B. TECH. PROJECT REPORT

On

Design and development of a single-seater stair climbing electric vehicle for persons with temporary/permanent disability

BY

Shubham Gondey

DISCIPLINE OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Design and development of a single-seater stair climbing electric vehicle for persons with temporary/permanent disability

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of
BACHELOR OF TECHNOLOGY
in

MECHANICAL ENGINEERING

Submitted by:
Shubham Gondey (1200333)

Guided by:
Dr. Shanmugam Dhinakaran, Associate Professor

INDIAN INSTITUTE OF TECHNOLOGY INDORE
November 2016

CANDIDATE’S DECLARATION

We hereby declare that the project entitled **“Design and development of a single-seater stair climbing electric vehicle for persons with temporary/permanent disability”** submittedin partial fulfillment for the award of the degree of Bachelor of Technology in ‘Mechanical Engineering’ completed under the supervision of **Dr. Shanmugam Dhinakarn, Associate Professor, Mechanical Engineering,** IIT Indore is an authentic work.

Further, I/we declare that I/we have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student(s) with date

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Signature of BTP Guide(s) with dates and their designation

Preface

This report on "**Design and development of a single-seater stair climbing electric vehicle for persons with temporary/permanent disability**" is prepared under the guidance of **Dr. Shanmugam Dhinakaran**.

Through this report I have tried to give a detailed design of a stair climbing vehicle and try to cover every aspect of the design, if the design is technically and economically sound and feasible.

We have tried to the best of our abilities and knowledge to explain the content in a lucid manner with the help of CATIA. We have also added 3-D models and figures to make it more illustrative.

Shubham Gondey
B.Tech. IV Year
Discipline of Mechanical Engineering
IIT Indore

Acknowledgements

I wish to thank **Dr. Shanmugam Dhinakaran** for his kind support and valuable guidance.

In addition, I would also like to acknowledge **Kailash Patel** for his sincere support.

It is theirhelp and support, due to which I became able to complete the design and technical report.

Without their help, support and valuable insight from time to time, the completion of the project could not have been possible.

Shubham Gondey
B.Tech IV Year
Discipline of Mechanical Engineering
IIT Indore

Abstract

First wheelchair model evolved long back in 18th century, but rapid development in this field has initiated since mid of 20th century due to the increase in number of elderly and disabled people. The work has been paid more attention since then and focuses on making the life of these people easier. This project involves the design of an ergonomic electric stair climbing wheelchair which can be used for domestic use. It can help physically disabled people to move more flexibly and comfortably. The stair climbing functionality is embedded in the design through its structure and mechanism. The walking mechanism is designed in this paper, along with the theoretical design and calculations which was used to decide the structure and dimension. The product mainly consists of 3 modules viz. seat, links and frame. Anthropometric measures are considered in the dimensioning of seat. The frame and wheels are designed and developed through the equations generated from the statistical data of dimensions of staircases in our institute. The design is validated by developing Digital Mockups of individual parts are generated in CATIA and are assembled to form the final product. Stress analysis for different materials of the frame was carried out in CATIA in order to realize optimal selection for the material. Finally, images are made to show how the wheelchair works in different situations.

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1. Introduction

A motorized wheelchair or electric-powered wheelchair is a wheelchair that is propelled by means of an electric motor rather than manual power. Motorized wheelchairs are useful for those who are not able to impel a manual wheelchair or who may need to employ a wheelchair for distances or over terrain which would be strenuous in a manual wheelchair. They may also be used not just by people with conventional mobility impairments, but also by people with cardiovascular and fatigue based conditions. Electric wheelchairs have enhanced the quality of life for many people with physical disabilities through the mobility they afford. The selection of power chair will rely on many factors; including the kind of surface setting the chair will be driven over, the need to settle thresholds and curbs, and clearance widths in accustomed environment. The most fundamental job of the chair is to take input from the user, usually in the form of a small joystick, and decipher that motion into power to the wheels to move the person in the preferred direction. The last few years have seen abundant improvements and models that give the user unmatched control of the wheelchair in terms of both user effort and vehicle aptitude.

1.1. Problem Statement

A single seater stair climbing electric vehicle designed for physically challenged person.

1.2. Objective of Work

The objective of this project is to analyse and prototype a motorized wheelchair based on extensive fact findings and research on existing models, technology used, market scenario and customer requirements. The course of our work begins with the planning phase involving initial research, literature review and background study. It is followed by concept generation phase that includes evaluating customer requirements, outlining specifications and generating concept designs. Next comes the system level design in which product architecture is defined and parts are modelled in CATIA. The fourth phase is detailed design phase where we focus on design for assembly and manufacturing and simulation in virtual environment. In the final phase, we progress towards prototyping and testing a feasible model.

2. Literature Review

The research and analysis of motorized wheelchairs dates back in time with several scientists and researchers evaluating the stair climbing mechanism. Ghani et. al. [1] investigate the control of a stair climbing wheelchair used for indoor purposes. This paper evaluates different stair climbing mechanisms viz crawler type, leg type, hybrid type and wheeled type. The model of a stair climbing wheelchair based on two wheels is generated using MSC Visual Nastran 4D (VN) design software. The humanoid model is developed using requisite anthropometric data. Various forces and torques acting on the wheelchair while climbing the stairs are evaluated. Preferably, the outer support assembly comprises wheels on either side of the chair. An inner support assembly, closer to the centreline of the chair, also supports the seat assembly. Franco et. al. [2] did work related to development of a stair climbing wheelchair that can move in structured and unstructured environments, climbing over obstacles and going up and down stairs. The wheelchair design is vividly elaborated. The wheelchair consists of a frame, seat and a linkage mechanism connecting the same. The frame consists of a chassis embedded with two motorized locomotion units, a support for two electrical gear-motors, two idle triple wheels units and a battery pack. The seat is a tubular structure that consists of a chair and a pivoting wheel. The linkage mechanism is responsible for relative motion between frame and seat during stair climbing operation. To successfully climb the stairs, it is required to move the seat backwards, then reorient it and finally lift up the pivoting wheel. When the seat is moved backwards, the centre of mass of the wheelchair shifts to a safe position, and toppling is thus prevented. A four bar linkage is appointed for the same. The linkage mechanism is actuated by a mini-motor connected to a lead screw device. When the seat reaches the desired position the motor is turned off and no extra energy is required to maintain the position. The customer requirements were studied and evaluated after referring them from the DLF (Disabled Living Foundation) factsheet. The factsheet aptly outlines what the user needs, wheelchair features, preliminary considerations before buying a wheelchair, wheelchair controls, how to negotiate curbs, specifications of batteries and chargers, special features of motorized wheelchairs, accessories of different types of wheelchairs as well as about insurance and customer requirements. Murray, [3] has elaborated the background as well as recent developments in mobility assistive mechanisms while discussing the relative importance of stairs and wheels. These various types include mobility scooters, track based stair climbers, clustered wheel concept and caterpillar wheel based devices. A mechanism is proposed which is based on the use of four wheels. The rear wheels are autonomously driven and front wheels are freewheeling castors. This proposed concept is numerically modelled and power calculations for linear actuator are made. Stair ascent and stair descent operations are described along with figures and equations. The control system and the stair edge sensor system are also investigated. The stepping algorithm is discussed in detail. The influence of external factors like cost, weight, aesthetics, range of operation, safety, operational efficiency, comfort are evaluated. The track based stair climber is also analysed similarly. Lockton [4] discusses the retro fitting of electric power into manual wheelchairs. The existing products and configurations are reviewed in a comparative table. Various product specifications are categorized and briefly described. These include control devices, drives, steering and position. Various configurations viz Twin-wheeled drive, rear-mounted, with differential steering, Single-wheeled drive, rear-mounted, with steering ahead of the wheel, single-wheeled drive, rear-mounted, with steering above the wheel, Single-wheeled drive, rear-mounted, with nutation steering and Single-wheeled drive, front-mounted, with handlebar/articulated steering are evaluated. The motors, mechanics, control technology and usability are investigated for the above mentioned combinations. Peizeret. al. [6] have investigated and summarized the evolution of wheelchairs over five years. Anthropometric parameters required to be considered for the design of seat ergonomically, a book on Indian anthropometric dimensions by Prof. D.K Chakraborty is referred. Necessary measurements and data have been collected from Indian Anthropometric Design.

