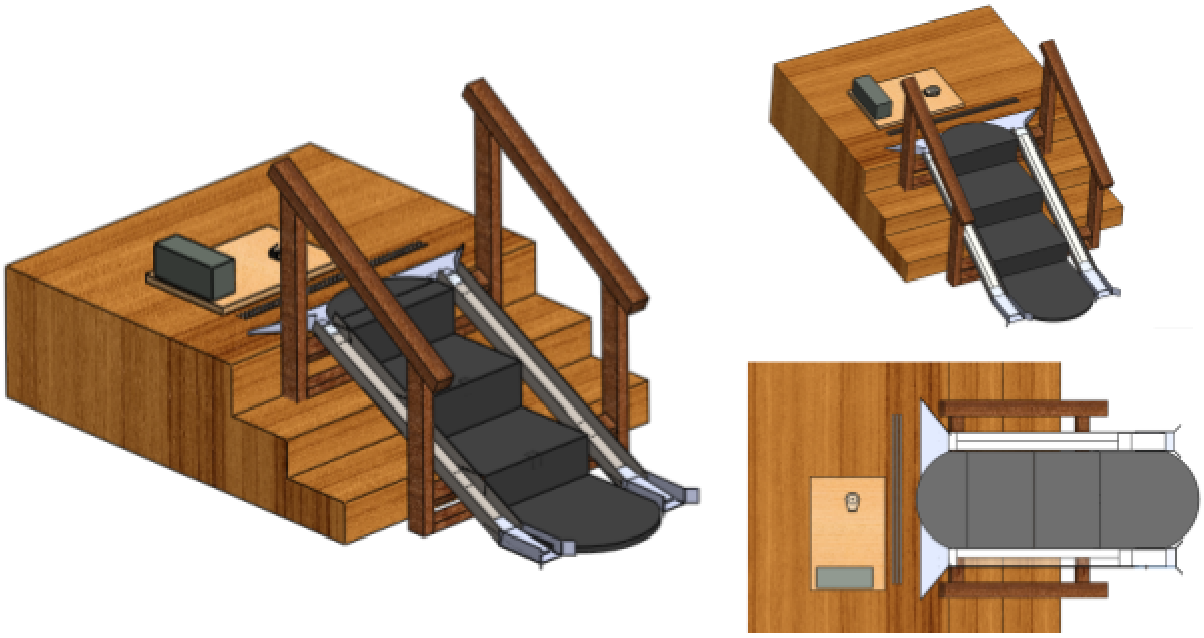


Figure 28. CAD of Outdoor Unit design.

Prototyped Outdoor unit is made up of:
Ramps made out of L bars 3mm thick Steel
Frame structure made out of Kapur wood 2 by 3 inches.
Transition slope made out of blue foam and aluminium plates
Top and bottom funnels of 2mm thick aluminium plates.
The main purpose for the outdoor system is to provide a support for the wheelchair to be wheeled up, and also for the space to be coexisted together with the walkway for the other people in the household. Thus not only it needs to be sturdy, it has to take up as little space as possible.

Which brought about this minimalistic design, to cater to both wheelchair users and non wheelchair users in mind. For this prototype design, there are various design focus; ramp channels, guiding mechanisms, transition slope, in-built staircase and the frame.

Ramp Channels

To create a design which co-share the space with both wheelchair and non-wheelchair users, space allocation priority plays a huge part. The usual ramp design is usually a rectangular plate that covers over the whole area under the wheelchair, such as show in the figure (x.x). This is useful as the wheelchair does not need to really align themselves to use the ramp. However, for tight areas, this prevents

Figure 29. Small ramp.

non-wheelchair users from using the steps underneath. Thus we decided to compromise and instead map out the most commonly used path by both users. For the wheelchair users, it would be the contact area of all 4 wheels and the ramp, for the users would just need sufficient space for one person to climb up or down the steps.

Thus, the usual ramp has been simplified into 2 supporting ramp instead and can be adjusted based on the user's width of the wheelchair. For the prototype, the ramp channels are made out of 2 L iron bars such as shown in the Figure 30. The Iron L bars are able to sustain up to 200 kg of load without any additional supports, which is why it was chosen as the prototyping material although it is hard to work with.

Figure 30. U-channel.

The overall ramp's angle of incline varies depending on the height of the staircase. For this prototype, with the step height of 44.3cm , the angle of incline is 26.8 degrees. Based off calculation of a manual wheelchair (which has a higher Center of Gravity than a motorized wheelchair), the tipping angle of the system is 36 degrees as seen in Appendix C.

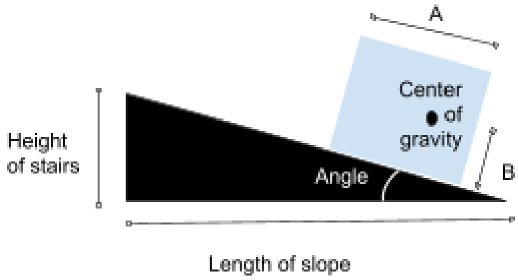


Figure 31. Diagram of slope.

Which means that the for this current prototype, the angle of inclination is feasible as it is below the tipping angle of a wheelchair. Also taken from a sample of various 3 step structures and existing steps outside of HDB, the range of incline angle is found to be 22-29.8 degrees. Thus it would be safe to say that this design would have a slope of inclination well below the tipping angle of a wheelchair for a 3 step feature.

Guiding Mechanisms

To help the wheelchair alignment with the tracks, guiding funnels and the laches on the first and last steps was used. The original design was to use 4 funnels each however, we felt that having too much funnels would cause a tripping hazard instead due to having additional risen features on the ground.Thus, it would be better to use the current available structures and modify it to suit the needs of alignment. The inbuilt steps was the next best solution. The first and last steps was risen at 3 cm off the ground which helps in guiding the wheelchair into the ramp. Also due to the colour difference and the size of the steps, it would be harder for users to forget or be unaware about the fixture. The friction tape was to help the castor wheels re-align when the wheelchair is descending down the slope. As castor wheels alignment depends on the motion of the wheelchair and the amount of time and distance is given for the castor wheels to correctly align, the additional friction is there to help realign the wheels over a shorter distance.

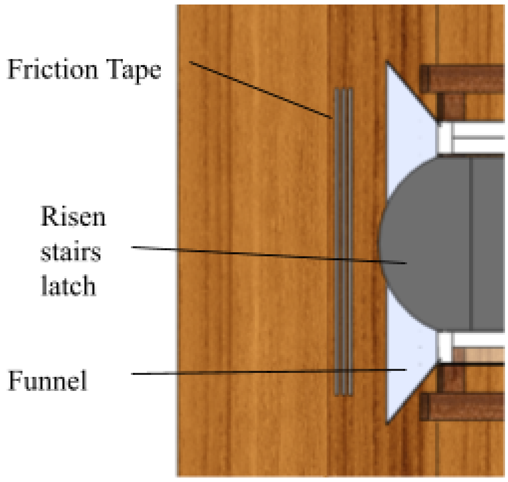


Figure 32. Top view of outdoor unit.

Transitional Slope

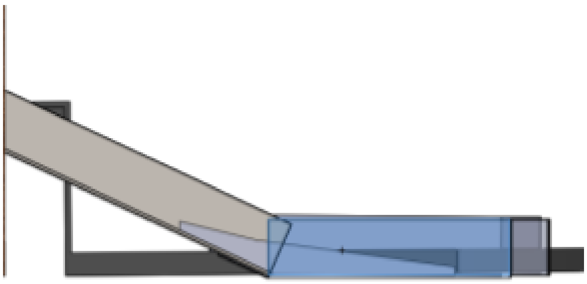


Figure 33. Side view of bottom of ramp.

We realized from our initial testings when the wheelchair is descending, the back wheels lodge itself between the space when the slopes meets the ground. This actually causes the wheelchair to flip backwards as the winch continues to release the rope. Thus with a transitional slope, it prevents this from happening and also ensure a smoother transition from slope to ground. To achieve this, the radius of the curvature of the transition slope is calculated to be bigger than the back wheel of the wheelchair.

Inbuilt Staircase

To help make the ramp be a safe co-sharing space for both wheelchair and non-wheelchair users, an inbuilt staircase was added to the design. The inbuilt staircase serves mainly 2 functions; hide tripping hazards, improve on the current steps.

It helps to hide tripping hazards as the frame support bars are all underneath the false steps. Also with the false steps and the risen first last step, it helps to align the wheelchair and also prevents the wheelchair from wheeling into the cavity between the ramp channels.

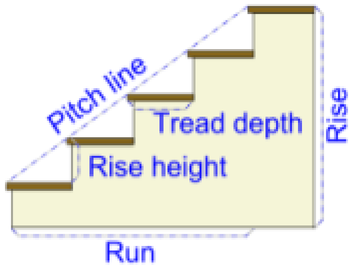


Figure 34. Steps dimensions.

It helps to improve on the current steps as for the 3 steps configuration there are quite a few cases where the height of all 3 steps vastly differs. Thus with the use of a false step, the height of the 3 steps can be of similar heights. More commonly also, the depth of a step tread of the 3 step configuration is 180mm to 200mm, based off Ah Mo Kio old HDB estates. This is less than the recommended tread depth for giving less shock to the users' spine, at 250mm to 300mm. (Rich, 1999) This value range is slightly lower for elderlies but having sufficient flat surface area to stand to gain support is vital. Thus by having false steps, the steps up can be kept roughly constant with a wider step thread, providing more landing surface (300mm).

Frame

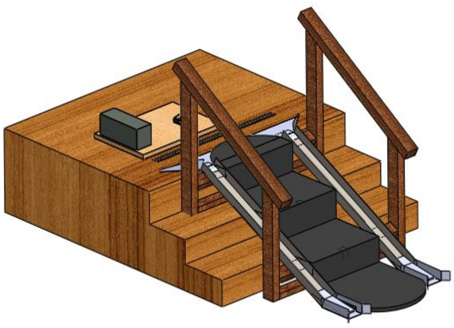


Figure 35. CAD of Outdoor unit and Indoor unit.

There are two main purpose for the frame (shown in dark brown), first is as a safety railings for the users, the second is to allow everything to be mounted on.

The railings are placed at a height of 0.8m as it is mainly for the wheelchair users to grab onto in the event of an accident or when the users panic.

The handrails and bar are mounted onto the staircase in a temporary fashion such as illustrated in the diagram below. This is to not infringe any HDB rules and regulations. Also this would ideally allow an easy instalment of the system without the need of any heavy equipments.

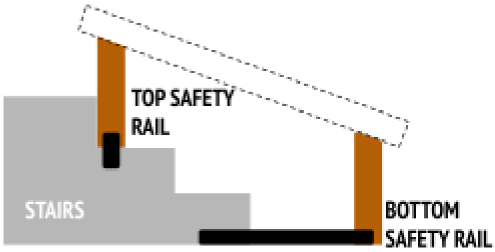


Figure 36. Schematic diagram of steps.

To mount the frame, 2 punched steel flat bar is installed underneath the top safety rail, the latch facing outwards. The steel bar is adjusted till it pushes against the steps or walls near it, creating a compressive force. Likewise for the bottom safety rail. The exact method of mounting really depends on the design of the 3 steps. There are three different types of configuration, as shown below.

Figure 37. Variations of doorstep configurations.

