Mechanical Design B
Design for Systems Integration and Assembly
(2020-21)

Design group report

Design Group No. 11
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1. Introduction

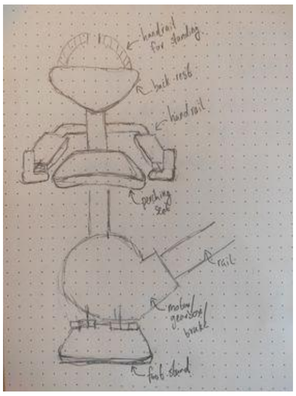
Stairlifts are a great solution for people who struggle to go up and down stairs without external support. Therefore, to help those who are immobile, a fully functioning stairlift has been created. This lightweight design is safe, easy to assemble and is suitable for small houses. In this report detailed descriptions of the proposed design can be found and demonstrated alongside 3D CAD models. The stairlift was thoroughly analysed and had various changes to its components and manufacturing methods to ensure the design was optimised and sustainable. Any changes to the design were justified and any impacts have been discussed.

2. Initial concept designs

The first conceptual design that was made was originally from *Figures (1,2,3),* showing the original sketches/CAD designs created to model our initial concept.

Stairlift specifications:

- Chair width (A)= 450-560 mm
- Chair width (B) = 295 mm
- Depth from wall (C) = 565 mm
- Total height (D) = 1340-1550 mm (Depending on set seat height)



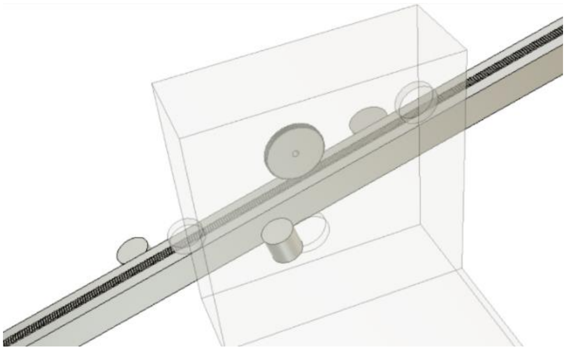
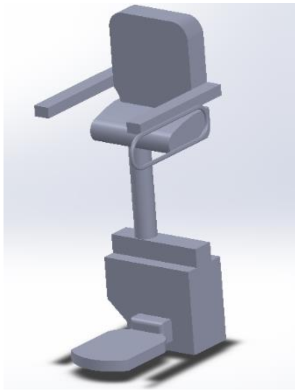



Figure 1(left): Initial sketches of Perch stairlift design.
Figure 2 (centre): CAD model showing how gears connect to the rack and pinion system. Figure 3 (right): CAD model of initial Perch stairlift design.

After reviewing the original design and receiving feedback, it was decided that to improve our stairlift model, the stairlift would have a seated design. The implications of this design change meant that the depth from the wall had to be considered as seated stairlifts take considerably more room. However, this design change led to a model that is easier to build, easier to use, and allows the user to take the weight off their feet throughout the journey up or down the stairs. Therefore, the rest of the report was created based on a seated stairlift design.

3. Safety features

Stairlifts intended for persons with impaired mobility must comply with the standards set by BS EN 81-40:2020[4], which sets the safety requirements for the construction and installation of stairlifts. The following design requirements will align with these rules, and any features on the stairlift that require input from the user will have human factors considered to ensure the product is easy and efficiently used.

1. Seatbelt: Fitted with adjustable seat belts to ensures the user does not slip off whilst in operation. The stairlift only require a seatbelt over the lap, however, an additional 5-point harness can be purchased for users who require extra back support. To encourage the use of safety features, the stairlift will not run unless the seatbelt is secured.

2. Auto seat lock and switch: The seat will swivel in both directions to accommodate easy access on both ends of the stairs. It simply requires the user to lift a lightweight lever up to release the lock and then the chair can rotate 90 degrees. The feature means the user can get on and off whilst the chair is facing backwards to the stairs, which reduces the risk of the user falling down the stairs. The stairlift will not travel if the seat is not locked into the central position and is unable to swivel when moving.

3. Armrests: To provide postural support, comfort and to provide a protective enclosure. The armrests are padded to support the user's forearm and does not engage with parts of the arm that are sensitive, i.e., the ulnar nerves in bony parts of the elbow. Therefore, a gap of approximately 100 mm between the back seat and the arm rest will be used. The arm rest will have to be a minimum 440 mm apart to accommodate the thigh breadth of the 95th percentile of females. The stairlift will not move unless both armrests are in proper position and locked down into place. The arms rests can fold up to allow other stair users to access the stairs without the chair acting as an obstruction. To release/fold up the arm rest, slight pressure on a button must be applied which releases the lock.

4. Footrest: The footrest provides comfort for the user, as the weight of their feet will be supported when seated and has a strong design which can support the user's weight as they embark/disembark. The foldable footrest is lined with needle punch floor carpet which has a ribbed surface for anti-slip properties, and uses a rotating lever located next to the seat, allowing control of the footrest without having to bend down, this also makes the stairlift more compact. The footrest must also be locked down into position before it is able to move and is accommodated with microswitches along the side which will apply brakes to the stairlift when in contact with any obstructions. The stairlift will not continue moving unless the obstruction is removed. If the obstruction is not moved, the stairlift will travel in the opposite direction, so that the user is not stranded in the middle of the staircase.

5. Backrest: The backrest will be designed to provide a medium level support. The higher the backrest, the better weight is supported. The design will be made to 660 mm to accommodate the 95th percentile man and to still meet the requirements of maximum stair lift height.

6. Momentary activation switch: Pressure must be applied to the switch for the stairlift to move. If pressure is released, the lift will stop in that position. This will be in the form of a toggle, located on the arm of the chair. The joystick can be moved in the direction of travel required for the user and will be light enough to push with one finger to allow most immobile users to control it.

7. Mechanical and Electrical Brakes: Both brake systems are installed. In the event where the battery for the electrical brakes fails, the mechanical brakes will step in to prevent the stairlift sliding back down. Overspeed governor will activate and stop the stairlift in case of uncontrolled descent. It is programmed to trip when the speed limit is reached and activates the brakes.

8. Key lock: A key lock will be used to turn the stairlift on and off. If the key is not present in the keyhole the stairlift will not turn on. The key can only be removed in the off position. This feature is incorporated to prevent children from activating the device in an unsafe manner.

9. Stopping blocks: Both ends of the stairlift will be fitted with stopping blocks, so that the lift stops at the correct position. Even if pressure is applied to the movement switch, the motor would not be able to move in the direction where the rails have ended

10. DC voltage: Batteries are used so that only 24V/12V of power runs on the stairlift. This would ensure lower risk of electrocution during operation, and still operate during a power outage. Batteries are charged at charging stations located at the top and bottom of the stairs.

12.Emergency holding button: There will be a button that the user can press to call for help, this will ensure the user has access to help no matter where they are on the staircase. If the stairlift is, for any reason, inoperable it will move itself to a position where it does not obstruct the staircase.

4. Additional features

1. On-board diagnostic display: Stairlift can show its status which can indicate to the user or engineer if there is a problem and suggest possible solutions. This makes diagnostics simple and quick.

2. Call and send joystick: This gives the user the ability to ensure the stair lift is in the right location by pressing a button which moves the staircase to the specific location, this is especially useful for households where multiple people will be using the stairlift.

3. Adjustable seating heights: An engineer will fit the chair according to the user's height for maximum comfort. The seat height should be adjusted to support a knee angle of 90 degrees to prevent leg swelling. Minimum height of the seat above the footrest will be designed for women in the 5th percentile starting from 380 mm and can adjust up to 500 mm. The seat width of 560mm, will be designed to accommodate clothed users.