3. Methodology

3.1.Market Study

The methodology for this project began with market study of the product under consideration. This involved extensive evaluation of the various types of wheelchairs available in the market and a precise overview of the Indian market scenario.

3.1.1. Electric Wheelchair

It's a wheelchair powered by motors which uses battery for power, user does not require efforts like he may require in standard type wheelchair. An electric-powered wheelchair is a wheelchair that is moved via the means of an electric motor and navigational controls which is usually a small joystick mounted on the armrest, rather than manual power. A power-assisted wheelchair is a recent development that uses the frame & seating of a typical manual chair while replacing the standard rear wheels with wheels that have small battery-powered motors in the hubs. This results in the convenience, small size & light-weight of a manual chair while providing motorised assistance for rough/uneven terrain & steep slopes that would otherwise be difficult or impossible to navigate, especially by those with limited upper-body function

Fig 1. Electric Wheelchair

3.1.2. All Terrain Wheelchair

It allow users to enter the water and provide a better mobility on beach sand and on uneven terrain, and even snow. The common adaptation among the different designs is that they have extra-wide wheels or tires, to increase stability on uneven or unsteady terrain. The wide tires on snow wheelchairs, for example, spread the weight of the chair user and the chair over a wider surface, similar to how snowshoes perform the same purpose for someone on foot, allowing the person to travel on top of the snow rather than sinking. Different models are available, both manual and battery-driven. In many countries in Europe, where accessible tourism is well established, many beaches are wheelchair accessible.

Fig 2. All Terrain Wheelchair

3.1.3. Smart Wheelchair

A smart wheelchair is any motorized platform with a chair designed to assist a user with a physical disability, where an artificial control system augments or replaces user control. Its purpose is to reduce or eliminate the user's task of driving a motorized wheelchair. Usually, a smart wheelchair is controlled by a computer, has a suite of sensors and applies techniques in mobile robotics, but this is not necessary. This is different from a conventional motorized or electric wheelchair, in which the user exerts manual control over motor speed and direction via a joystick or other switch- or potentiometer-based device, without intervention by the wheelchair's control system. Smart wheelchairs are designed for a variety of user types. Some platforms are designed for users with cognitive impairments, such as dementia, where these typically apply collision-avoidance techniques to ensure that users do not accidentally select a drive command that results in a collision. Such platforms typically employ techniques from artificial intelligence, such as path-planning.

Fig 3. Smart Wheelchair

3.1.4. Transportable Wheelchair

This type of power wheelchair can be easily conveyed by virtue of its light weight and thus it can be disassembled fast and hassle free. Because of its compact size, it is apt for slender doorways and halls. One of the models is shown in figure

Fig 4. Transportable Wheelchair

3.2.Indian Market Analysis

- Overview

Approximately 20 million people in our country suffer from various disabilities. About 11 million of them are locomotors disabled. The pervasiveness of locomotive debility is uppermost in India–at 1,046 per 100,000 people in the rural areas and 901 per 100,000 people in the urban populace. Low literacy, unemployment and widespread social stigma are the causes of such disturbing figures. The best way to empower the masses to deal with disabilities is through organizing awareness programs and conveying employable assistances. Government agencies and NGO's are working in the direction of advanced policy and frameworks for the incapacitated. India's wheelchair market is a nascent market with double digit growth rate. The market is broadly classified into unorganized and organized segments as shown in table 3.1.

Unorganised Segment		Organised Segment		
Domestic Manufacturers	Wholesalers	Indian Manufacturers E.g. Vissco, Janak, Sage and others	Indian distributers of foreign companies E.g. Vin Grace	Subsidiaries of foreign companies importing and selling in india E.g. Otto bock, Karma healthcare
It is estimated that about 80-100 player sells 100-150 wheelchairs in a year	They are based in wholesale markets and are involved in importing wheelchairs from China			

Table 3.1: Classification of Wheelchair market in India

- Domestic Players and Market share

The domestic players belong to the unorganized segment. It comprises of domestic manufacturers, who are assessed to be about 80-100 players selling 100-150 wheel chairs in a year and unorganized segment players usually accommodate demands of indigenous and provincial markets. The market for wheelchairs in projected to be 120,000 units worth US $ 15 million, emergent at a rate of 10% over the past 3 years. The organized market is worth $ 6 million, budding at a rate of 10% annually. The key to usability of wheelchairs in India is customization. However there are only a few companies who offer to do customization in our country.

- Future Projections

  Forthcoming demand of manual wheelchairs in organized segment is expected to reach a CAGR of 10% to reach $ 5 million in 2018 and that of motorized wheelchairs in is expected to register a CAGR of 5% to reach Euro 4 million in 2018.

- Roadblocks

  Access is the biggest obstruction for wheelchair users. Despite of the growing market of wheelchairs, utility for users still remains an issue. Healthcare entree for disabled is the principal trial in the India. Presently, in India, buildings, toilets, hospitals and other places are not locomotors disabled person friendly. Unpaved, poorly maintained sidewalks that are crowded by vendors are common across Indian cities which impede the movement of people bound to wheelchairs. However the scenario is rapidly altering e.g. some malls have taken initiative by constructing washrooms which are suitable for disabled masses.

3.3.Customer Requirements

- *A stable seating base*

  The convention says the seat should have a level base and be wide enough to house outdoor clothing if required. However it must not be so wide that the user is obligated to sit asymmetrically for support. Narrow seats cause discomfort and risk causing pressure sores. Poor sitting balance causes postural asymmetry or disparity in muscle tone, requiring a supportive seat unit with trunk and pelvic supports.

- *A vehicle that is easy to manoeuvre*

  A few wheelchairs are designed primarily for indoor use and have a tendency to be smaller and more manoeuvrable. We have to make sure that the wheelchair can

  - go through doorways and over thresholds
  - manoeuvre on floor planes
  - make constricted turns from hallways into living rooms

  - move backwards on requirement, e.g. reversing out of the toilet
  - go down shop aisles

The powered wheelchair does not adjust instantly to a variation in direction because the castors need a split second to twirl round. Vehicles intended virtuously for outdoor use typically have very wide turning circles and wide plodded tires for easier movement over uneven as well as lenient ground.

- *A stable vehicle*

All power-driven vehicles are stable on even ground. A user with a lower limb confiscation, particularly a high level or double amputation, should be cautious while choosing a wheelchair because the deficiency of weight at the front may distress the centre of gravity and could root the vehicle to tip backwards mainly when climbing kerbs. Stability can also reduce if the backrest of the wheelchair is reclined or is tilted backwards (tilt-in-space).

- *Freedom of travel*

Motorized vehicles permit the user to navigate long distances without too much individual effort. Even though many wheelchairs have a decent distance per battery ratio, to travel these distances more time is essential. It might take a minimum of four hours to cover 25km in a pavement-only vehicle.