Currently right now, the method of mounting caters only to the step configuration of no wall or 2 wall. For the no wall configuration, the latch compresses the 3 steps. For the 2 walls configuration, the top railing bars pushes against the wall while the bottom railing bars compresses the walls.

For this prototype, the frame has been made out of wood to allow not only the ease of manufacturing but also to test out the different methods of attachments and to cater and try on different staircases and the staircases varies in height. The actual design seeks to have the frame made out of aluminium rods making it weatherproof and even more sturdy and smaller in size.

Indoor Unit

The indoor unit consists of the winch, pulley and hook station. The components are installed onto a platform which is attached to the floor inside the flat.

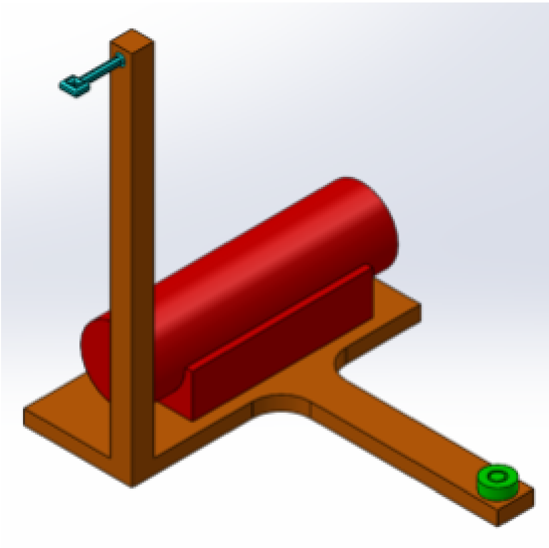


Figure 38. CAD of Indoor unit.

Red: Winch used to pull the wheelchair
Brown: Mounting platform to secure the winch pulley and hooking station
Green: Pulley to change the direction of the cable of the winch
Blue: A hooking station for hooking the winch hooks when not in use.

Figure 9. Winch.

Winch: To apply the necessary forces to the wheelchair, a winch is proposed. In the actual product, The winch will be mounted on the ground or on the wall by bolting it through the concrete.

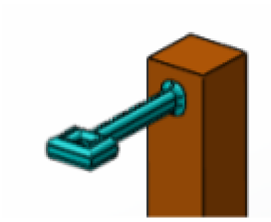


Figure 40. Hookin station.

Hook station:
Place to store hooks when system not in use.

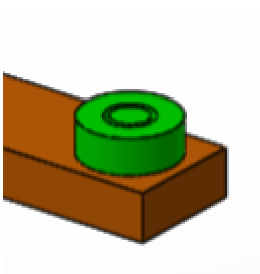


Figure 41. Pulley.

Pulley which positions the pulling wire at the center of the wheelchair. The pulley will be pinned to the mounting platform using a bolt. The pulley will be a commercially available pulley. The pulley helps to redirect the cable, thus allow the winch to be place at the side. Therefore, the winch will not be in the way of the pathway in the flat.

Since the pulley is much thinner than the winch, it will be possible for wheelchair users to roll over the pulley.

Methods of installation, mounting and storage of prototype.

In order to implement the design discussed above, some modifications were made.
The following is the CAD for the design the prototype to be manufactured.

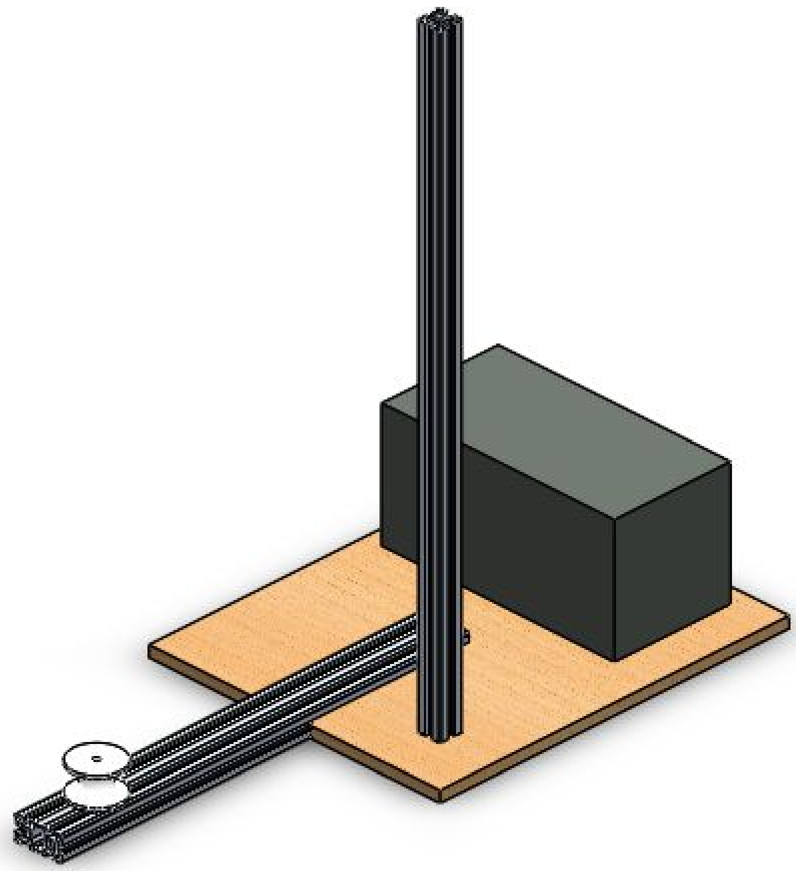


Figure 42. Indoor unit. The winch system is represented by the black box.

The winch obtained is a commercially available winch, with the additions of two hooks added to the end of the winch cable. Batteries or AC to DC converter will be needed to operate the winch of 12V.

Force Calculations for Indoor Unit

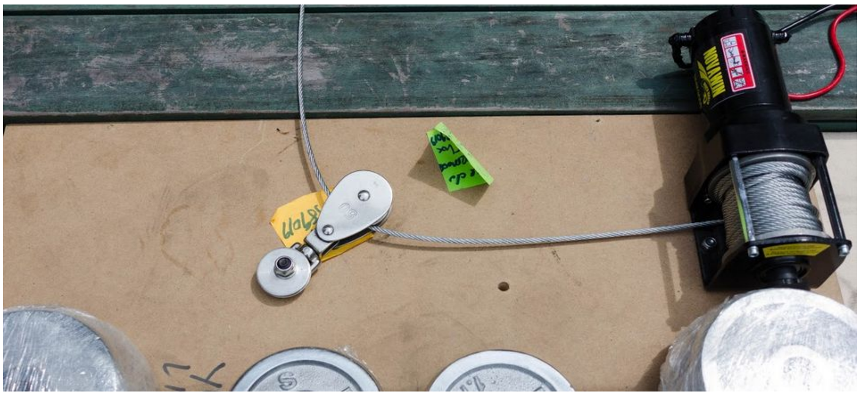


Figure 43. The pulley and winch mounted onto MDF board.

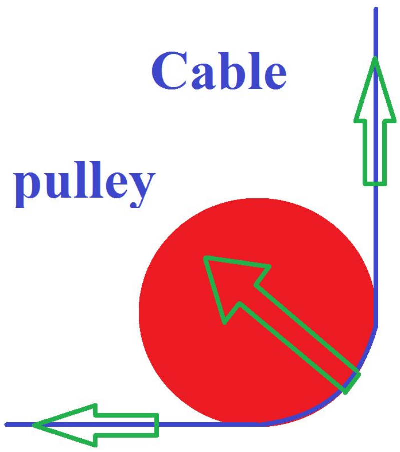


Figure 44. Pulley Diagram.

From the diagram on the left, the resultant force will be 2774 as the tension on the cable is 1962 N.

Pulley have to be able to take more than 2774 N of force, pulley also have to be reasonably big to prevent the damage of the cable as it is rather thick. In our prototype, the cable is able to take 1 ton of load but in the real design, it only requires to take 200 Kg of load.

Shear Strength of mild steel = 0.58 (yield Strength of mild steel = 247 MPa)
Maximum Shear Stress = Force / area = (200 x 9.81)/(2π x R^2) = (0.58 x 247 MPa)
R = 0.00147m = 1.47mm, Diameter of bolt required for mounting is 2.94mm~3mm
Since we are using 6 mm bolt as the size of the hole for mounting the winch is fabricated with the winch. we will be very safe as there is at least 2 safety factor even that the material of the bolt is stronger than mild steel.

Bearing strength of wood plank use is 6.2 MPa
Maximum bearing stress = Force / Area = (200 x 9.81)/(2 x Diameter x Length) = 6.2 MPa
Area = 1.58 x 10^(-4) Since the bolt diameter is 6 mm.
Length = Area/Diameter = 1.58 x 10^(-4) / 0.006 = 0.026 mm
Therefore, wood mounting plank of 3 cm is use.

[PROTOTYPE ASSESSMENT]

Testing Iterations

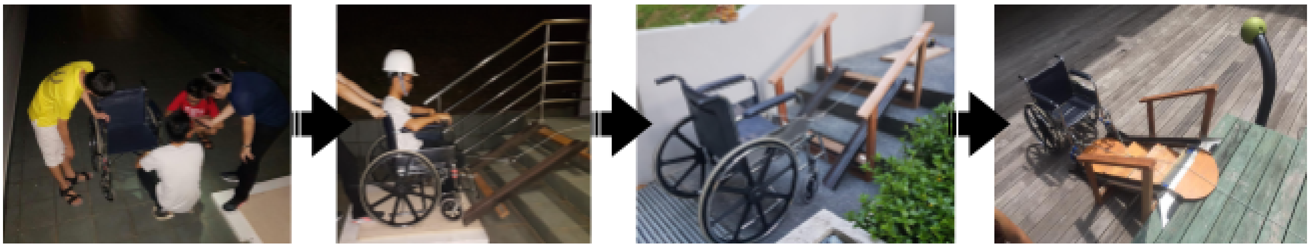


Figure 45. Process flow diagram.

Throughout the whole project, multiple testings were done at various stages of completion to understand more about the factors and the user's perceived security when using the prototype. For these testings, due to the uncertainty and safety reasons, we were the one who sat and test the prototype.

From these testing iterations, my design changes were influenced and made from the testing takeaways. Below is a list of key takeaways learnt from these testing which would heavily influence future iterations of the designs.

- ❏ Feature for safety or hooking needs to be at the comfortable arm range for the wheelchair users.
- ❏ Castor wheels need to be properly aligned before descending if not the whole wheelchair would be stuck midway on the ramp.
- ❏ Castor wheels cannot be lifted off the ground at any time during descent as it pose as it cause the castor wheels to miss align .
- ❏ A transition slope connecting the slope to the ground is vital to prevent the wheelchair from being stuck.
- ❏ Perceived safety by the user as the user transitions from the top flat ground to the start of the slope.

Actual Wheelchair User Testing

Due to time constraints and safety concerns, we were only able to conduct one actual user test. And to really ensure the safety of our test users, the prototype was reduced to the core design essentials which the wheelchair users would interact with.

Figure 46. User testing at Enabling Village.

On 14 January 2017, with the kind help of our mentor, Mr Mano, we were able to gain first hand information from a wheelchair user and also observe the way a user would interact with our prototype. The testing with Mr Mano provided us with many valuable insights that have aided in the future design development.