4. Easy-to-clean upholstery: The seat/back support and arm rest will be lined with a comfortable sponge padding and the upholstery material will be leather. This stain resistant upholstery is aesthetic and easy to clean. The materials used will be flame retarded and self-extinguishing.

5. Stairlift inspection requirements

Table 1 indicates methods by which the safety requirements and stairlift parts shall be checked, all verification records shall be kept by the manufacturer.

Table 1: Safety Requirement Methods

Safety requirement	**Visual inspection**	**Performance test**	**Calculations verify design requirement met**	**User inspection- in instruction handbook**
Equipment should be protected against harmful external influences	✓	✓	✓	✓
Check guide rails in good working condition	✓	✓	✓	
Check safety gear and overspeed detection device are working	✓	✓	✓	
Check rack and pinion condition	✓	✓	✓	
Check driving systems meet general requirements	✓	✓	✓	
Check braking system working	✓	✓	✓	
Check emergency system operation	✓	✓		✓
Working/reliable power supply	✓	✓		✓
Check motor and braking circuit	✓	✓	✓	
Chair stable and adjusted for user	✓	✓	✓	✓
Working cableless control devices	✓	✓		✓

6. Motor selection calculations

To find a suitable motor for the stairlift, a power rating had to be calculated first. Using the schematics of a Freebody diagram, F1 and W were calculated using the following equations.

Assumptions:

- Friction is negligible
- The stairlift is inclined at the maximum angle allowed for a staircase, at 52° to the horizontal
- The lift is travelling at a maximum velocity is 0.15 m/s
- The total mass applied on the staircase is 200 kg, assuming the maximum human load is 150 kg and the stairlift is 50 kg
- A factor of safety of 2.5 is used to follow BS EN 81-40-2020 standards for stairlift designs

W = mgcos(Ø) = 200 x 9.18 x cos(52)= 1207.93 N **Eq.1**

F1= mgsin(Ø)= 200 x 9.81 x sin(52) = 1546.10 N **Eq.2**

Power = Force x velocity =1546.10 x 0.15 = 231.92 W **Eq.3**

By considering power required and factor of safety of 2.5, we are aiming to look for a motor that can produce a power of around 500 W. The motor specifications have been summarised as seen below in *Table 2.*

Table 2: specifications for motor

Criteria	Value
Motor Power	0.67 HP (500W)
Travel Speed	0.15 ms^{-1}
Power supply	24V DC

7. Design for sustainability and optimisation (Footrest)

Footrest theoretical analysis (Deflection formula)

To calculate the maximum deflection of the footrest, it had to be treated as a beam. The selected material for the footrest was Low alloy steel as it is relatively cheap and provides good mechanical properties for the application at hand.

F = 120 x 9.81=1177.2 N

L = 470 mm, *b* = 310 mm, *h* = 50 mm

E = 200 GPa

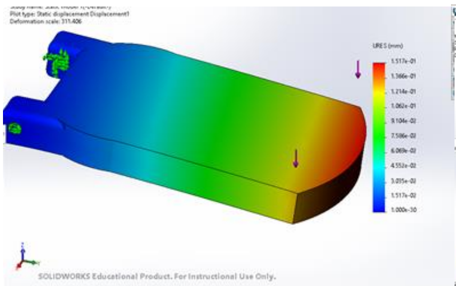
Where =maximum deflection, *F* = load applied, *L* = length of beam, *E*=Young's Modulus and *I* = second moment of area

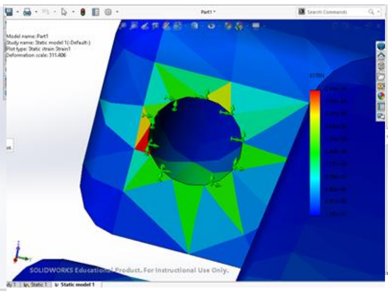
$$\partial = \frac{FL^2}{3EI} = 0.134\ mm \quad \textbf{Eq.7} \qquad I_x = \frac{bh^3}{12} = 3.23 \times 10^{-6}\ m^4 \quad \textbf{Eq.8}$$

Footrest FEA

Finite element analysis was used to create a simulation to understand what stresses will be induced onto the footrest, and these results were used to enhance the design. The footrest requires thorough analysis since it must be able to support the whole load of a person as they embark and disembark onto the stairlift. In the analysis it was assumed that the person is standing on the edge of the footrest, as this would be the worst-case scenario. Our design is being created to withstand a load of up to 120 kg therefore the force acting on the footrest was modelled as 2 separate forces of 588.6 N (representing each foot). Since we were carrying out a simplified analysis, the movement/deflection was not considered for the rest of the staircase and therefore the end of the footrest was treated as fixed. Since it was treated as a worse-case scenario, it was modelled as if there is no hinge in place.

For the first analysis, the footrest was originally designed with a thickness of 50 mm and the material chosen was low carbon alloy steel. The following figures show the results achieved from the FEA simulated through Solidworks.





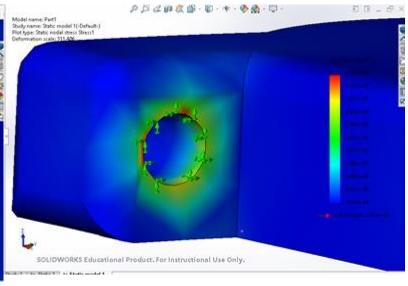


Figure 7 (left): Displacement profile. Figure 8 (centre): Strain profile. Figure 9 (right): Von mises profile

As seen in *Figure 7* the maximum displacement that would occur is on the edge of the beam which has a value of 0.15 mm. This closely matches our predicted calculation of 0.134 mm (**Eq.7**) the differences in values are likely due to modelling the area of the footrest as a square whereas the actual CAD model has a more complex geometry. However, since the deflection calculations were similar it shows that any assumptions made are feasible and that our calculations are reliable. For *Figure 8/9* the main concentrations of stress are around the 2 holes that support the footrest. Using the yield strength of 2.413 x 10^8 $Nm^2$and the maximum von mises stress (9.941 x 10^7 Nm^2) that was found from the simulation, the yield factor of safety (FOS) can be found using the following equation: Yield stress/Actual stress= 2.43. This value is slightly low as a minimum FOS of 2.5 was required. Therefore, the model was redesigned to reduce the stresses occurring at these points. On the other hand, the rest of the structure showed little stress which can be seen in the contours of *Figure 9*. Besides around the holes most of the surrounding material was blue which suggests the rest of the footrest showed stress of around 1.989 x 10^7 Nm^2 leading to a FOS of 12. This value is significantly large and therefore shows that there is opportunity to reduce some materials to be more sustainable, whilst still meeting the safety requirements of this project.

<u>Optimisation</u>

The following *Figures (10,11,12)* show the model after having some altercations added to the design. The thickness of the structure was significantly reduced to dispose of any unnecessary use of material, therefore the new thickness used is 35 mm. The material was altered to a slightly less dense material of high carbon steel, which reduced the mass of the footrest without impacting the strength. The deflection slightly increased to 0.26 mm however this impact is not significant as it is still relatively small compared to the thickness of the footrest.