- *A vehicle that is easy to transport*

Transport of a wheelchair requires flexibility, strength and standing/walking stability. Majority of motorized wheelchairs have a collapsible frame that can be pleated once the batteries have been detached. A few wheelchairs also contain separable motors. The frame might not fold down as efficiently as the frame of a manual wheelchair and will be bulkier to lift. If the backrest of the wheelchair folds down, they can be carried into the back of a car through ramps.

- *A vehicle that meets the Assistant's needs*

For easy handling by the assistant, controls are positioned on the right or left pushing handle of the wheelchair. Dual controls not only empower users to be autonomous when required, but also enable someone else to help when the need ascends. In order for the assistant to undertake routine upkeep, such as pumping up tyres and putting the wheelchair on charge, and dismantling and assembling the wheelchair then he/she must be convoluted in the choice of the vehicle to ensure that the essential tasks are manageable.

3.4.Concept Development

Different mechanisms had been studied and researched upon, depending on different power drives and transmission mechanisms, such as mid-wheel powered, front wheel powered, track mechanism, clustered wheel concept and caterpillar wheel concept. Following different concepts had been generated.

3.4.1. <u>Concept of cluster wheel</u>

Features-

- stair climbing ability
- Suitable to almost all stairs
- Compact
- Operate as general purpose powered wheelchair
- Lightweight

Drawbacks-

- Requires assistance if not motorised
- Orbital stair climbing operation may be uncomfortable for passengers

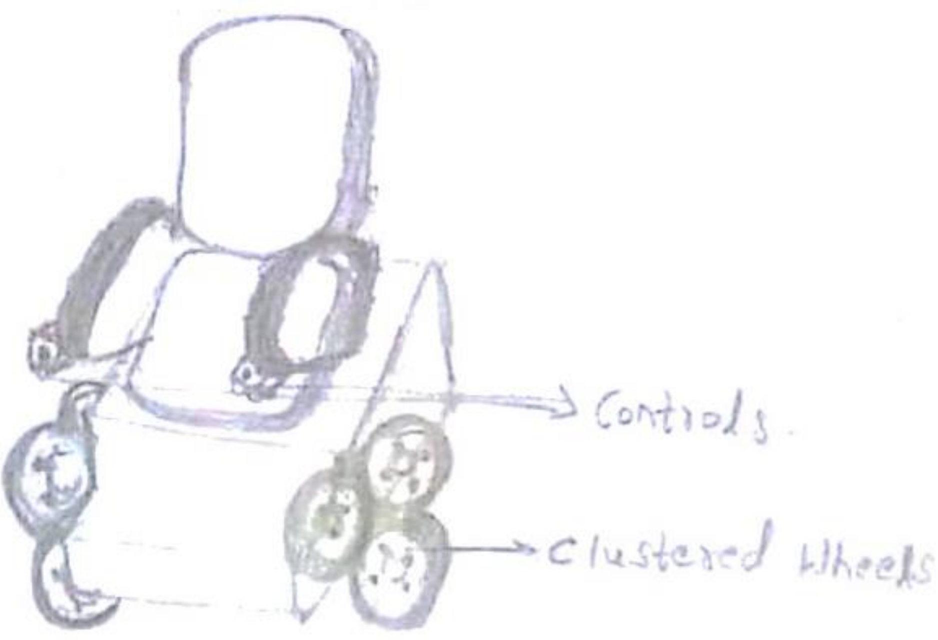


Fig 5. Cluster Wheels

3.4.2. Concept of crawler mechanism

This electric stairs-climbing wheelchair is a crawler belt walking mechanism and a crawler belt driving mechanism are equipped on a vehicle frame among front wheels and rear wheels. A seat balancing mechanism is hinged to a seat support. The rear wheel elevating mechanism is hinged to the vehicle frame. A storage battery assembly is connected with a crawler belt walking motor, a seat balancing motor and a rear wheel elevating motor through a control mechanism. The power output ends of the three motors are respectively connected with the crawler belt walking mechanism, the seat balancing mechanism and the rear wheel elevating mechanism through a respective transmission mechanism.

At present stair-climbing wheelchair with tracked mechanism has been widely used and compare with the planetary wheel mechanism tracked mechanism uses more continuous motion and has high transmission efficiency. The movement of the gravity centre of the tracked mechanism wheelchair is always along with a line which is parallel with the connection line of each stair edge when the wheelchair goes up and down stairs, and the wheelchair moves very smoothly.

The biggest weakness is that it has great resistance when it is moving on the ground, and inflexible high pressure will be exerted on the edge of the stairs when tracked mechanism goes up and down stairs, so the stairs are easily damaged by the wheelchair

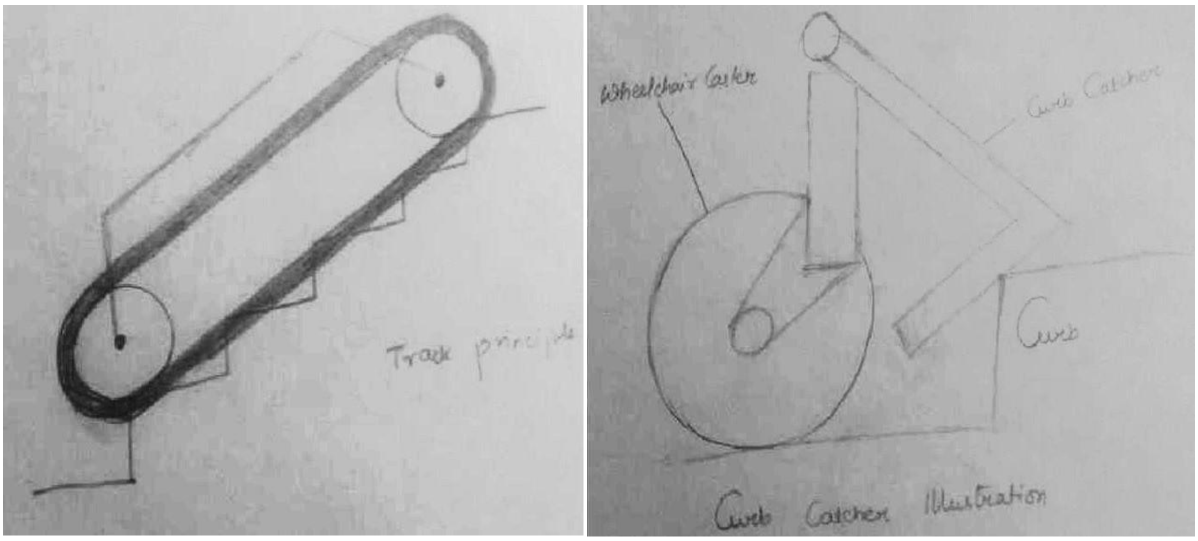


Fig 6. Track Mechanism

3.4.3. Concept of iBOT

The iBOT has a number of features distinguishing it from most powered wheelchairs:

- By rotating its two sets of powered wheels about each other, the iBOT can "walk" up and down stairs, like a cog railway or a rack and pinion with the two wheels as the "teeth" of the gear.
- Custom software receives data via various sensors and gyroscopes, allowing the iBOT to maintain balance during certain manoeuvres. For example, during curb climbing the seat remains level while parts of the chassis tilt to climb the curb.
- It allows the user to rise from a sitting level to approximately 6' tall, measured from the ground to the top of the head, and depending on the size of the occupant. It does this by raising one pair of wheels above the other to elevate the chassis, while a separate actuator raises the seat slightly more than usual. In this configuration the device is on two wheels, the gyroscope with the help of software maintain the wheelchair at equilibrium position and it also allows the user to travel in the standing position.