NOISE

Sound of the winch is too noisy, going home late and leaving early poses a problem

TOP ALIGNMENT

Not a huge issue, wheelchairs are part of their body awareness. Guidelines initially for users to get the feel. However, if the device is to be designed for temporary or new wheelchair users alignment is still a major issue.

NEED OF DISTRACTION

When going down, there is a need to distract users and keep their hands busy (eg on a remote). As holding on to their back wheels serves as a reassurance to them but poses a huge problem on the way down.

BUMP ON THE TOP

Not such a huge issue, going backwards and overcoming the bump when the initial part is automatic

TRACKS NEED/CAN BE WIDER

For Mr Mano's case his own wheelchair could not go up the ramp due to the larger gap between the alignment of the front and back wheels. Wider track also help in caster wheel alignment

[FUTURE DEVELOPMENTS]

From insights highlighted in the previous chapter, the following future developments is suggested for the indoor unit and the outdoor unit.

Outdoor Unit

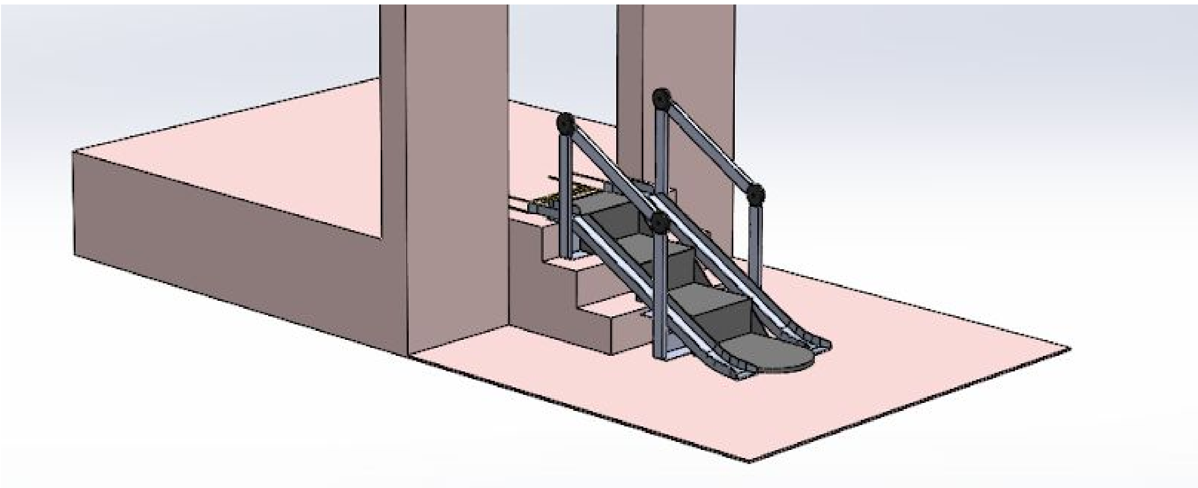


Figure 47. CAD of Outdoor unit setup.

The previous prototype was mostly made out of kapar wood as it provides the flexibility of any design changes while we are testing. However because of the previous material choices, the system was rather bulky and had dissimilar design textures, making it unsightly and also redundant in ways as there is no function sharing. Thus as improvement, ideally the whole system is to be re design and build using different materials. Below shows the top and side view of the system with its key design features highlighted out.

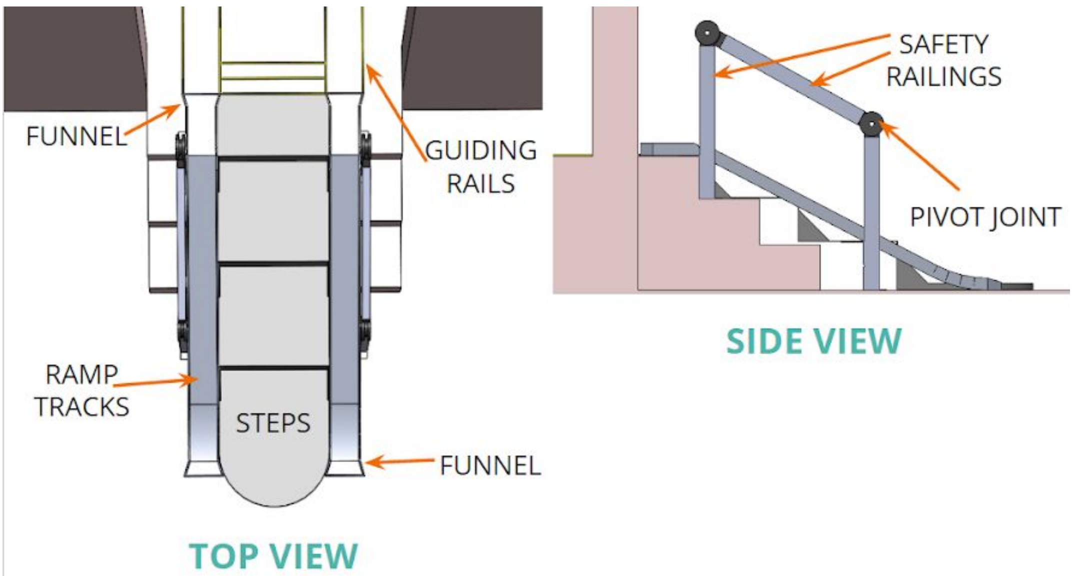


Figure 48. Top and side view of system.

Ramp Tracks

The new ramp track would combine the features of the funnel and the transitional slope also, creating a seamless design. By the use of function sharing, other components of the system is used to help in wheelchair alignment, also from the user testings done, we realized the funnel width need not be that wide.

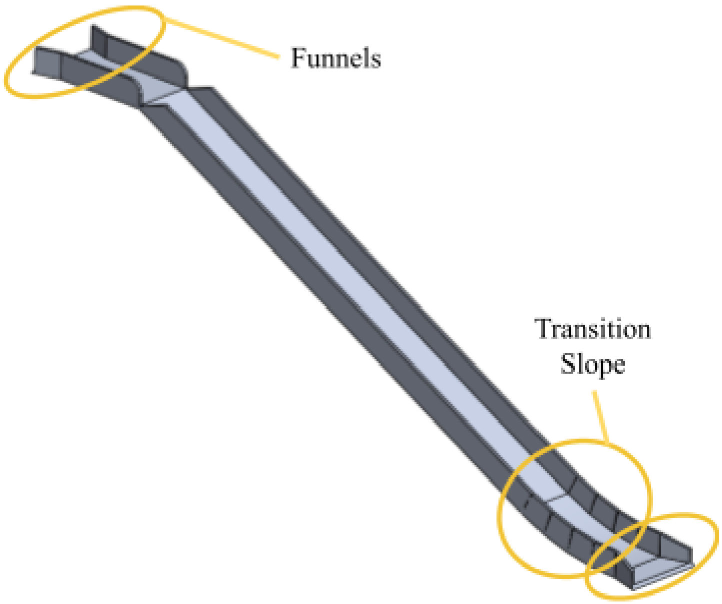


Figure 49. New ramp design.

To achieve this design, it would be best to manufacture using aluminium 5052 sheet metal and constructed using sheet metal bending. To be able to withstand the loading resulting from the wheelchair and its users, the thickness of the sheet metal would need to be at least 5 mm thick.

However, the width of the c-channel itself has to be of a certain width to allow the ramp to accommodate for a bigger variety of wheelchairs. The front and back wheels of a wheelchair are not aligned when viewed from the front of the wheelchair. Since each ramp has to support a front wheel and a back wheel each, the ramp width has to accommodate the offset between the wheels.

Increasing the width of the c-channel is also better because it allows the front wheels to turn incase of misorientation. The front wheels of the wheelchair are castor wheels. These wheels orientate themselves based on the direction the wheelchair is going. When the wheelchair user rolls back onto the ramp to exit the flat, the castor wheels are in the backwards orientation. However, during the transition from the horizontal surface to the inclined ramp, the front wheels are lifted off the ground, Due to the nature of the weight distribution of the castor wheels, this forces the wheels turn about a vertical axis to a forward position (yaw motion). If the ramp width is smaller than the diameter of the castor wheels, the castor wheels will get stuck when it is changing orientation, hence if possible the ramp width should be bigger than the castor wheel if possible.

However, it is also important to note that there is still sufficient space for the steps in between each c-channel despite the increase in width. Increasing the ramp width too drastically will result in a narrow set of steps which makes the stairs difficult to ascend.

Hence, an alternative to solving the castor wheel turning can be considered. One can be to have a sleeve on the ramp which moves along the ramp with the castor wheel; orientating the castor wheel before it gets onto the ramp. It is also possible to design a mechanism to be fitted onto the wheelchair front wheels to fix it in position prior to going down.

In-Built Stairs

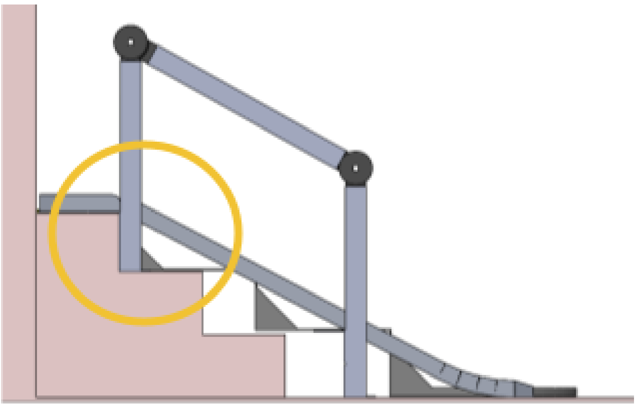


Figure 50. The circled first step

For the steps in the prototype, it was made out of plywood as it was meant to be a visual prototype. For it to be able to interact with the users, it needs to be made out of a stronger material.

False steps for industrial used is often made out of 3mm threaded aluminium plates as it provides a good friction surface to prevent the users from slipping.

From the testings conducted, we realized that having the first step protrude out does cause an obstruction for wheelchairs with low hanging bars as it it pivoting about the first step edge. Thus the steps are moved backwards till it is in contact with the first step, as shown in the picture above, in the area marked by the circle.

Using function sharing, the steps has design features which helps in the wheelchair alignment. Both the top and bottom steps are to be at least 25mm thick to prevent the wheelchair from easily running over them.

Safety Railings

For the safety railings to be sturdy yet be non bulky, aluminium tubes and L bar can be used. This materials choice would allow the outdoor system to be hardy to weather elements also. A CAD diagram on the next page showcases the bottom and top railings.

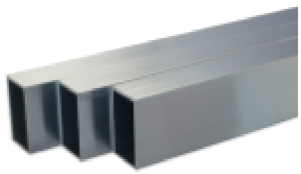


Figure 51. Aluminium hollow bar.

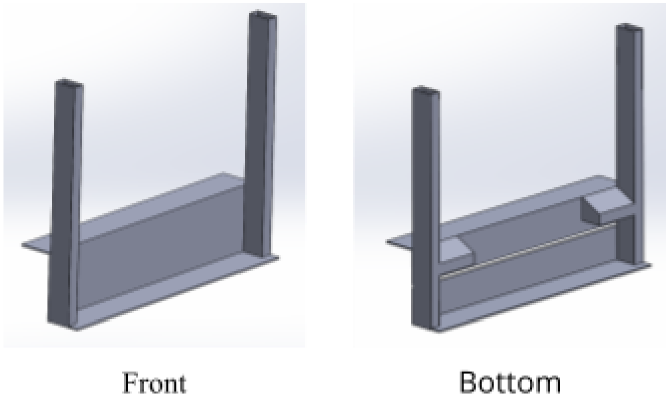


Figure 52. Bottom and top railings.