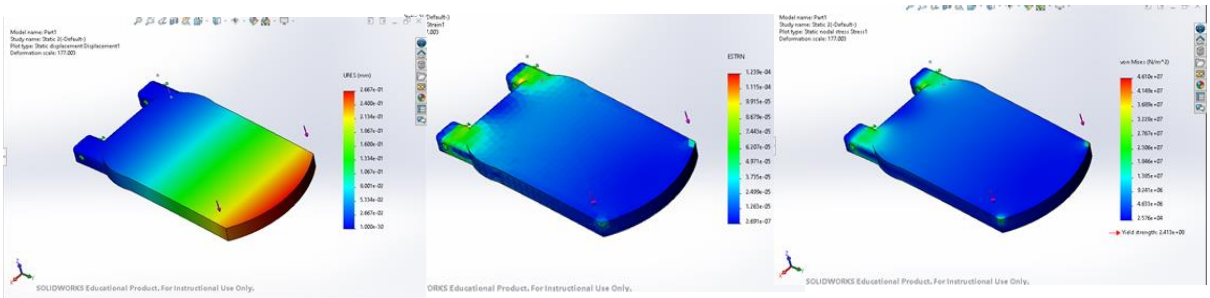


Figure 10 (left): Displacement profile. Figure 11 (centre): Strain profile. Figure 12 (right): von mises profile.

The yield strength is 2.413 x 10^8 Nm^2 and the maximum stress which was around the holes was 4.61 x 10^7 Nm^2 therefore the FOS is 5.23 exceeding the required value of 2.5. However, this meant further reductions could be made to the design around other areas as the FOS was still above 2.5. The length and width of the footrest was to the British standard therefore the size stayed the same and the thickness stayed at 35 mm to prevent any more deflection occurring. However, parts of the material were removed internally to save unnecessary weight and costs. A volume of 0.00125 m^2 was removed throughout the centre of the footrest, significantly reducing the amount of wasted material. The maximum stress acting was now 4.57 x 10^7 Nm^{-2} meaning the FOS was 4.8.

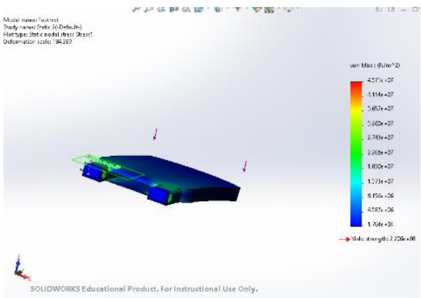


Figure 13: Von mises profile for the new footrest design and projection view showing the reduced material content

The footrest has now been efficiently designed with a material that has a high yield strength to minimise internal stress within the structure. The FOS was successfully found for our original concept and then design parameters were optimised to ensure the FOS was high enough to prevent risk of failure but to also make it more conservative to create a sustainable model. This was done by removing as much excess material from the internal structure as possible where stress concentrations were low before the FOS was penalised.

Table 3: summary of design changes for the footrest

Parameters:	**Initial design**	**1st redesign**	**2nd redesign**
Thickness	50 mm	35 mm	35 mm
Material	Low carbon steel	High carbon steel	High carbon steel
Volume	0.003827 m^3	0.003827 m^3	0.002567 m^3
Mass	3.8 kg	3.8 kg	2.6 kg
Maximum stress	9.941 x 10^7 Nm^2	4.61 x 10^7 Nm^2	4.571 x 10^7 Nm^2
FOS	2.43	5.23	4.8
Deflection	0.15 mm	0.26 mm	0.26 mm

8. Design for sustainability and optimisation (Rail and carriage)

Theoretical stress calculations analysis:

Assumptions:

- Maximum mass allowed on the chair decreased from 150 kg to 120 kg
- Mass of the chair is 50 kg
- Total length of the rack is 3 metres
- Maximum moment applied is at the centre of the rack

Rack analysis (Flexure Formula): See appendix for full worked solutions

$$\sigma_x = \frac{My}{I_x} \quad \text{Eq.4} \qquad I_x = \frac{bh^3 - bh^3}{12} \quad \text{Eq.5} \qquad M = Force \times Distance \quad \text{Eq.6}$$

Where σ_x= maximum bending stress, *M* = moment about neutral axis, *y* = perpendicular distance to the neutral axis and I_x = second moment of area.

The above equation (Eq.4) is known as the flexure formula and is a simple method used to calculate the maximum tensile strength for a symmetric beam (rack). From the equation, it was noticed that on the neutral axis itself (y=0), the stress applied was equal to zero. The flexure formula also shows that the maximum tensile stress is at the bottom surface of the beam and the maximum compressive stress is on the bottom surface of the beam. The second equation (Eq.5) is used to calculate the second moment of area for a hollow cross-section.

$$I_x = \frac{(0.08)(0.08)^3 - (0.064)(0.064)^3}{12} = 2.01 \times 10^{-6}\ m^4$$