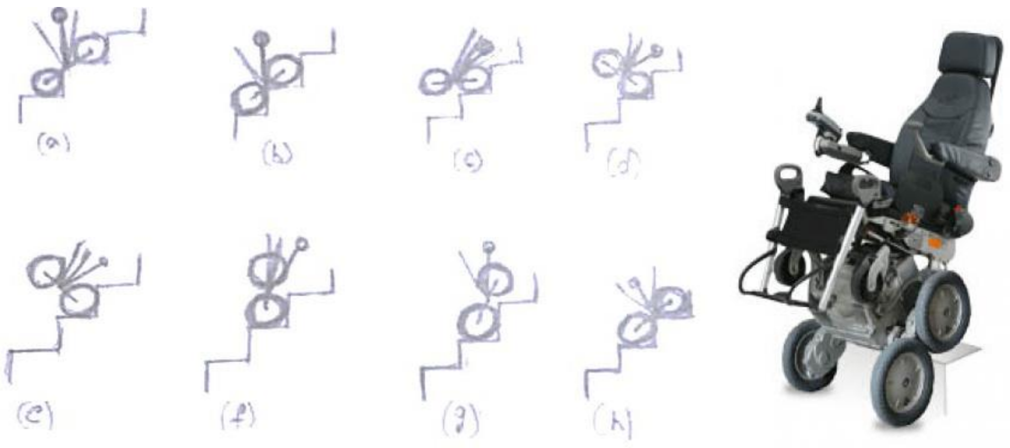


Fig 7. Concept of iBOT

3.4.4. Concept of Cluster wheel using Epicyclic gear train

The wheel mechanism is constituted by several small wheels that are equally distributed on a tie bar with shapes like "Y" or "+". The small wheels can revolve on its axis, and it can also make a revolution around the central shaft. Every small wheel revolves on its own axis, when the wheelchair moves on the ground and every small wheel revolves round the central axis, when the wheelchair goes up or down stairs. This type of stair-climbing wheelchair can fulfil overloading and move smoothly but has low automation.

Advantages of using this Mechanism over other mechanism

- Planetary Stair-Climbing wheelchair are light weight compared to tracked wheelchair and also protects the stairs.
- Automation rate rises greatly compared to the leg stair climbing wheelchair and stability increased.

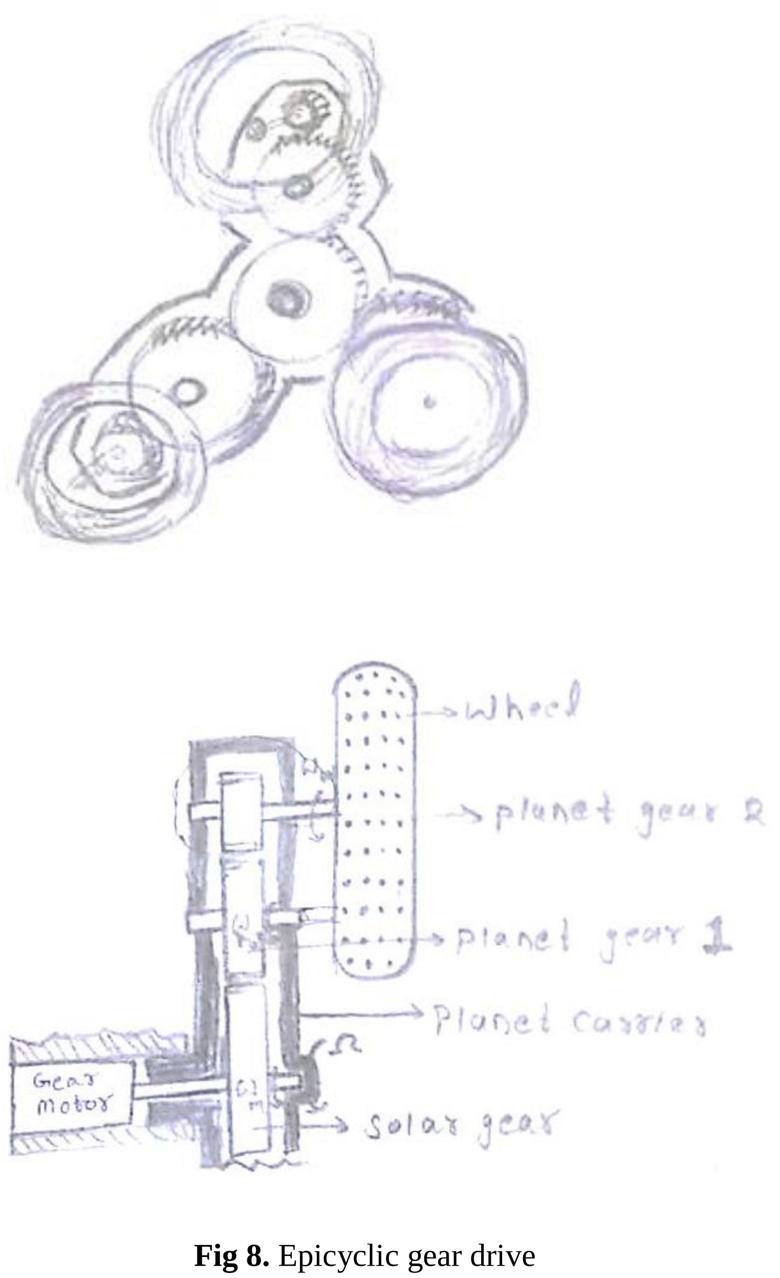


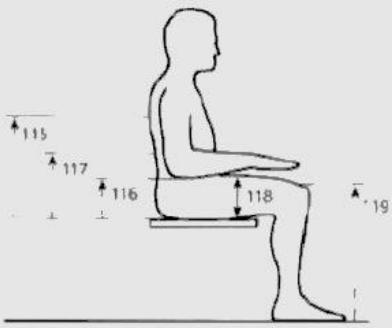
Fig 8. Epicyclic gear drive

3.5. System Level Design

3.5.1. <u>Seat</u>

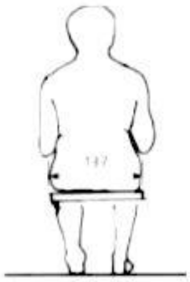
The seat is a tubular structure carrying a chair and a pivoting wheel. The seat consists essentially of two tubular structures, connected by means of crossbars, a chair support and a pipe that ends with a pivoting wheel. Connection points, in tubular structure, are hinges for the linkage mechanism. The seat can move relative to the frame: during stair climbing operations in fact the wheelchair is moved backwards and reoriented

The seat is designed ergonomically, considering all the required anthropometric measurements. Parameters considered along with their measures are as shown below



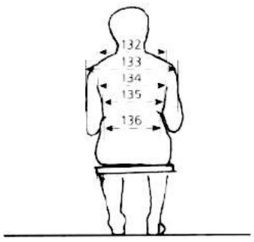
R.No.	Parameters	Definition (brief)
115	**Tip of shoulder blade**	Lower tip of the shoulder blade (scapula).
116	**Elbow rest**	Lower most part of the elbow.
117	**Waist**	Upper margin of the lateral iliac crests (where the belt is worn).
118	**Mid thigh**	Top of the middle thigh.
		Heights from floor
119	**Knee**	Uppermost point on the knee (at lower thigh).