For the aspects of the joints, pivot joints can be used instead as it is easy to fit and allow more freedom in terms of the angle of the safety railings. To construct the whole system, it would require welding, and as student it is understandable there is some limitations in terms of manufacturing capabilities. Thus, T-slotted bars can be used instead for the construction of the frame.

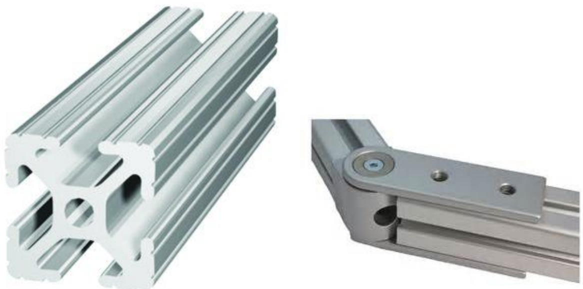


Figure 53. Aluminium extrusions and joints.

Guiding Rails

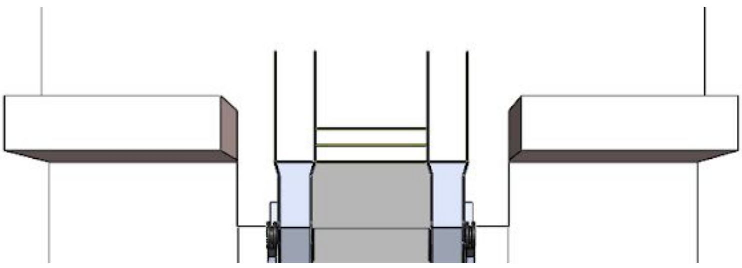


Figure 54. Top view of guiding rails.

From the testing done, we found that alignment of the wheelchair has to be done over a much longer distance for both the safety and security of the users. Due to the limited amount of space available before the door and the inability to have any extruded components inside the house due to the door, other guiding methods need to be used. Thus the idea of using raised floor markings, like those used to guide the blind in public areas, was introduced.

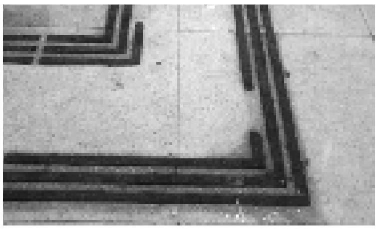


Figure 55. Guiding marks.

Using these markings does not cause any obstructions for the door, and it is does not pose as a tripping hazard for the other non-wheelchair users in the house. With these guiding rails, the wheelchair users can use their sense of sight and touch to make sure they stay on track while the wheelchair.

Indoor Unit

In the physical prototype tested, we realized that it was necessary to hide all free wires lest it poses as a tripping hazard to non-wheelchair users. Also another aspect which was not considered yet when manufacturing was when the user is dismounting and wheeling away when in his/her house. Thus for further improvements, a cable hider and cable cover can be introduced to the design. The cable hider and cover would be made out of aluminium extrusions.

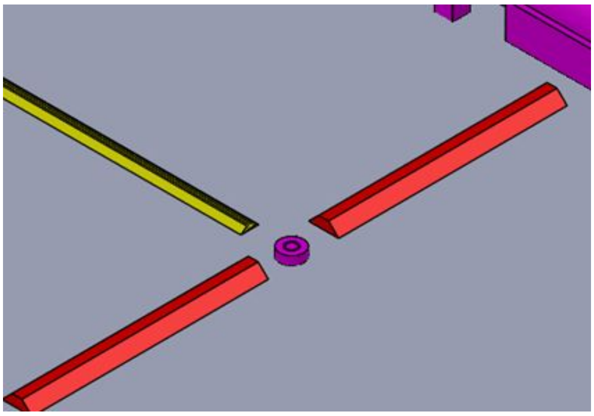


Figure 56. CAD of cable hinder and cable cover.

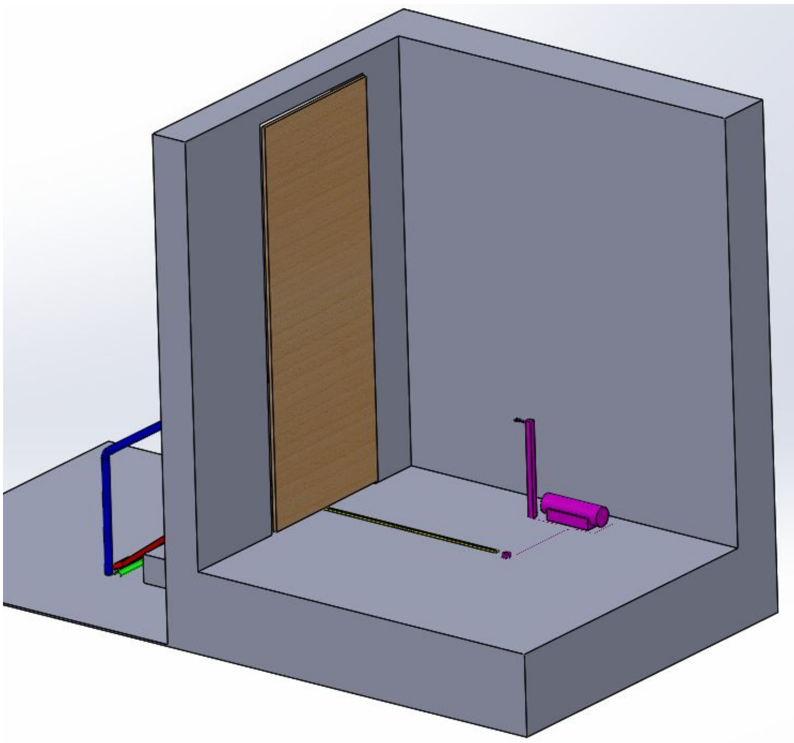


Figure 57. CAD of system with cable hinder.

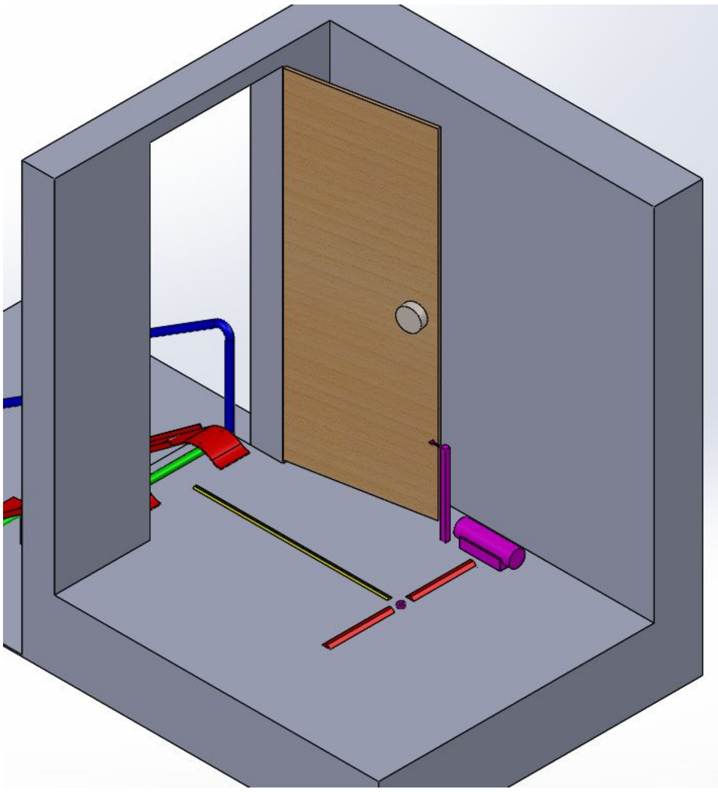
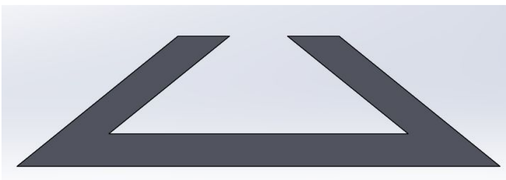
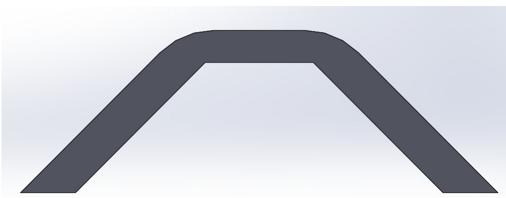


Figure 58. CAD of system with cable hinder and cable cover.

Table 3

Cross-sections of cable hider and cover

	Cross-Sections	Purpose
Cable-hider (yellow)		Prevent people from tripping over the cable
Cable-cover (red)		Allow wheelchair users to move over it and also prevent people from tripping over the cable

The cable of the winch can also be cut short and re clamped to prevent the cable from getting stuck when the cable is tangled.

Electronics

Micro Control Unit

Add an arduino in between the remote control and the winch, the RC will control the winch via this arduino. We can calibrate and embedded constant time of operation of the winch through the arduino. Such that when user press up, it activates the winch to pull up in a constant duration and stop.
This simplifies the job of user with one press instead of constantly pressing until the wheelchair has reached the high floor.

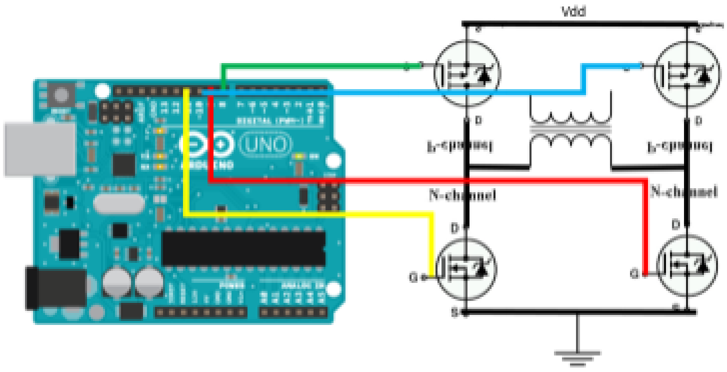


Figure . Arduino setup connection.

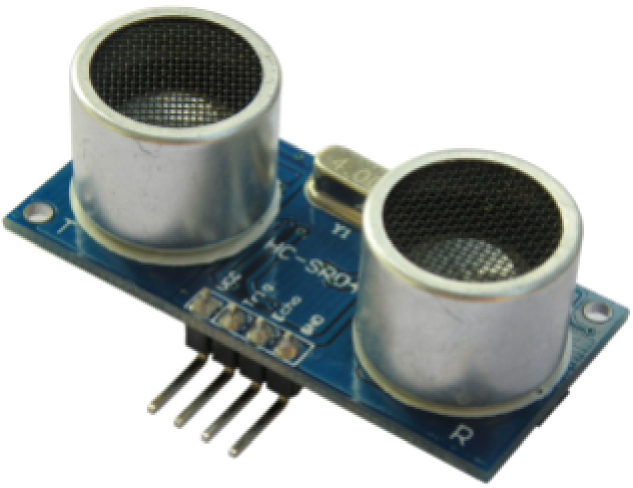


Figure 60. Ultrasound sensor for Arduino

Sensor

The use of arduino also enable the system to deploy and use many types of sensors (such as ultrasonic sensor). Instead of hardcoding a constant time in the software, we can detect whether the user has reach a specific position and perform proper action. This can act as a safety guard as well. For example, if the sensor detect that user are not in correct position, the system will not activate when pressing the button in the RC.