$$M = (120 + 50)(9.81)(0.625) = 1040\ Nm$$

$$y = 0.04\ m$$

$$\sigma_x = \frac{1040\ x\ 0.04}{2.01\ x 10^{-6}} = 20.7\ MPa$$

$$I_x == 2.01\ x 10^{-6}\ m^4$$

$$M = 1040\ Nm$$

$$y = 0.04\ m$$

$$\sigma_x = 20.7\ MPa$$

Optimisations

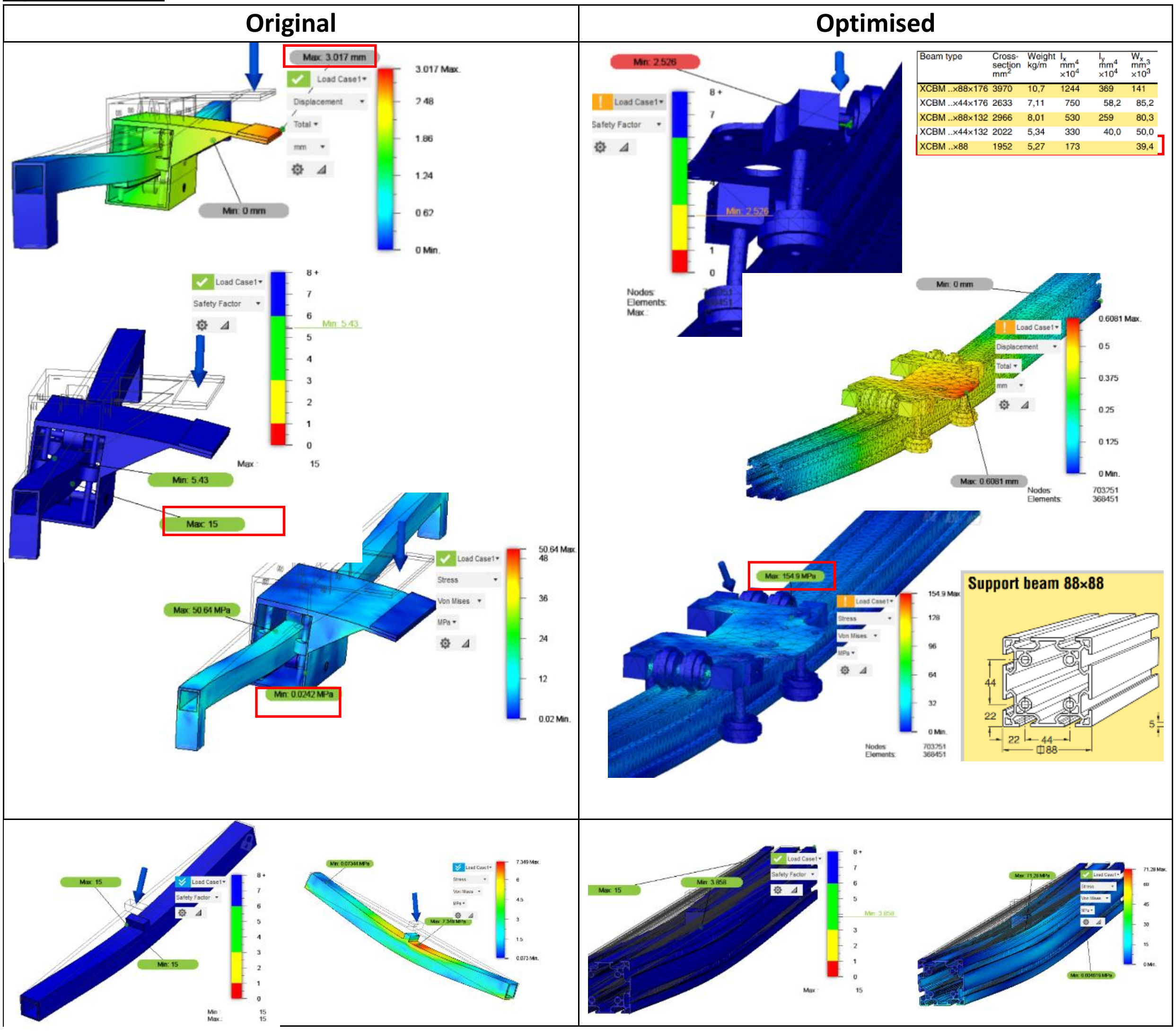


Figure 14: Displacement plot for the rails and carriage with 6061 aluminium and 170kg downward load

Table 4: Summary of design changes for the rail

Parameters:	Initial design	Optimised rail/carriage design
Geometry	80x64 mm hollow generic square beam	XCBM FlexLink 88x88 mm extruded profile
Material	Aluminium 6061	Aluminium 6061
Second moment of area	2.01×10^{-6} m^4	1.73×10^{-6} m^4
Volume	0.0115 m^3	0.0059 m^3
Mass of rail	31.2 kg	26.4 kg
Maximum Von Mises stress	50.6 MPa	154.9 MPa
FOS	5.43 carriage, 15+ rail	2.52 carriage, 3.86 rail
Max deflection	0.187 mm	0.608mm

A generic square hollow beam was initially used. The safety factor for the rails were found to be 5.43, nearly double the 2.5 target value. This shows that the beam size, 88 mm x 64 mm, with 8 mm thickness is more than adequate for the simulated load case. However, to save on material and cost, the thickness of beam was reduced. Then, to reduce weight, highly standardised and cost-effective aluminium extrusion profiles were created which led to a lower second moment of area. A good candidate identified was the 80 series lightweight aluminium support beam (88 × 88 mm) from FlexLink[3] which is available at max length of 5 m, roughly the same length required for one storey stairlifts. This means no rail connection will be required.

9. Systems integration

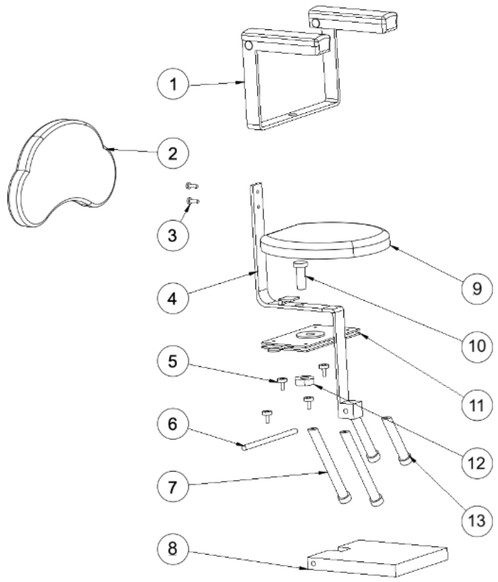


Figure 15: Exploded and labelled view of chair

Table 5: BOM for original chair design

No.	Description	Qty	Materials if applicable	Made/ bought out	Essential/ Non-essential
1	Chair standoff long	2	6061 aluminium	made	Essential
2	Chair standoff short	2	6061 aluminium	made	Essential
3	M28 nut	1	N/a	bought	Non
4	m28 bolt	1	N/a	bought	Non
5	Chair arm rest	1	6061 aluminium	made	Essential
6	Seat support	1	N/a	made	Non
7	Back rest	1	6061 aluminium	made	Essential
8	Backrest M6 bolt	2	N/a	bought	Non
9	Seat	1	N/a	bought	Essential
10	M28 bolt	1	N/a	bought	Non
11	Swivel module	1	N/a	bought	Essential
12	M28 nut	1	N/a	bought	Non
13	Chair standoff short	2	6061 aluminium	made	Essential

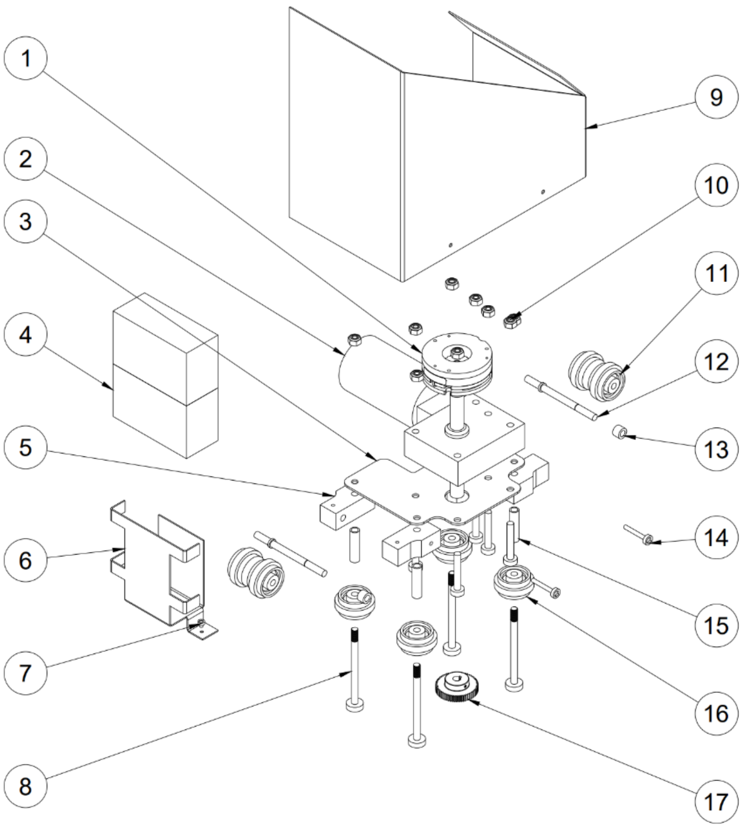


Figure 16: Exploded and labelled view of carriage

Table 6: BOM for original carriage design

No.	Description	Qty	Materials if applicable	Made/ bought out	Essential/ Non-essential
1	SMB130-00 spring brake	1	N/a	Bought	Non
2	PM63-100-GB12 motor and gearbox combo	1	N/a	Bought	Non
3	Steel plate	1	Stainless steel 304	Made	Essential
4	12V lead acid battery	2	N/a	Bought	Non
5	Wheel block	4	6061 aluminium alloy	Made	Essential
6	Battery holder	1	Stainless steel 304	Made	Essential
7	Battery holder M6x40mm bolts	2	N/a	Made	Essential
8	Horizontal roller bolts	4	N/a	Bought	Non
9	Sheet metal enclosure	1	Stainless steel 304	Made	Essential
10	M8 nylon locknuts	8	N/a	Bought	Non
11	FlexLink XCAW rollers (vertical)	4	N/a	Bought	Non
12	Motor axle with retainer ring	2	stainless steel 304	Made	Essential
13	Roller spacer	2	Nylon	Bought	Non
14	M6 enclosure bolts	2	N/a	Bought	Non
15	Vertical rollers spacers	4	N/a	Bought	Non
16	FlexLink XCAW rollers (horizontal)	4	N/a	Bought	Non
17	60T 60mm PD pinion gear	1	1045 carbon steel	Bought	Non