Fig 9. Anthropometric Measurements



137	**Hip breadth**	Maximum horizontal distance across the hips

Fig 10. Anthropometric Measurements



R.No.	**Parameters**	Definition (brief)
		Breadths
132	**Bi-acromion**	Maximum horizontal distance across the shoulders, breadth measured between the most lateral points on the superior surfaces of the acromion processes of the scapula.
133	**Bi-deltoid**	Maximum horizontal distance across the shoulders, breadth measured to the protrusions of the deltoid muscles.

Fig 11. Anthropometric Measurements

The CATIA model of the chair is as follows. Here lumber lordosis of spinal column of humans is also considered as shown in the design below.

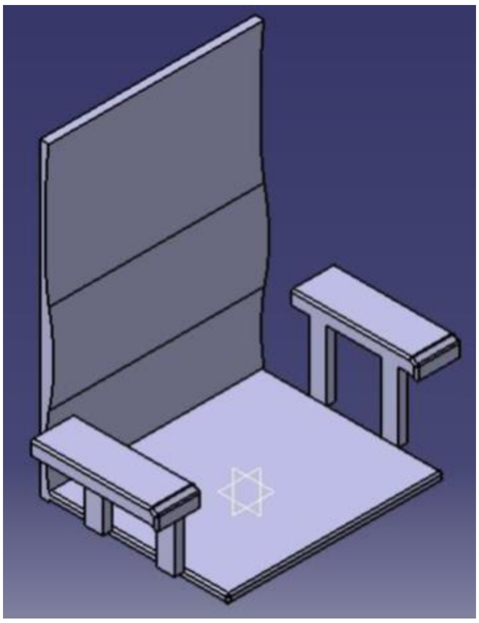


Fig 12. CATIA model of Seat

3.5.2. Staircase

Stairs Dimension of our Institute

Rise of stairs (h) = 14 cm

Run of stairs (b) = 29 cm

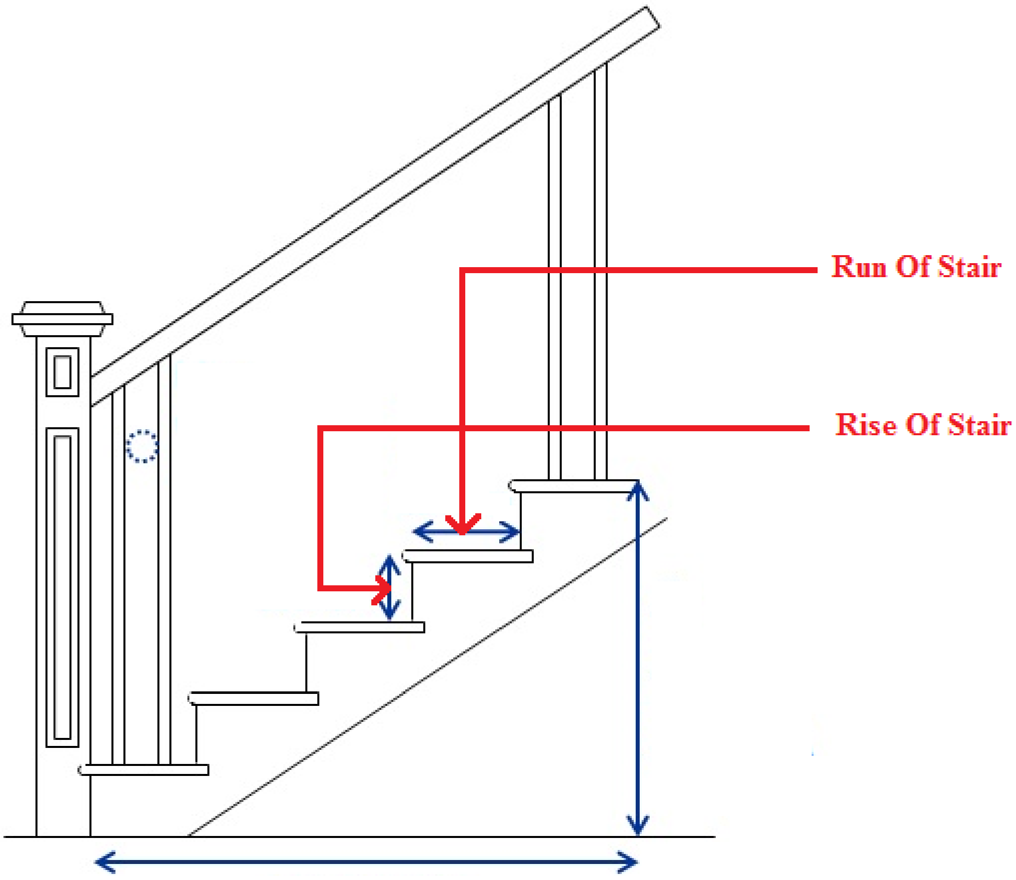
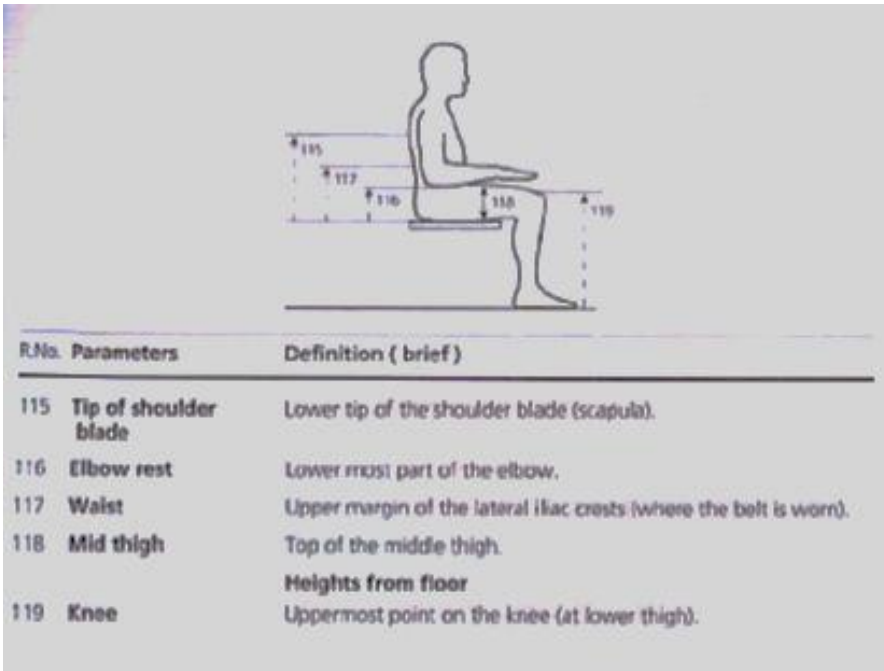


Fig 13. Staircase of Institute

3.5.3. Frame

The frame consists of a chassis that carries two motorized locomotion units, a support for two electrical gear-motors, two idle triple wheels units and a battery pack. The chassis consists mainly of two tubular structures, connected by means of crossbars; two triangular tubular structures on the front support the triple wheel units. Connection points are hinges for the linkage mechanism. The triple wheel units consist of a spider, rotating around a central axis, with three idle wheels placed at its vertices. Wheel size was chosen on the basis of the consideration that large wheels can better absorb vibrations caused by uneven terrain, while small wheels reduce overall dimensions. Accordingly, larger wheels were selected for the locomotion unit and for the pivoting wheel, which are in contact with the ground most of the time, while smaller ones were chosen for the triple wheel units, in contact with the terrain only during the stair climbing operation.