Automated System

We have come up with a basic idea of a full automated system to minimize user actions as below:

Going Up: In this use case, we assume the user is at the bottom of the stairs.

1. User takes the cable from the outside pole and attaches cable to the wheelchair.
2. User presses button Up using remote control.
3. System pulls up the winch until the user reach the floor. Then system releases the winch at a small distance for user to detach the wire.

4. User detaches the wire from the wheelchair in hook it up into the inside pole.

Going down: In this use case, we assume the user is inside the house.

1. User takes the cable from the inside pole and attaches cable to the wheelchair.
5. User presses button Down using remote control.
6. System releases exactly enough wire for user to move and align himself right at the top of the stairs.
7. User moves and aligns himself at the top of the stairs.
8. User presses Down one more time when he is ready.
9. System releases wire until user reach the lower ground.
10. User detaches the cable and hooks it up to the outside pole.

Data range of variable data

There is a need for data on measurements of the flats and wheelchairs. The numerous possible permutations of wheelchair combinations complicates the design process. This report limits the types of wheelchairs and flats combinations which can use our proposed method as elaborated in the Introduction. However, there is no data on how many cases meet the required constraints.

For the doorstep designs, there is no consistent design for older HDB flats and so there exists a myriad of doorstep designs. The possible variations of steps against walls were highlighted in the design of the outdoor unit. Moreover, the number of steps, height, depth and protrusion of these doorsteps vary from one area to the next, that is the doorsteps in Ang Mo Kio may vary from those in Bedok. There may also be variation of the corridor width which limits the space allowed for the prototype.

Within the flat, space for installation of the indoor units and the positioning of the hooking points must also be ensured. Much like the doorsteps, there exists a variation of floor plans for the space right after the door. To ensure the proposed solution is workable in the majority of situations, it is advised to procure the exhaustive list of floor plans for the space at the front door of older HDB flats with doorsteps.

The nature of the commercial wheelchair industry results in the variation of wheelchair designs. Aside from the general weights and sizes, the offset between the front wheel and the back wheel is critical in the proposed design proposed in this paper. Because an exhaustive list may be difficult and unnecessary, it is advised to limit the range to wheelchair sizes between 14-18 (Tan, personal communication, February 3, 2017).

Obtaining the range of possible measurements highlighted above would identify the percentage of cases the proposed design can cater to, or may highlight the need to change certain designs to fit the majority of cases.

Hooking stations

To secure the wheelchair to the winch, the user is required to hook the winch cables to two mounting points on the wheelchair. However, there is a possibility the user may accidentally drop the hooks of the winch upon retrieving them, and may not be flexible enough to pick them up. A solution to such a problem may be to automate the hooking process of the hooks onto the wheelchair. Alternatively, a pair of thongs may be placed at the hooking stations but there is also a possibility the user may drop the thongs as well.

Certification considerations

There is a need to ensure devices used are certified. Safety is critical for the solution and using only certified products will ensure the minimum criteria are met. There is also a need for certification if the solution is to be commercialised.

The wheelchair is considered a medical device and there are restrictions to wheelchair modifications. The current proposed solution only requires add ons and do not modify the wheelchair frame. It is believed that the current modification does not require additional certification in Singapore (Tan, personal communication, February 3, 2017).

The winch used needs to be certified for use. The current winch used is made to be used for towing heavier vehicles. There may be a need to use another type of winch which is certified for wheelchair transportation. An example of which may be the winch used in vans used to transport wheelchairs as shown below (Fiorella, n.d.).

Figure 61. Belt used for winching a wheelchair into vans.

[CONCLUSION]

This project aims to enable wheelchair users to overcome doorsteps in front of their flats. The criteria of independent operation, safety, user friendly, low cost and HDB and BCA code compliance was highlighted as necessary characteristics of the solution. Market research and patent searches for a currently available solution were conducted and documented. No ideal solution was found and thus a different solution was proposed. Specifically, the winch and ramp combination was proposed solution to best meet the previously listed criteria. A prototype was fabricated and tested to prove the concept. Insights from testings were compiled. Possible future developments were suggested based on the current limitations met by the team during the project. The project's problem statement will continue to be pursued by the Technology Development team of 2017.

[APPENDIX]

Appendix A: Compilation of relevant building codes

All buildings in Singapore need to adhere to the standard building codes. There are a few building codes relevant to this project. They are the Fire Code 2013 and the Building and Construction Authority (BCA). Additionally, our project is to be done on a Housing and Development Board (HDB) building and thus the HDB and town council regulations have to be adhered to.

Fire Code 2013

The Singapore Civil Defence Force (SCDF) specifies under the Fire Code 2013 that the minimum clear corridor width is 1.2m in accordance with the clause 2.3.2 (b) and clause 2.2.9 (SCDF, 2013, p. 96; SCDF, 2014). This clause is applicable for the project because HDB flats have a shared corridor, which is the only means of egress for flat occupants during an emergency. Additionally, the buildings in question are residential flats, and its corridors are considered an internal exit passageway.

Building and Construction Authority (BCA) regulations

In accordance with Building and Construction Authority (BCA), there are several relevant codes in which the final product has to adhere to. These are listed as below.

1. Accessible route
   In accordance with section 4.2.1.1 Table 3, there has to be a route of at least 1.5 m accessible at residential areas, including at the HDBs (Building and Construction Authority [BCA], 2013, p. 36). However, for existing buildings the minimum width is reduced to 1.2 m. Since our product would only be deployed at older HDBs and buildings*, we would design with the more lax 1.2 m clearance in corridors (BCA, 2013, p. 37). This, in addition to clause 4.2.4.1.2, would mean our product cannot occupy the 1.2 m width accessibility route of the HDB corridor.

2. Handrails
   Since the ramp has a rise higher than 175 mm, the ramp would require handrails installed. Handrails must be on both sides throughout the whole length of the ramp; and be at the height between 800 to 900 mm from the floor level in compliance to Clause 4.6.6.1 (BCA, 2013, p. 65).
   Handrails must also comply to Clause 4.7.3 which states that handrails must be slip resistance and with sufficient grip surface, free from rough objects (BCA, 2013, p.

70). Handrails must also be able to carry 1.3kN loading both vertically or horizontally (ibid).

3. Detectable warning surface
   With the height difference between levels exceeding 200 mm, the ramp has to have a band of contrasting color or texture with the floor surface, spanning across the width of the ramp in compliance with Clause 4.5.3 and 4.5.4 (BCA, 2013, p. 59).

4. Steepness in vertical level change
   With the rise of more than 200 mm the change in level gradient must not exceed 1:12 (BCA, 2013, p.63). However, this code not applied to the existing stairs at HDB and would be difficult for this project to implement due to space restrictions of the infrastructure in question. Moreover, our proposed solution will assists the wheelchair up the ramp using a winch, so the wheelchair users does not need to push themselves up the ramp.

5. Width of ramp
   Minimum clear width of a ramp is to be 1.2 m (BCA, 2013, p. 62). However, this project uses a pair of narrow ramps, similar to telescopic ramps instead of a single wide ramp. This dual ramp method is applicable to this project because the navigation of the wheelchair is guided by the winch and the c-channels of the ramps. There is also no need to accommodate for a wide range of wheelchair widths as the ramps will be customised to the wheelchair user using the solution.

6. Surface of ramp
   Surface of ramp would be required to be slip resistance in accordance with the SS 485 standards (BCA, 2013, p. 62). The slip resistant material would run to the landings if applicable in compliance with Clause 4.6.5.2 (BCA, 2013, p. 63). The coefficient of friction for the slip resistance surface should be at least 0.2 and is recommended to be 0.75 in compliance with Appendix F (BCA, 2013, p. 237).

7. Clearance at the door
   This project assumes the usage of automatic doors, and thus do not require to meet any specific clearance in compliance with Clause 4.4.6.1 (BCA, 2013, p. 48).
   However, using the stairlift as a guide, a maneuvering space of 1500 by 1500 mm is recommended after the door (BCA, 2013, p. 78).

8. Controls
   The use of controls may be implemented. If they are used, the must adhere to Clause 6.2 (BCA, 2013, p. 127).
   Floor space of at least 900 by 1200 mm must be clear at the controls. Controls are to be located adjacent to this space, at the height within the range of 450 to 1200 mm,

operable using only one hand with a maximum force of 22 N, and without requiring agility of user's' hand.

*Note: BCA currently requires the difference between the floor and entrance of residences to be less than 50 mm. Therefore, this project would not be required at newer residences.

Regulations with regards to Renovations of HDBs

There are regulations set by HDB and the town council with regards to renovations of the flats as well as outside of the flats. For the shared space outside the flat unit, both HDB and town council approvals are required. Specifically, HDB is concerned with the actual doorsteps whereas the town council has authority over the corridor (Tan, personal communication, February 3, 2017).

Addition of any permanent structure will be considered a modification to the current infrastructure. Hence, a permit will be needed from both the town council and HDB as a form of approval from said parties. Such permit application will not incur any monetary costs. (Tan, personal communication, February 3, 2017)

It is unclear whether town council restrictions and guidelines on renovations of corridors exists, but HDB regulations do cover rules of renovation comprehensively, and so we will be only discussing the regulations set by HDB.

Generally, HDB strongly forbids forms of renovations where:

1. The loading onto the building is beyond the allowable limit.
2. The external facade of the building is changed.
3. A nuisance to the public may be caused
4. A fire hazard is posed
5. public area is encroached upon
6. Any form of lease agreement or statutory regulation is infringed. (HDB, 2014, p. 4-5)

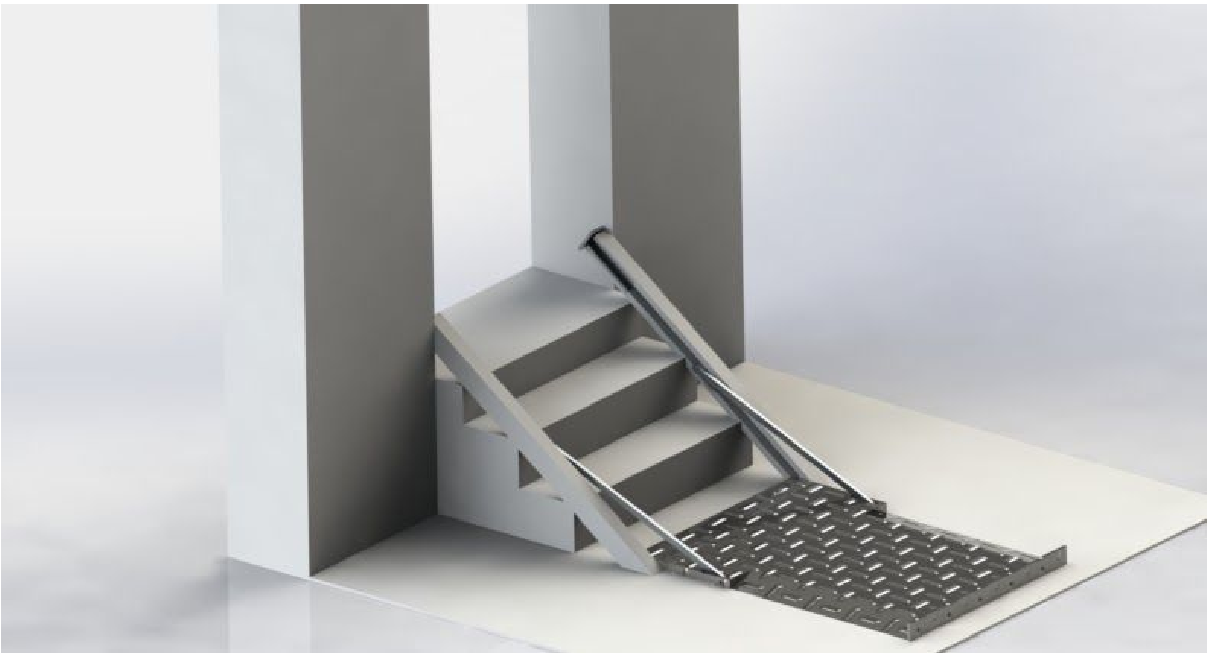
From these constrains, the issue of public area encroachment can be argued to be violated if a setup is placed outside the flat unit, depending on the ownership status of the doorsteps in question.