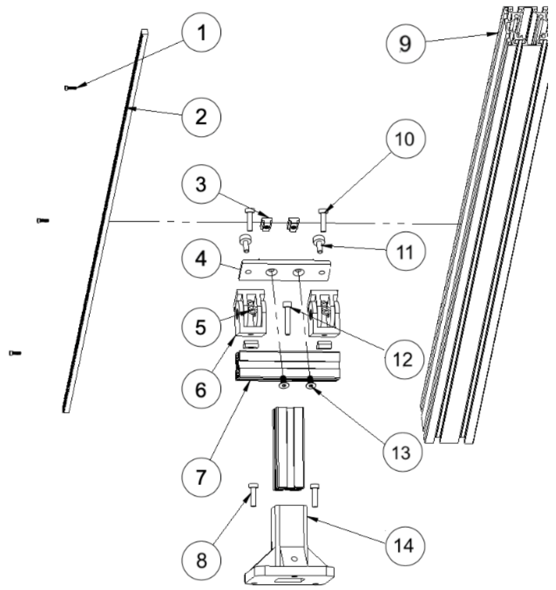


Figure 17: Exploded and labelled view of original rail support design, and pinion rack attachment

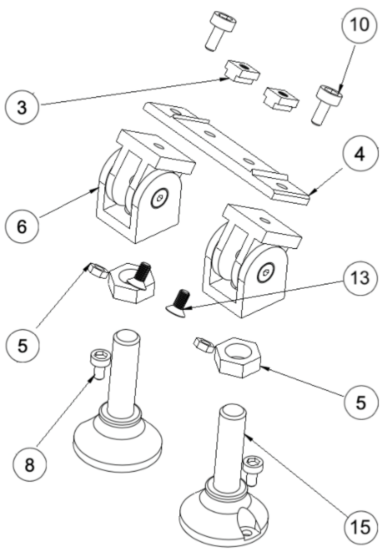


Figure 18: Exploded and labelled view of improved rail support design

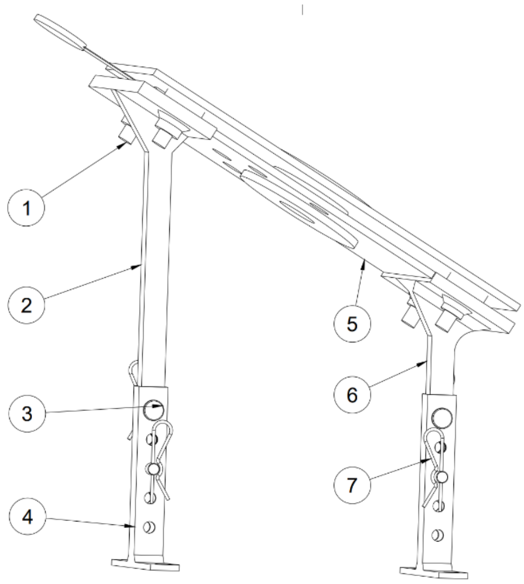


Figure 19: Exploded and labelled view of improved chair leg design

Table 7: BOM for rail support for figure 17 and 18

No.	Description	Qty	Materials if applicable	Made/ bought out	Essential/ Non-essential
1	M4 bolts for pinion rack	3	N/a	Bought	Non
2	McMaster-Carr pinion rack 2485N202, PH 8.8 mm	1	1045 Carbon steel	Bought	Essential
3	T slot nut, M8	4	N/a	Bought	Non
4	FlexLink XCFB 44X88 A mount plate	1	N/a	Bought	Essential
5	M6 nut	4	N/a	Bought	Non
6	FlexLink XCFJ 44 F adjustable bracket	4	N/a	Bought	Essential
7	FlexLink XCBM 44x44mmx164mm	2	N/a	Bought	Essential
8	M8x25mm support bolt	4	N/a	Bought	Non
9	FlexLink XCBM 5X88 Beam	1	N/a	Bought	Essential
10	M6x30 mm bolt	4	N/a	Bought	Non
11	M8x25 mm bolt	4	N/a	Bought	Non
12	M8x45 mm bolt	1	N/a	Bought	Non
13	M6x20 mm countersunk bolt	4	N/a	Bought	Non
14	FlexLink XCFF 44X130 Base Plate	1	N/a	Bought	Essential
15	FlexLink XLFS 20P adjustable feet	2	N/a	Bought	Essential

Table 8: BOM for improved chair leg design

No.	Description	Qty	Materials if applicable	Made/ bought out	Essential/ Non-essential
1	M8x30mm low profile bolt	4	N/a	Bought	Non
2	Long upper chair leg	1	304 Stainless steel	Made	Essential
3	Clevis pin 8mm diameter	4	Stainless steel 304	Bought	Essential
4	Lower chair leg	2	304 Stainless steel	Made	Essential
5	Swivel seat unit	1		Bought	Essential
6	Short upper chair leg	1	304 Stainless steel	Made	Essential
7	Spring cotter pin, 2mm diameter	4	N/a	Bought	Non

The main interface of the carriage shown in *Figure 16* is the steel plate. It connects the 4-wheel mounts, 8 rollers, gearbox, and the seat post. It is suitable as steel provides structural rigidity and allows all components to be bolted on for easy assembly.

The main interface of the chair is the swivel unit. 4 chair posts, and the seat is bolted into the unit.

The main interface for the rail support feet would be the FlexLink mount plate. The bracket and T nuts are both mounted onto the plate.

10. Lucas analysis of current design (chair structure)

The first Lucas analysis was conducted on the chair components. The original chair design contained some complex components and parts that could be difficult to manufacture; therefore, this analysis was used to highlight parts of structure that could be improved.

The following questions was asked for each part to assess its functionality to decide whether the part was essential or not:

- During operation of the product, will the part move relative to other parts assembled?
- Must the part be of a different material from all other parts already assembled? Or isolated from them?
- Must the part be separate from all those already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

To conclude, the Lucas analysis was applied only to the components what have been designed ourselves. And nuts, bolts, washers etc were considered as non-essential components.

Design Efficiency:

$$\boldsymbol{EI = \frac{A}{A+B} \times 100}$$

A (Essential)= 5

B (Non-essential) = 6

$$=\frac{\mathbf{5}}{\mathbf{5+6}} \times \mathbf{100} = \mathbf{45\%}$$

It was shown that the number of parts in group B needed to be decreased to improve the design efficiency.

Feeding ratio:

The feeding index values (A + B + C + D) were found and the results were summarised in *Table 9 which can be found in the appendix*

$$\text{Feeding ratio} = \frac{\sum Feeding\ index}{Number\ of\ parts\ in\ group\ A}$$

$$\frac{2.2\ +\ 2.2\ +\ 1.3\ +\ 1.8\ +\ 1.8\ + 1.5\ + 1.5\ 1.8\ +\ 1.8\ 2.7\ + 1.3\ + 1.8}{5} = 4.04$$

Summary:

The feeding index for each part was scored, the target index for each part was 1.5. Since the index for some of the parts was greater than 1.5, some of these parts had to be improved. The values highlighted have poor designs and those highlighted in red were considered for redesign. The feeding ratio was then calculated as 4.04, the target is to achieve a value of 2.5.