The dimensions of the frame are calculated according to the space constraints. These space constraints are obtained from height of base of seat from ground and dimensions of chair. Seat height is based upon the anthropometric measurements of the parameter ‘Knee height’. According to the Indian anthropometric measurements, 95th percentile of knee height in sitting posture is 55 cm. Assuming 15 cm as clearance, a total of 70 cm of gap is considered. Therefore, frame dimensions are decided upon the space constraints of 48x63x70 cm.



R.No.	Parameters	Definition (brief)
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116	Elbow rest	Lower most part of the elbow.
117	Waist	Upper margin of the lateral iliac crests (where the belt is worn).
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		Heights from floor
119	Knee	Uppermost point on the knee (at lower thigh).

Fig 14. Anthropometric Measurements

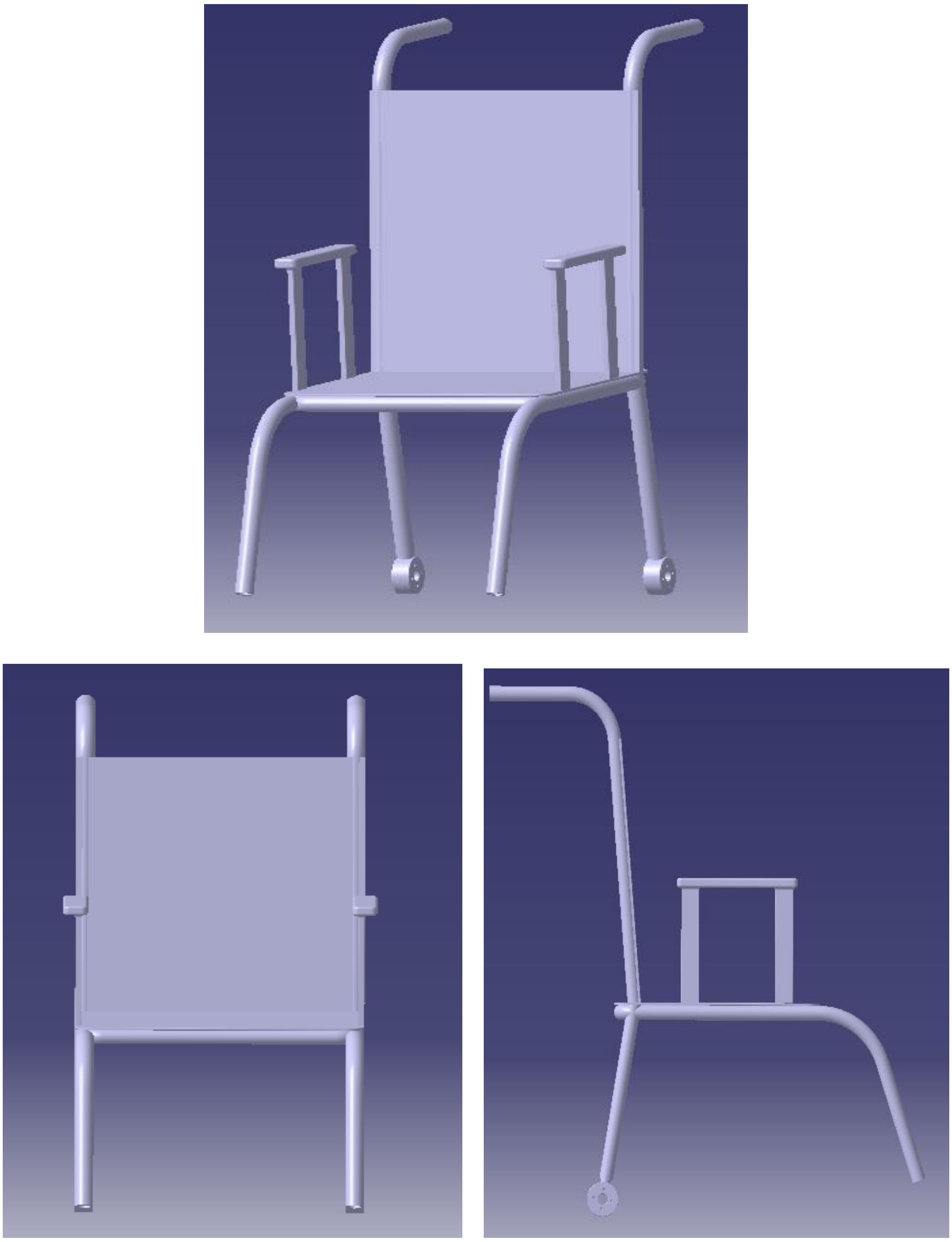

Fig 15. CATIA model of Frame

3.5.4. <u>Gear Motor</u>

A gear motor is used as locomotion unit and this motion is transmitted to the clustered wheels. This motor is mounted on a support provided by the frame as shown. The dimensions and specifications of gear motor are obtained from standard motors available. A gear motor of 750 watt power and 1:64 reduction gear ratio can be used. It is as shown below.

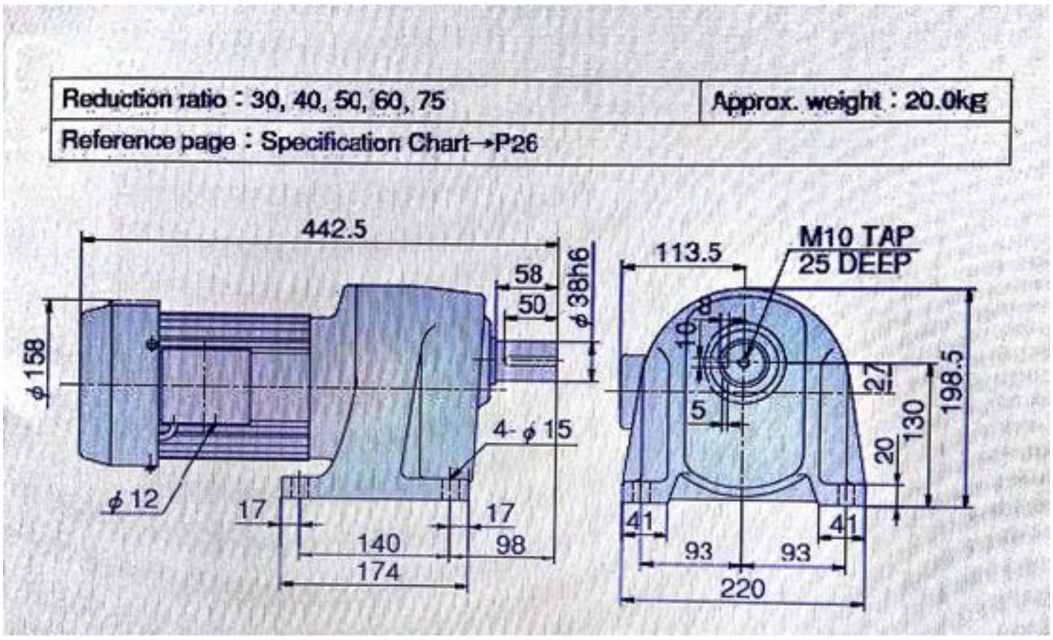

Fig 16. Gear Motor

3.5.5. Wheels

Here a clustered wheel concept is being developed in order to accommodate stair climbing feature. Three wheels are arranged in a triangular array, such that centres of each of the wheels coincide with vertices of an equilateral triangle. Now the side of an equilateral triangle and radius of the wheel are calculated using certain equations, which are described below. These are taken from ergonomic standards. As the wheelchair being designed is intended for domestic use, steps would rather be even and so their heights and depths are approximately taken as 140mm and 290mm respectively. Also the evenness of these stairs led to the equilateral configuration of wheel arrangement