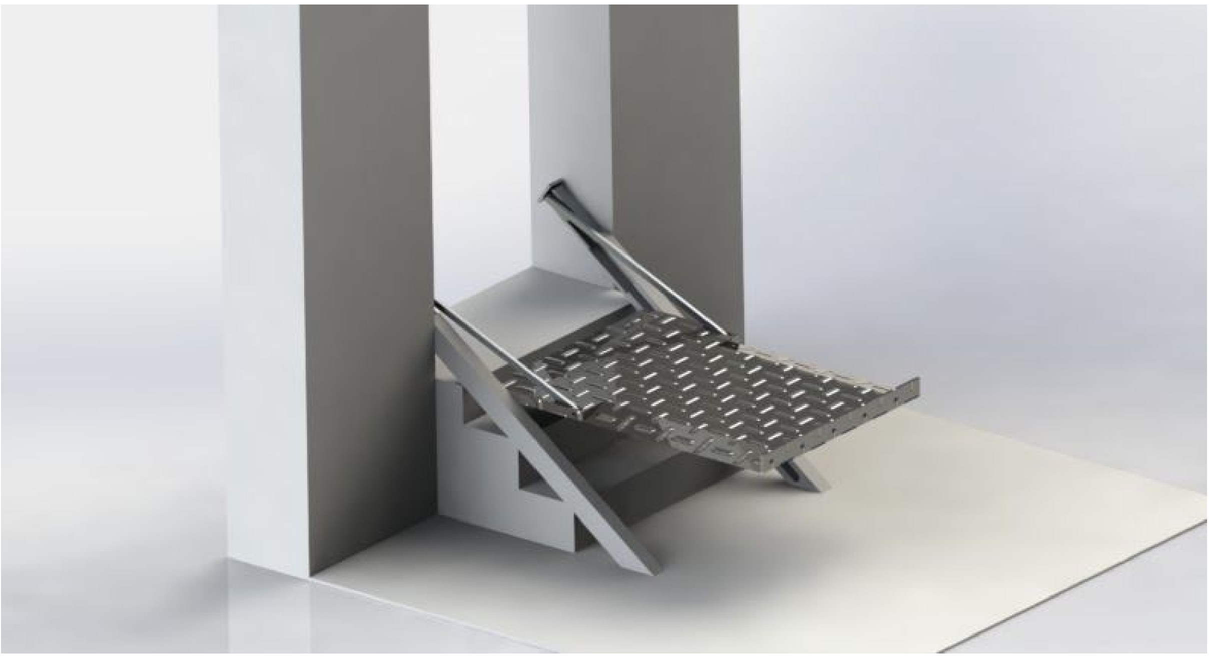
Any renovation or modification to the doorsteps would require prior approval from HDB. HDB specified a list of renovation works which do not require prior HDB approval (HDB, 2014, p. 5-6). Since no mention of doorsteps were listed as approval waived, the works would require HDB approval before proceeding (HDB, 2014, p. 5).

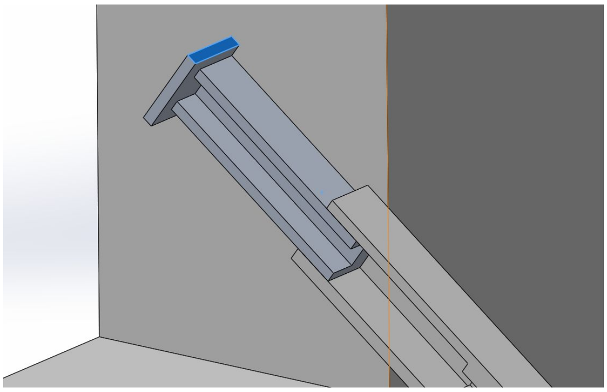
Moreover, HDB requires all renovation works be done by a HDB Registered Renovation Contractor (HDB, 2014, p. 1; HDB, n.d.).

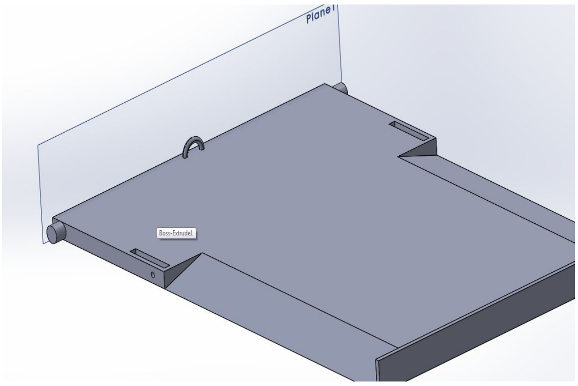
Appendix B: Design concepts from ideation phase

Design 1: Folding ramp





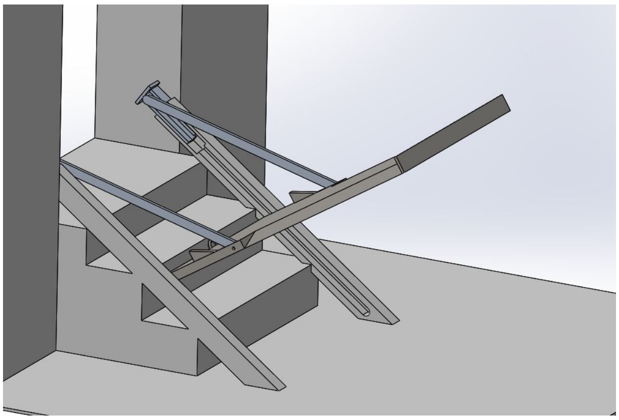


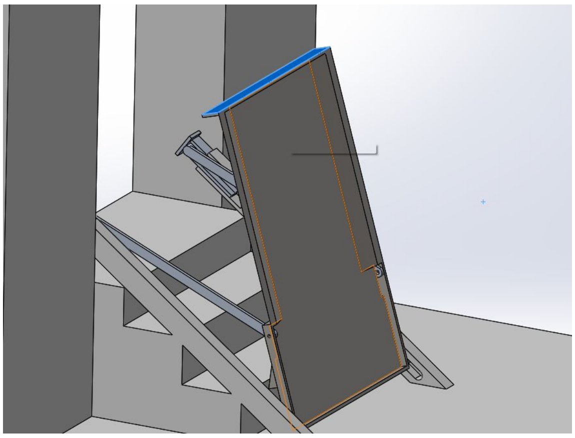


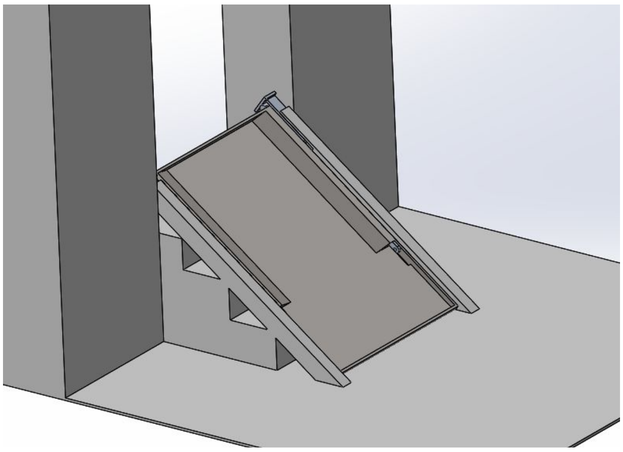
Working mechanism

A winch is attached to the hook at the middle of the front of the base plate. The winch is retracted to pull the base plate up and release to move the base plate down.

Modifications







Working mechanism of modification: (to reduce the blocking of corridor)
There is a anchoring point beyond the long link. A rope to connected to this anchoring point and when the rope is pulled, the base plate will flip over. If the base plate is thick enough we can even add stairs on the underside of the base plate. Or not we can add friction on the

underside so that if the inclination is low people can even walk into the home using the base plate as a ramp.

Pros:

1. Simple design, easy to manufacture.
2. Can be remove easily if ever winch is spoiled.
3. Effective for tall stairs
4. Do not require modification to the wheelchair.

Cons:

1. Still blocks the corridor quite significantly when it is up. Solution: modification which allow the base plate to flip
2. Not effective for short stairs
3. The linkage will partially block the wheelchair from going up onto the raising platform.
4. High concentrated stress at anchoring point.
5. Load bearing on 2 sides of the HDB door, is there such an anchor space?
    1) Stowage when not in use?
    2) Not much of a leverage, therefore the hydraulic strength has to be huge, and that will add strain to the structure resulting in extra weight and more hydraulic power required
    3) Structural strain at the end of the platform

Design 2: Hydraulic platform

1) Proven design
2) Hydraulics and scissor lift requires a baseline height. So a side ramp on the hydraulic platform is needed.
3) HDB restriction of not have permanent object in their corridor is a problem
4) Weight consideration (BCA)

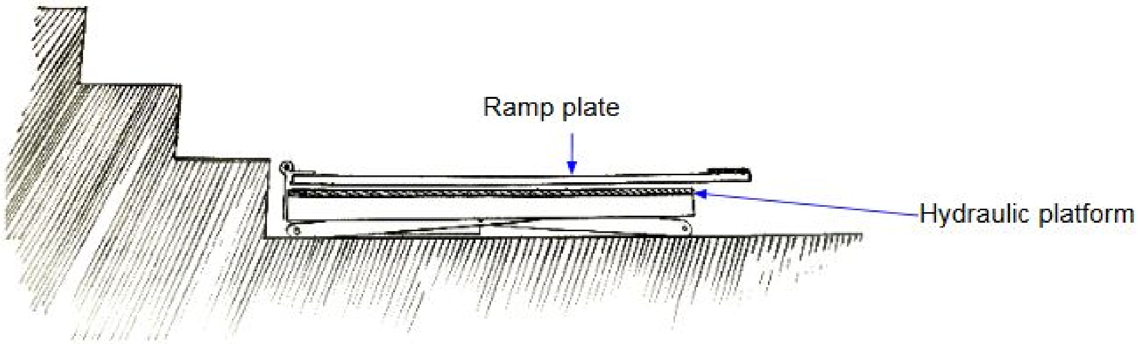


Fig1. Kept configuration.