Fitting Ratio:

The fitting indexes were found for each part and the results have been summarised in *Table 10* which can be found in the appendix.

$$\text{Fitting ratio} = \frac{\sum Fitting\ index}{Number\ of\ Essential\ components}$$

$$\frac{2.1 + 2.1 + 2.7 + 2 + 2.1 + 2.8 + 2.8 + 2.1 + 3.2 + 2.7}{5} = 4.92$$

Summary:

A fitting index of 1.5 for each part is desired and the goal is to achieve a fitting ratio of 2.5. It is important to notice that fitting indexes usually have a greater variance than feeding ratios.

Manufacturing cost index:

The manufacturing cost index is based on all self-designed parts. See *Table 11* in the appendix for the results. The indexes that are highlighted in red are the parts of the model that will be redesigned since they have significantly high manufacturing cost indexes.

11. Lucas analysis of current design (carriage)

A Lucas analysis was also conducted for the carriage design. The original carriage design contained many components and parts that could be difficult to manufacture therefore, this analysis was used to highlight parts of structure that could be improved.

Design Efficiency:

$$\boldsymbol{EI = \frac{A}{A+B} \times 100}$$

A (Essential)= 8

B (Non-essential) = 10

$$= \boldsymbol{\frac{8}{8+10} \times 100 = 44.4\%}$$

Feeding ratio:
The feeding index values (A + B + C + D) were found and the results have been summarised in Table 12 which can be found in the appendix.

$$\text{Feeding ratio} = \frac{\sum Feeding\ index}{Number\ of\ part\ in\ group\ A}$$

$$\frac{1.5 + 1.5 + 1.5 + 1.3 + 1.8 + 1.6 + 1.7 + 1.2 + 1.5 + 1.5 + 1 + 1.8 + 1.7 + 1 + 1.2 + 1.2 + 1.7 + 1.2}{8}$$

$$= 3.22$$

Summary:
The feeding index for each part was scored, the target index for each part is 1.5. As the index for some of the parts is greater than 1.5, these parts will be considered for redesign. The values highlighted have poor values and those highlighted in red have been prioritised to be redesigned. The feeding ratio was then calculated, the target is to achieve a value of 2.5 which would require further redesigning of individual components to achieve.

Fitting index:
The fitting indexes were found for each part and the results have been summarised in *Table 13 and can be found in the appendix.*

$$\text{Fitting ratio} = \frac{\sum Feeding\ index}{Number\ of\ Essential\ components}$$

$$\frac{2.1 + 2.8 + 2.1 + 2.1 + 2.1 + 2.8 + 2.1 + 2.3 + 2.7 + 2.8 + 2.1 + 2.7 + 4.3 + 2.8 + 2.3 + 2.4 + 4.8 + 2.3}{9}$$

= 5.94

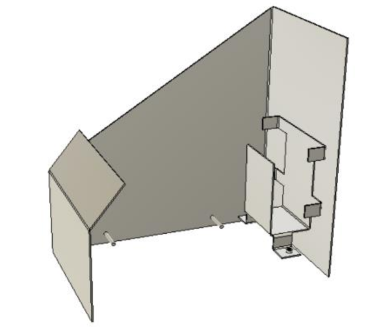
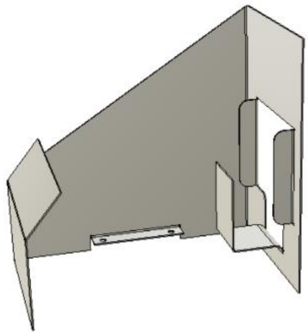
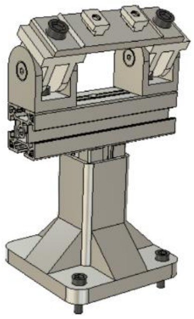
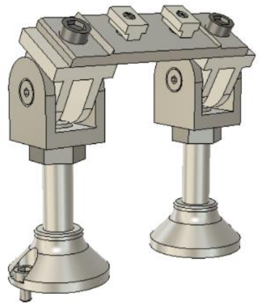
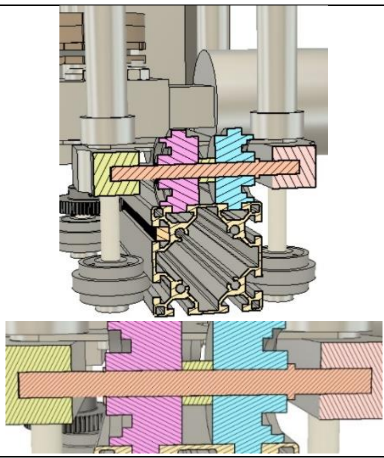
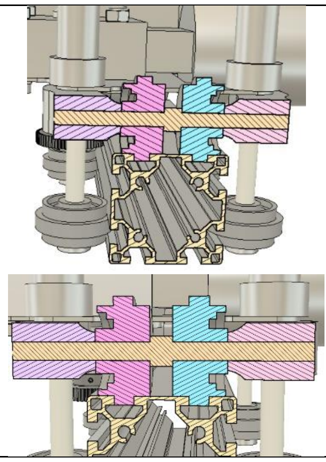
Summary:

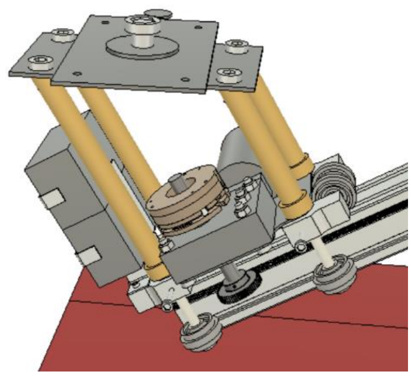
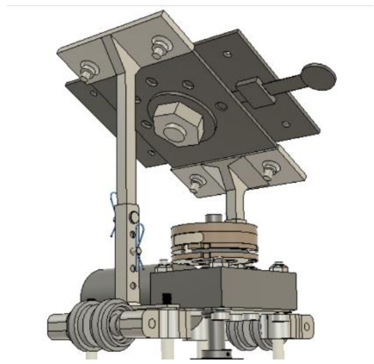
A fitting index of 1.5 for each part is desired and the goal is to achieve a fitting ratio of 2.5.

Manufacturing cost analysis:
The manufacturing cost index is based on all self-designed parts. See *Table 14 in the appendix* for the results.

12. Improvements of designs based on Lucas analysis results

Table 15: Improvements made to parts that were highlighted in the Lucas analysis

Part	Improvements made	Original design	Improved design
Sheet metal enclosure	• Combined 6 components into 1 • Similar manufacture difficulty (can still be made by sheet metal forming) • Bolted to carriage using existing bolts used for mounting gearbox to steel plate • Easier to align with less complicated parts		
Rail supporting feet	• 22 components reduced to 15 components • Easier installation, less awkward to reach areas. • The height can now be adjusted • Standardised the bolts used to one size		
Aluminium wheel block	• Reduced component count from 7 to 5 • Made assembly and alignment easier • Integrated spacer into shaft, removed retainer ring as it was too complex • Modified aluminium block to integrate spacer into the block		

Chair leg /Standoffs	• Changed from solid aluminium standoffs to hollow bolted steel structure • Despite increased component count from 4 to 8, the clevis pin and clip now allow height adjustment • Added side edges to align the holes during assembly. Standoff do not provide any locational references		

By altering the enclosure, a design with sufficiently less parts has been created. The enclosure has the same dimensions and can still be manufactured using sheet metal forming with the battery holder integrated within the structure. This has not impacted the function of the stairlift since the enclosure does not meet moving parts and there were no significant changes to the weight.

By choosing a different rail supporting feet meant that installation process would be easier as there are less components. The parts requiring bolts in the feet are also easier to reach. Also, the reliability has been improved by creating two supporting legs for each foot which distributes the loading more evenly which improves. Therefore, the performance of the stairlift will not be impacted as the new design can sufficiently support the load of the stairlift.