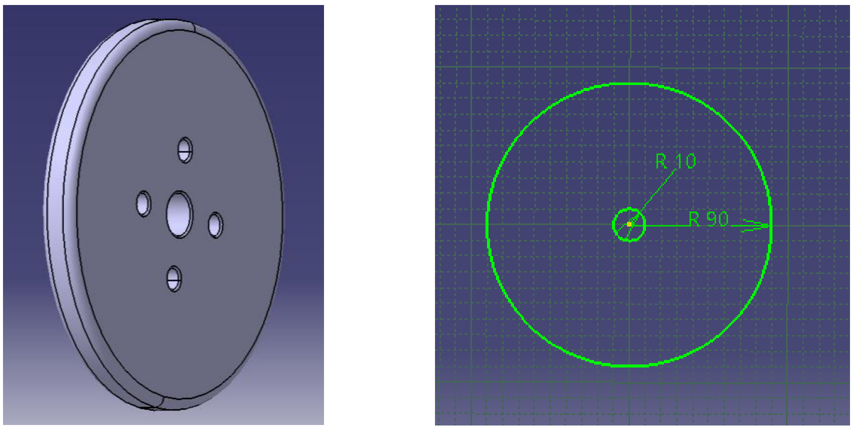

Fig 17. CATIA model of wheel

4. Calculations

4.1.Radius of Wheel

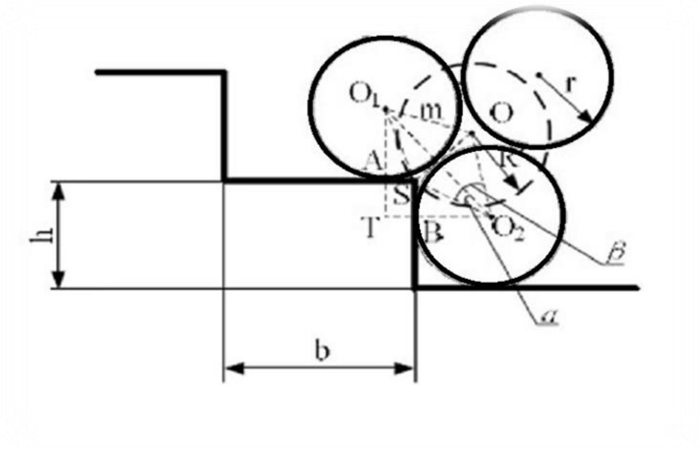

Fig 18. Dimension of wheels

$SO_2 = \sqrt{BO2^2 + BS^2} = \sqrt{r^2 + (h-r)^2}$

$O_1O_2 = 2m*\cos 30 = \sqrt{3}m$

$(AS + r)^2 = (TB + BO_2)^2$

$AS = \sqrt{3m^2 - h^2} - r$

$SO_1 = \sqrt{O1A^2 + AS^2} = \sqrt{r^2 + (\sqrt{3m^2 - h^2} - r)^2}$

Therefore

$$\text{Cos}\alpha = \frac{SO2^2 + O1O2^2 - SO1^2}{2*SO2*O1O2} = \frac{h(h-r) + r\sqrt{3m^2 - h^2}}{m\sqrt{3r^2 + 3(h-r)^2}}$$

Considering non-interference between the planetary wheels, the rotation arm m=104mm is selected.

4.2. Maximum radius of Shaft

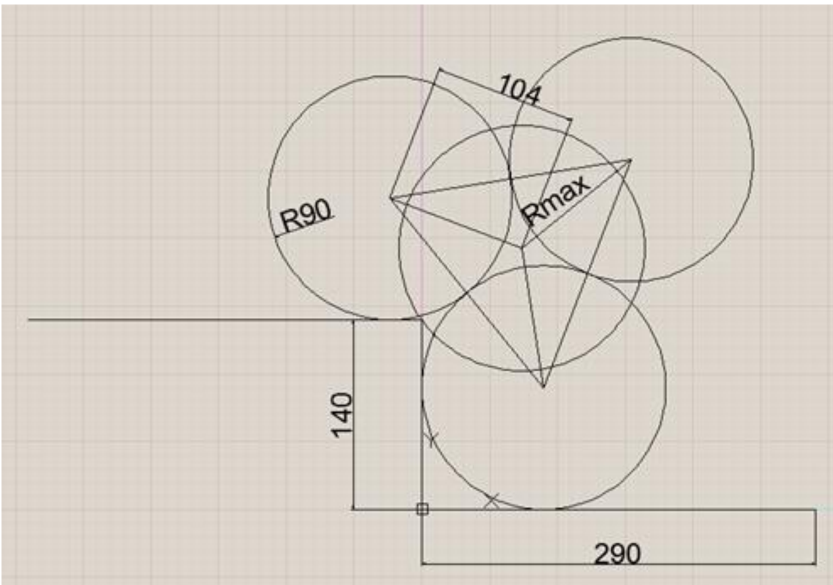

Fig 19. Radius of Shaft

After calculation

$$\alpha = 21.95° \approx 22°$$

Therefore: $\beta = \alpha + 30° = 52°$

R_{max} = OS = $\sqrt{OO2 + SO2^2 - 2 * OO2 * SO2 \cos\beta} \approx 90.7$mm

The maximum dimensions of the drive shaft centre should not exceed the radius R_{max} in order to ensure that there is no interference between the wheelchair and the edge of the stair when the wheelchair climbs the stairs.