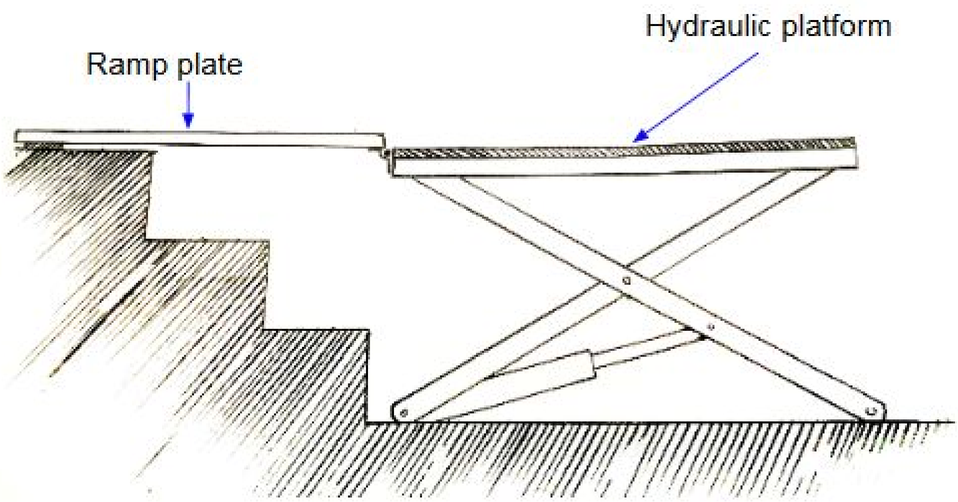


Fig 2. Deployed configuration.

Using the similar concept of the commercially available hydraulic platforms. eg:

Going up:

1. The device is at kept configuration (Fig1).
2. The ramp plate is flipped open.
3. The wheelchair is positioned onto the platform with the aid of a small ramp at the sides (small ramp is not shown in figures).
4. The platform is raised by hydraulic system into deployed configuration (Fig2).
5. The wheelchair user rides off the platform to the ramp plate and into the home.
6. The ramp plate is folded back, the platform is lowered back into kept configuration.

Going down:

1. The system is deployed to fig2
2. The user rides to the hydraulic platform via ramp plate
3. Platform is lowered
4. User rides off the system
5. The ramp plate is folded back, kept configuration is achieved

Pros:

- Reliable lifting mechanism; hydraulics can lift large weights and is an old technology
- Simple design should be able to make a 1:1 if purchase of hydraulic system is possible

To be discussed:

- Mounting of hydraulic platform
- Moment about tip of platform as user rides off
- Security as the user is elevated and when the user is moving relative to elevated platform(a simple handrail perhaps?)
- Movement of ramp plate (to be manual/automated/mechanisms of)
- Keeping of platform: obstruction of corridor ways

Design 3: Fold up ramp (similar to Design 2)

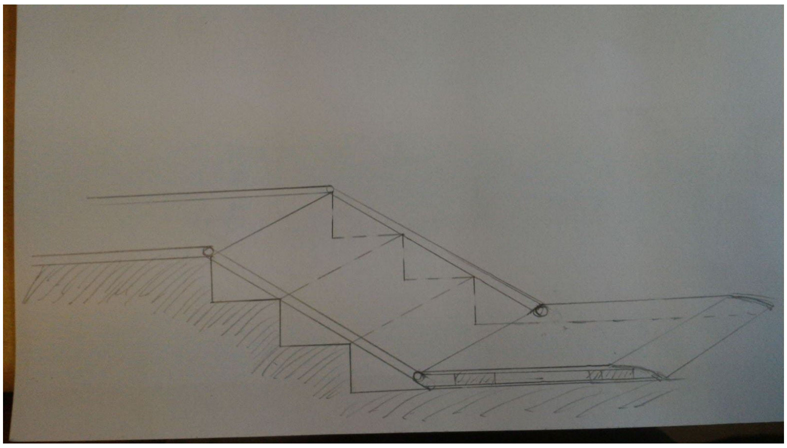


Fig 1. Overview

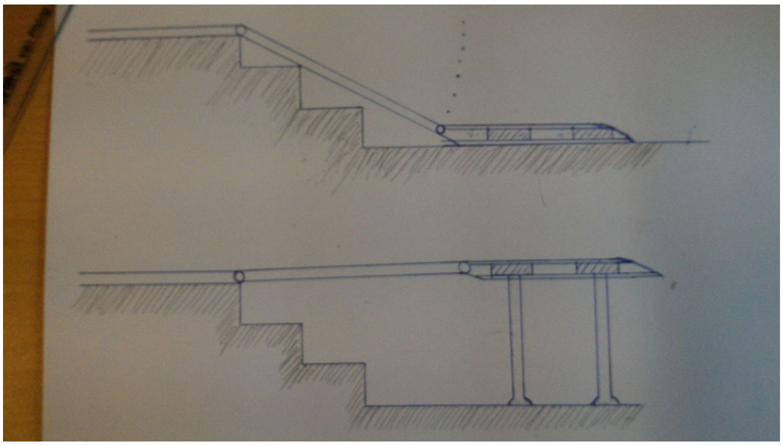


Fig 2. Usage

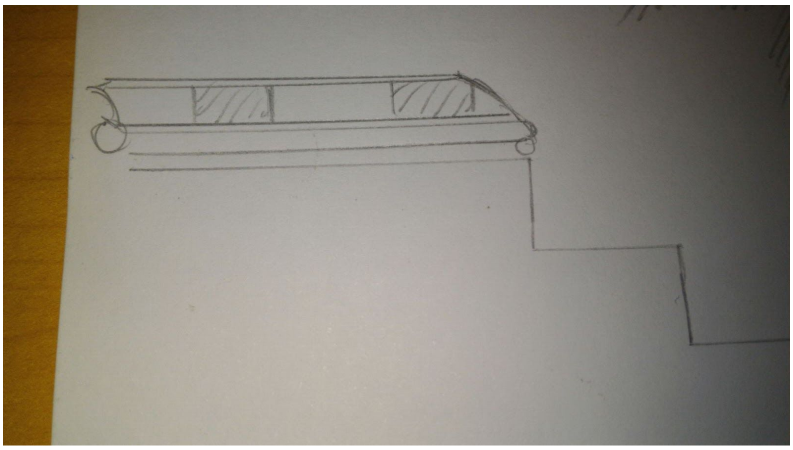
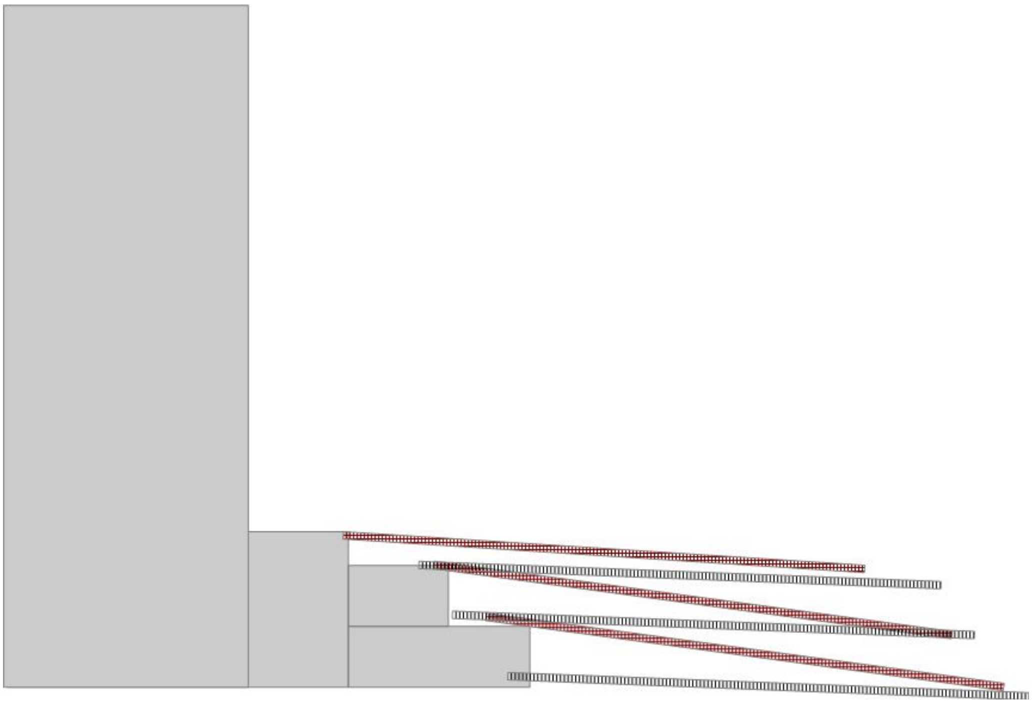


Fig 3. Folded/Storing

Pros: Can be folded and stored indoor

Design 4: Varying Climbing Slope



Conceptual design of moving up gradually with varying slope.

Thought process

The following write-up is how the group have come to adopt the current final design.
From the meet with SPD, we have come to the understanding that the design must provide independence for the user and the cost have to be affordable. Independence means only the wheelchair user is needed to operate the product. While affordability means the product have to be cheaper than current commercial solutions like stairs climbing wheelchair. We can then set the price to be from \$750 - \$1000 as these amount is expected by SPD clients.

Stairs-climbing wheelchairs are rejected as there are already commercially available. Furthermore, they cost on average about \$15000 for each unit. Therefore, they are too expensive for many to afford it.

Next Wheelchair elevator have also been rejected as it requires a large amount of space. Design 1 to 3 are all in this category. The reason why most early iteration of design are similar to a wheelchair elevator is because we wanted a very safe and comfortable product while a elevator is able to provide as it can ensure that the wheelchair is allows parallel to the ground. However, the load of the wheelchair and user is rather high, thus a relative strong structure is need to hold the weight of the user and wheelchair. As such, the elevator will have to be rather thick, thus it will block the HDB corridor which is against the BCA code which requires 1.2m of walkway for fire escape. Therefore, the solution would be to store the elevator in the home and it can be deployed when needed. However, such a system can be quite expensive and not affordable. In the case of a design where the elevator can be deployed from within the home which can be cheap enough to be produce and also not blocking the space in the home. It should be considered.

ST engineering have proposed an interesting concept which is to install a lifting device on the ceiling of the HDB. This concept may also be considered but there needs to be a clear understanding of the loading bearing of the ceilings of the HDB. As there is a strict limit on the load bearing of the ceiling, such a system may not be able to be adopted in many places, thus this idea was not builded upon. Balancing the wheelchair user during lifting and obtaining permits for installation will also be a challenge.

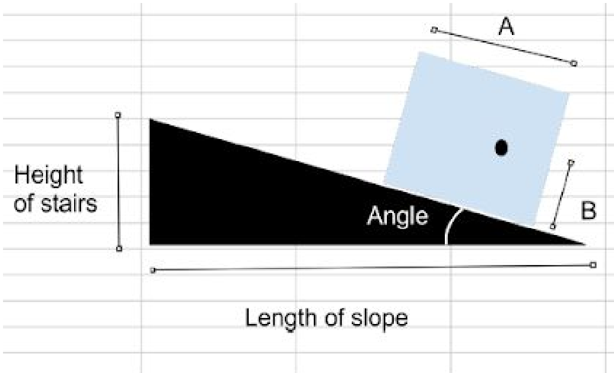
Convertible stairs would is shown in the background research cannot be adopted as the stairs cannot be remove due to regulations. In a situation when such a regulation can be changed, this idea can be considered. The convertible stair can have a hydraulics below which can lift the wheelchair user.