The shaft diameter increased from 10 mm to 12 mm as it had been identified from FEA that majority of the shear stress acted on the shaft, hence this change will increase lifespan and durability. By integrating the roller spacer into the shaft, it allows for easier alignment during assembly. The aluminium blocks were extended to act as spacers, so engineers can distinguish correct alignment when aligning the shaft with the block.

Adding the clevis pin and spring cotter pin to the standoff's design meant maintenance and height adjustment can be done easily without tools. To ensure the changes did not affect the function of the stair lift the materials was changed from aluminium to steel to ensure the new structure could sufficiently support the load.

13. Lucas analysis of revised design

Feeding index:
The feeding index values (A + B + C + D) were found and the results have been summarised in *Table 16* which can be found in the appendix

Fitting index:
The fitting indexes were found for each part and the results have been summarised in *Table 17* which can found in the appendix.

Manufacturing cost analysis:
The manufacturing cost index is based on all self-designed parts. The following values were found- See *Table 18 in the appendix* for the results.

Lucas analysis results comparison:

Category	Before (chair design)	After (chair design)	Percentage increase /decrease	Before (carriage design)	After (carriage design)	Percentage increase /decrease
Design efficiency	45.0	50.0	+11.1%	44.4	50.0	+12.6%
Feeding ratio	4.04	2.61	-35.4%	3.22	3.03	-5.9%
Fitting ratio	4.92	3.76	-23.6%	5.94	5.00	-15.8%
Manufacturing cost index (average)	916	360	-60.7%	919.5	302.5	-67.1%

Summary:

The number of essential parts for the chair increased to 6, therefore improving the design efficiency as desired. The improvement in the design for the standoffs then led to an improved feeding ratio, as their index decreased from 2.2 to 1.3 -- this is ideal as the target index was around 1.5. This led to a decrease in feeding ratio to 2.61, almost reaching the desired ratio of 2.5. Moreover, the feeding indexes decreased from 2.1 to 1.1 exceeding the target of 1.5. This redesign also impacted the fitting ratio, as it decreased to 3.76. Although not quite 2.5, it was a significant reduction from the previous result of 4.92, highlighting the success of the redesign. To further reduce this value, the use of non-essential parts could have been decreased further. The manufacturing costs was significantly reduced by removing waste material and improving the structural alignment; this led to successfully reducing costs by 60%.

The number of non-essential parts decreased for the carriage and therefore, reduced the design efficiency. The feeding ratio was reduced slightly to 3.03, this value is lower and close to 2.5 making it ideal. The fitting ratio was reduced to a value of 5, despite a successful decrease from the previous design of 5.94, there could have been a greater impact if less non-essential parts were used. The manufacturing costs were successfully reduced since the installation processes were improved and saves costs of up to 67%.

14. Stairlift initial design and revised design

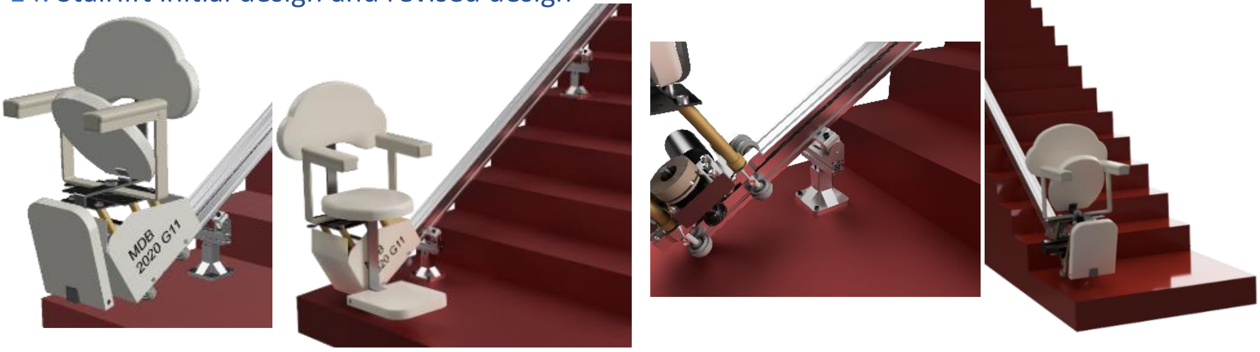


Figure 20: Original design renders

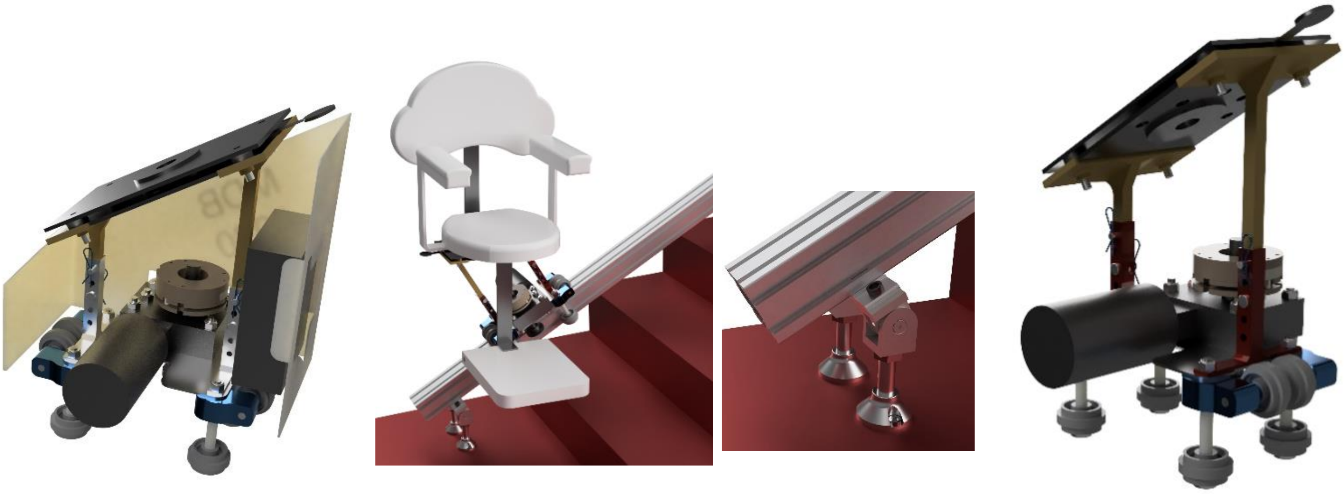


Figure 21: Revised design renders

15. Conclusion

The stairlift that has been created is unlike any other design that is currently available on the market. This design not only has exceptional user features, but is also lightweight, compact, easy to assemble and requires minimal components. Before displaying our final concept, each component in the design was thoroughly analysed, and any parts not meeting the standards were redesigned. Finite element analysis methods were used to create sustainable yet safe designs. For example, the footrest weight was significantly reduced by removing waste materials, whilst the FOS was enhanced to a safe value of 4.8. The Lucas analysis methods were also used to improve the design for manufacturing; this was shown for the chair and carriage assemblies. By doing so, the parts in each product have been minimised, the costs of production have been reduced, and any attachment methods have been simplified, whilst maintaining a high standard of quality.

16. References

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[4] British Standards Institution (2020). *BS EN 81-40:2020:* Safety rules for the construction and installation of lifts - Special lifts for the transport of persons and goods, Part 40, Available at: https://shop.bsigroup.com/ (Accessed: 21st December 2020).

17. Appendix

Table 9: Feeding Index Chair Parts

Part	A	B	C	D	A + B + C + D
Chair standoff long	**1.5**	**0**	**0.5**	**0.2**	**2.2**
Chair standoff short	**1.5**	**0**	**0.5**	**0.2**	**2.2**
M28 nut	**1**	**0**	**0.1**	**0.2**	**1.3**
m28 bolt	**1.5**	**0**	**0.1**	**0.2**	**1.8**
Chair arm rest	**1.5**	**0**	**0.1**	**0.2**	**1.8**
Seat support	**1.5**	**0**	**0**	**0**	**1.5**
Back rest	**1.5**	**0**	**0.1**	**0.2**	**1.8**
Backrest bolt	**1.5**	**0**	**0.1**	**0.2**	**1.8**
Chair hinge bolt	**1**	**0**	**0.1**	**0.2**	**1.3**
Standoff m10 bolt	**1.5**	**0**	**0.1**	**0.2**	**1.8**

Table 10: Fitting index for Chair component

Part	A	B	C	D	E	F	Fitting index
Chair standoff long	**2**	**0.1**	**0**	**0**	**0**	**0**	**2.1**
Chair standoff short	**2**	**0.1**	**0**	**0**	**0**	**0**	**2.1**
M28 nut	**2**	**0**	**0.7**	**0**	**0**	**0**	**2.7**
m28 bolt	**2**	**0**	**0**	**0**	**0**	**0**	**2**
Chair arm rest	**2**	**0.1**	**0**	**0**	**0**	**0**	**2.1**
Seat support	**2**	**0.1**	**0.7**	**0**	**0**	**0**	**2.8**
Back rest	**2**	**0.1**	**0.7**	**0**	**0**	**0**	**2.8**
Backrest bolt	**2**	**0.1**	**0**	**0**	**0**	**0**	**2.1**
Chair hinge bolt	**2**	**0**	**1.2**	**0**	**0**	**0**	**3.2**
Standoff M10 bolt	**2**	**0**	**0.7**	**0**	**0**	**0**	**2.7**

Table 11: Manufacturing cost indexes for the self-designed Chair parts

Part	Envelope type	Complexity CC	Limiting section CS	Basic processing cost/ Quantity Pc	Material suitability Cmp	Waste coefficient Wc	Tolerance Ct	Surface finish Cf	Material cost selection Cmt	Volume (mm³)	Manufacturing cost index
Chair standoff long	A1	1	1	38	1.5	1.1	3	2.4	0.00341	2.3E+5	916
Chair standoff short	A1	1	1	38	1.5	1.1	3	2.4	0.00341	2.3E+5	913
Chair arm rest	B5	2.6	1	38	1	1.4	2.5	2.6	0.00243	3.1E+6	10764
Seat support	C1	1	1	38	1.5	1.1	2.4	2.4	0.00341	3.2E+5	1254

Back rest	B4	1.8	1	38	1.5	1.3	2.5	2.6	0.00341	6.4E+6	28277

Table 12: Feeding Index for Carriage parts

Part	A	B	C	D	A + B + C + D
Rollers	1.5	0	0	0	1.5
Axle	1.5	0	0	0	1.5
Axle spacer	1.5	0	0	0	1.5
Axle retainer ring	1	0.3	0	0	1.3
Pinion gear	1.5	0.3	0	0	1.8
Spring brake	1.5	0	0.1	0	1.6
Gearbox shaft keyway	1.5	0	0.1	0.2	1.8
M10 nuts	1	0	0.1	0.2	1.3
Aluminium blocks	1.5	0	0	0	1.5
Battery holder	1.5	0	0	0	1.5
Battery	1	0	0	0	1
Steel plate	1.5	0.3	0	0	1.8
Motor and gearbox	1.5	0	0.1	0.2	1.8
Roller spacers	1	0	0	0	1
M10x130mm	1	0	0.1	0.2	1.3
M10x70mm	1	0	0.1	0.2	1.3
Enclosure	1.5	0	0.1	0.2	1.8
Enclosure m6 bolts	1	0	0.1	0.2	1.3

Table 13: Fitting Index for Carriage parts

Part	A	B	C	D	E	F	Fitting index
Rollers	2	0.1	0	0	0	0	2.1
Axle	2	0.1	0.7	0	0	0	2.8
Axle spacer	2	0.1	0	0	0	0	2.1
Axle retainer ring	2	0.1	0	0	0	0	2.1
Pinion gear	2	0.1	0	0	0	0	2.1
Spring brake	2	0.1	0.7	0	0	0	2.8
Gearbox shaft keyway	2	0.1	0	0	0	0	2.1
M10 nuts	1	0	0.1	0	1.2	0	2.3
Aluminium blocks	2	0	0.7	0	0	0	2.7
Battery holder	2	0.1	0.7	0	0	0	2.8
Battery	2	0.1	0	0	0	0	2.1
Steel plate	2	0	0.7	0	0	0	2.7
Motor and gearbox	2	1.6	0.7	0	0	0	4.3
Roller spacers	2	0.1	0.7	0	0	0	2.8
M10x130mm	1	0	0.1	0	1.2	0	2.3
M10x70mm	1	0	0.1	0	1.2	0	2.4
Enclosure	4	0.1	0.7	0	0	0	4.8
Enclosure M6 bolts	1	0	0.1	0	1.2	0	2.3

Table 14: Manufacturing cost indexes for each part of the carriage

Part	Envelope type	Complexity CC	Limiting section CS	Basic processing cost/ Quantity Pc	Material suitability Cmp	Waste coefficient Wc	Tolerance Ct	Surface finish Cf	Material cost selection Cmt	Volume (mm³)	Manufacturing cost index
Axle	A1	1	1	38	1	1.1	2.2	2.3	0.00243	1.12E+04	67
Aluminium blocks	B1	1.8	1	38	1	1.1	1.7	2.4	0.00243	8.36E+04	292

Battery holder	B2	1.2	1	38	1	1.1	1.9	2.4	0.00243	7.77E+04	253
Steel plate	C1	2.1	2	38	1.5	1.1	2.2	2.3	0.00341	1.03E+05	626
Enclosure	C2	2.3	2	38	1	1.2	1.9	4.6	0.00243	4.69E+05	1542

Table 16: Feeding Index for Redesigned Parts

Part	A	B	C	D	A+B+C+D
Enclosure	1.0	0	0.1	0.2	1.3
Rail feet	1.0	0	0	0.2	1.2
Aluminium block	1.0	0	0	0	1.0
Standoffs	1.0	0	0.1	0.2	1.3

Table 17: Fitting analysis for Redesigned Part

Part	A	B	C	D	E	F	A+B+C+D+E+F
Enclosure	1	0.1	0.7	0	0	0	1.8
Rail feet	1	0	0	0	0	0	1
Aluminium block	1	0	0	0	0	0	1
Standoff	1	0.1	0	0	0	0	1.1

Table 18: Manufacturing Cost Analysis for Redesigned Parts

Part	Envelope type	Complexity CC	Limiting section CS	Basic processing cost/ Quantity Pc	Material suitability Cmp	Waste coefficient Wc	Tolerance Ct	Surface finish Cf	Material cost selection Cmt	Volume (mm^3)	Manufacturing cost index
Enclosure	C2	2.3	1	38	1	1.2	1.5	2	0.00243	7.77E+04	313
Rail feet	A3	1.3	1	38	1	1.2	1.9	3	0.00243	8.49E+04	297
Aluminium block	B1	1.8	1	38	1	1.1	1.7	2.4	0.00243	8.36E+04	292
Standoffs	A1	1	1	38	1.5	1.1	3	2.4	0.00341	8.08E+04	360