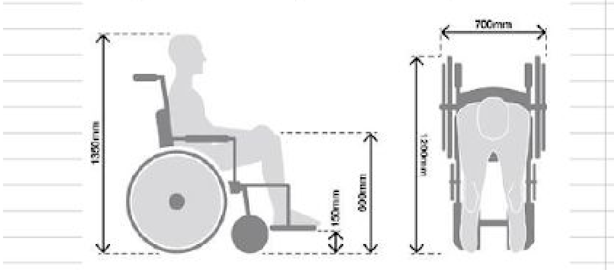
Motorised wheelchairs cannot be left outside the home as it is a safety hazard, thus any design idea that required users to switch wheelchair when moving in and out of the home can only work for manual wheelchairs, Furthermore, the wheelchairs have to be parked properly to allow a 1.2m walkway for fire escape.

Summary for the rationale of the final design:

1) The ramp is steep so that it will not block the corridor. Moreover, most flats will not have enough space for a regular ramp that is at most 10 degrees in gradient.
2) Ramp is designed to allow easy installation of it.
3) Hump at the top of the ramp is to prevent wheelchair from falling down the ramp unintentionally.
4) Transition slope at the bottom of the ramp is to prevent the wheelchair from tilting when moving from the ramp to the lower ground.
5) Railing are added to help user in case of emergencies and also provide confidence when using the ramp.
6) Using a commercially available motor helps to reduce cost significantly.
7) Placing the motor in the house can allow wiring to be done much easily.
8) A pulley is used to redirect the cable so that the motor can be place at the side and not obstruct the path in the house.
9) Cable hider and cover is to prevent damage on the cable when wheelchair user needs to move over it.

Appendix C: Tipping Angle Calculations





WHEELCHAIR					
Parameters					
	(mm)				
A	1200	400			
B	550				
Tipping Angle					
Rads	0.6287962864				
Degree	36.02737339				
RAMP	Steps	1(mm)	2(mm)	3(mm)	Total
Height of staircase	3	150	140	150	440
Length of	3	290			870
Hypo	974.9358953				
Angle of slope	0.4682347328	Rads			
	26.82787401	Degree			
length of ramp	1275	mm			
Width	120				
Ramp					

Appendix D: Preparation for Prototyping

A list materials and machining processes needed for manufacturing

Estimated cost of full system				
Part No.	Item	Per cost	Units	Cost($)
1	3/4 elbow	1.5	3	4.5
2	1" elbow	1.5	1	1.5
3	25mm saddle	1.6	2	3.2
4	L Shape Trim 6 M	10.5	1	10.5
5	Kapur Wood 1ft	1.6	26	44.51
6	Right angle holder	6	1	6
7	Foam Pad	1	2	2
8	Anti Slip Mat	2	1	2
9	Plywood	-	13	68
10	bracket L	9	1	9
11	Friction Tape	5.9	1	5.9
12	kapar wood: 3m	26.75	1	26.75
13	pulley	17	1	17
14	Heavy duty Carabiner	12	1	12
15	Wire sling	12.5	2	25
16	Pipe Connector	7/8	2	15
17	Motor	380	1	380
18	Electric wire + plug + fuse	7.8		7.8
			Total (SGD $)	640.66

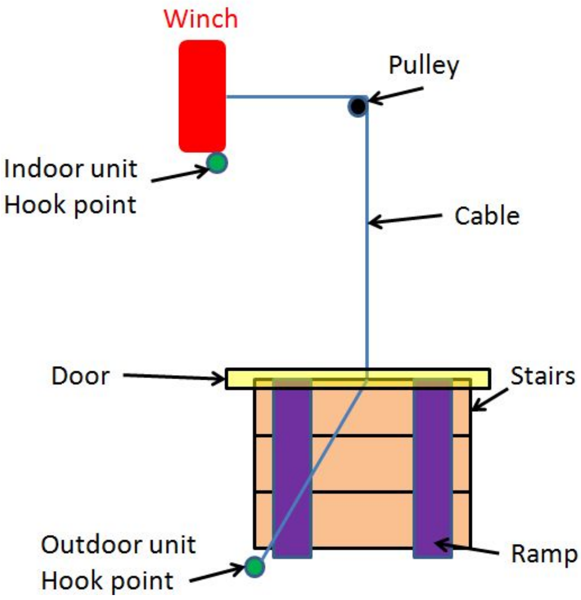
Total Prototype Testing Transport (van transport) cost: $117.75

The cost of a commercial equivalent of the prototype may be higher. The bulk of the cost would most likely be from the winch, where a certified belt winch may be required. An example of such a winch may be similar to the winch used in vans by the company

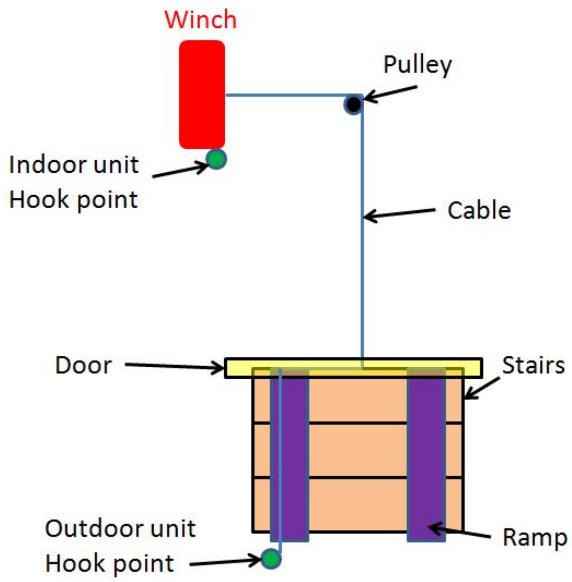
FIORELLA as shown in the figure below. The cost may also increase due to marketing costs and maintenance required. It may also be important to consider the cost of the automatic door necessary to complement any proposed solution, which may cost approximately SGD 1,000 (Tan, personal communication, February 3, 2017). While the cost of the automatic door is a given, the team is advised to not burden the user considering the users who stay at older HDB flats tend to be financially limited.

Retrieved from:
http://www.fiorella.ws/images/Prodotti/F-Winch/F-Winch-Combo-Interno.jpg

Appendix E: Assuming a Door Sweeper Mechanism



Position of cable after use



Position of cable after sweeping effect

When the user use the device to exit the house and hook the cable onto the outdoor unit. (hook point on the rails) The cable will be position diagonally on the stairs which can cause people moving across the stairs to trip. Hence, we assume that the door which will be a automatic door will have a sweeping mechanism which can sweep the cable to the side and prevent people from tripping over.

[REFERENCES]

Building and Construction Authority (BCA). (2013). *Code on Accessibility in the Built Environment 2013.* Retrieved September 25, 2016, from http://www.bca.gov.sg/friendlybuilding/contents/Contents.aspx?ContId=439

DNR Wheels. (n.d.). *Telescopic Ramp - 5 ft.* Retrieved February 02, 2017, from http://www.dnrwheels.com/Ramps?product_id=709

Fiorella. (n.d.). *WHEELCHAIR TOWING WINCH.* Retrieved February 16, 2017, from http://www.fiorella.ws/wheelchair-lifts-for-vans-and-accessibility-products/wheelchair-loading-winch

Fry, D. (n.d.). *Patent WO2013067623A1 - Apparatus for ascending and descending stairs with a wheelchair.* Retrieved November 3, 2016, from https://www.google.com.sg/patents/WO2013067623A1?cl=en&dq=stairs%2Bramp%2Bfor%2Bwheelchair&hl=en&sa=X&ved=0ahUKEwisz52enarPAhXJPI8KHYwtAPYQ6AEILzAD

Housing and Development Board (HDB). (2014). *Guidelines for Renovation Works.* Retrieved February 2, 2017, from http://www.hdb.gov.sg/cs/infoweb/doc/parkland-hougang-reno-guidelines

Housing and Development Board (HDB). (n.d.). *Important Information.* Retrieved February 16, 2017, from http://www.hdb.gov.sg/cs/infoweb/residential/living-in-an-hdb-flat/renovation/important-information

Inc., P. S. (n.d.). *Multilift Vertical Platform Lift.* Retrieved February 02, 2017, from https://www.savaria.com/products/wheelchair-lifts/multilift-deck-lift

Littlejohn, D. J., Hessler, J. H., Watkins, B. R., & Technologies, I. Q. (n.d.). *Patent US5123495 - Wheelchair stair climbing control system.* Retrieved October 1, 2016, from https://www.google.com.sg/patents/US5123495?dq=stairs%2Bramp%2Bfor%2Bwheelchair&hl=en&sa=X&ved=0ahUKEwisz52enarPAhXJPI8KHYwtAPYQ6AEIKDAC

Mobility Toys. (n.d.). *Wheelchair Stairclimber.* Retrieved November 02, 2016, from http://www.mobilitytoys.com/wheelchair-stairclimber/

Norris, R. E., & E, N. R. (n.d.). *Patent US6957716 - Emergency stairway escape apparatus for wheelchairs.* Retrieved February 02, 2017, from https://www.google.com.sg/patents/US6957716?dq=stairs%2Bramp%2Bfor%2Bwheelchair&hl=en&sa=X&ved=0ahUKEwisz52enarPAhXJPI8KHYwtAPYQ6AEISzAH

Packer, L. (n.d.). *Patent US4528711 - Portable wheelchair ramp*. Retrieved November 12, 2016, from https://www.google.com.sg/patents/US4528711?dq=stairs%2Bramp%2Bfor%2Bwheelchair&hl=en&sa=X&ved=0ahUKEwj_gbuxpKrPAhWKMo8KHbZdAPA4ChDoAQggMAE

Rich, P. M., & Dean, Y. (1999). *Principles of element design.* Oxford: Architectural Press.

Ride Away. (n.d.). *BraunAbility UVL Wheelchair Lift | Scooter Lift | Ride-Away.* Retrieved December 02, 2016, from https://www.ride-away.com/research/mobility-products/wheelchair-lifts-and-ramps/braunability-uvl-wheelchair-lift/

Rollaramp. (n.d.). *Powered Van Ramps | Van Ramps | Roll-A-Ramp.* Retrieved November 12, 2016, from http://www.rollaramp.com/van-ramps-powered

Singapore Civil Defense Force (SCDF). (2013). *Fire Code 2013, Chapter 2.* Retreived from https://www.scdf.gov.sg/content/dam/scdf_inter/Buildings%20Professionals/Publications%20and%20Circulars/Fire%20Code%202013/Chapter%202.pdf

Singapore Civil Defense Force (SCDF). (2014, October 02). *Fire Safety Guidelines for HDB Estates.* Retrieved February 16, 2017, from https://www.scdf.gov.sg/content/scdf_internet/en/community-and-volunteers/community-preparedness/fire_safety_guidelinesforhdbestates.html

Seth, R. (2013, May 04). *Convertible Ramp.* Retrieved February 02, 2017, from http://www.yankodesign.com/2013/05/09/convertible-ramp/

W. (2013, September 29). *Walk & Roll Stairs, The Alternative Stairlift for trolleys, strollers, hand trucks, wheelchairs.* Retrieved November 02, 2016, from https://www.youtube.com/watch?v=OTv77IFRGAg