4.3. Stair Climbing

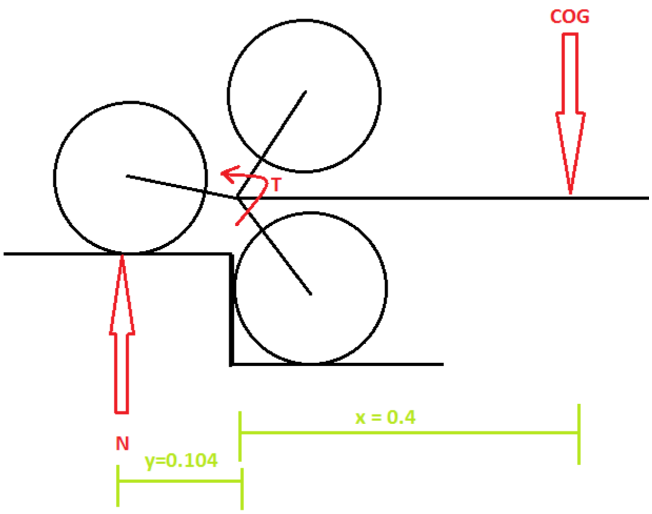

Fig 20. Stair Climbing

T = x*COG + y*N

For one side weight and normal reactions can be distributed

T = 0.4*100 + 0.104*81

T = 40+8.424 = 48.5 N·m

Therefore, Power for motor

Taking $\omega = \frac{2\pi}{3}$ rad/sec

$P = T\ \omega = 48.5 * \frac{2\pi}{3} = 101.62$ Watt

Therefore, each motor selected must be greater than 105 Watt

4.4.For no slipping of wheelchair

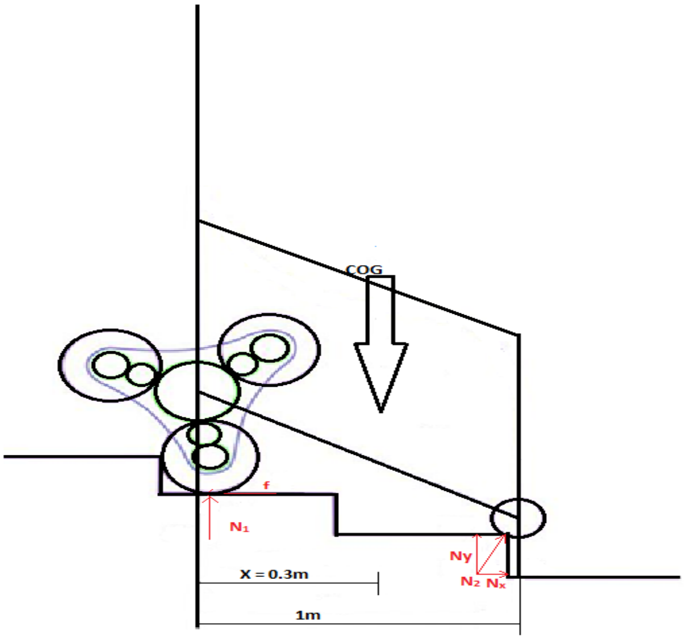

Fig 21. No Slipping Condition

Length from centre of planetary wheels to centre of caster wheel is 1 m

From force and moment equilibrium following equations are obtained

N_y = x*COG $\qquad$ N_1 = (1-x)*COG $\qquad$ $N_x = N_y$*tan30°

For no slip condition while climbing upstairs

$\mu N_1 \geq N_x$

μ*(1-x)*COG $\geq$ x*COG*tan30°

0.3*(1-x) $\geq$ x*(0.58)

x $\leq$ 0.34m

The centre of the gravity should be close to the back of the wheelchair to prevent topple while climbing stairs and at a maximum of 0.34m from the rear wheel i.e. planetary wheels.

4.5.For Inclined surfaces

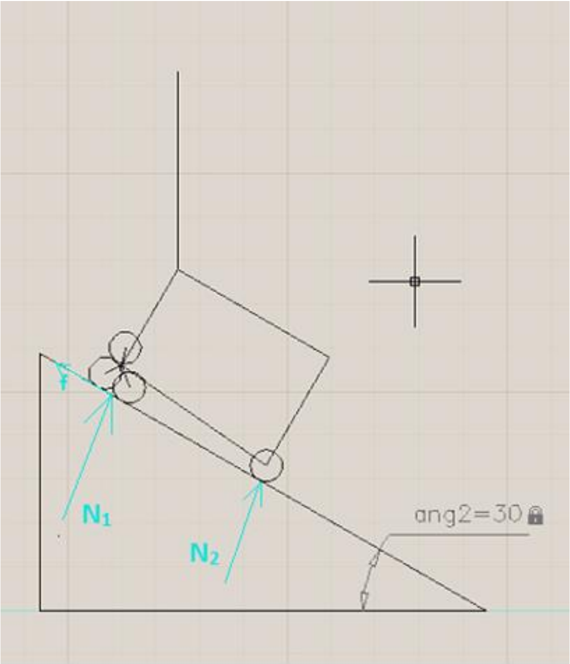

Fig 22. Wheelchair on Inclined Surface

For safety considering COG at x=0.3m from rear end

$2N_1Cos30° + N_2Cos30° = mg$

$2\ N_1 + N_2 = 230.94$

$2\ N_1 - (1\text{-}x)^*\ COG^*Cos30° = 0$

$N_1 = 80.83N$

$N_2 = 69.23N$

$f = \mu N_1$

Taking $\mu = 0.7$

$f = 56.58N$

$T = f \times r = 56.58^*.09 = 5.09\ N{\cdot}m$

4.6.Planetary Gear Train

Transmission of motion from gear motor to the wheels is through this planetary gear train. The specifications of these gear wheels are obtained partly from existing commercial gears used in motorized wheelchairs and partly by customization

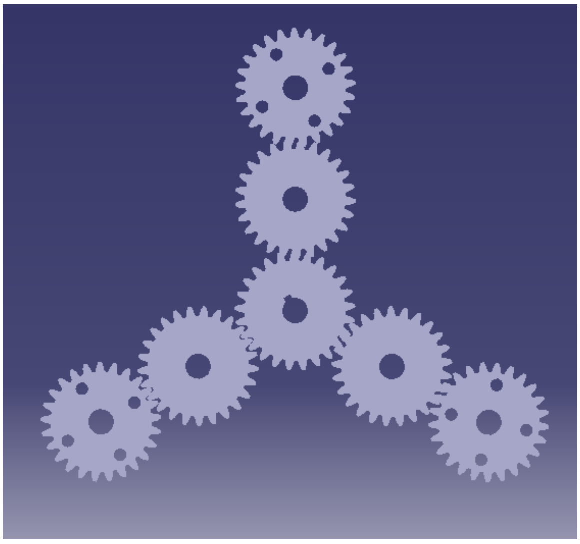

Fig 23. Planetary Gear System

Number of teeth (N) = 25

Module (m) = 3.5

Pitch circle radius = 43.75 mm

Clearance circle radius = 41.125 mm

Addendum circle radius = 47.25 mm

Dedendum circle radius = 39.375 mm

Filet radius = 1.365 mm

90/N*1deg = 3.6 degree

Fillet radius 0.39*m

Thickness = 15 mm

4.7.Planet Carrier

The shape and size of planet carrier depends on the arrangement of wheels in triangular array and also on the dimensions of gears. As calculated above, distance between centres of wheels. The figure is as shown below

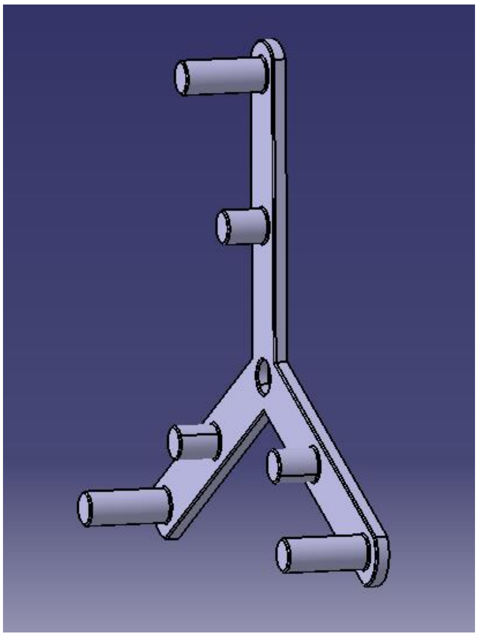

Fig 24. Planet holder

Thickness = 8mm

Centre to centre distance = 87.5mm

Diameter of Hole & Shafts = 20mm

4.8.Linkage Mechanism

In order to keep the base of the seat horizontal while climbing up or down the stairs, a linkage mechanism is provided connecting the seat and frame together. This mechanism is designed based on the second inversion of 4-bar linkage mechanism. It is similar to whit worth quick return mechanism. Here, a closed loop control is provided with mini servo motor being connected to the 2nd link. Strain gauges are used to feedback appropriate angle to be rotated to acquire stability and making no couple to act on the wheelchair. Here, mini motor keeps the seat in stable position bringing the Centre of gravity down. The linkage mechanism generates relative motion between the frame and the seat. During stair climbing operations it is required to accomplish three different tasks: moving the seat backwards, reorienting it and lifting up the pivoting wheel. When the seat is moved backwards, the centre of mass of the wheelchair is placed in a safe position, and overturning is thus prevented.

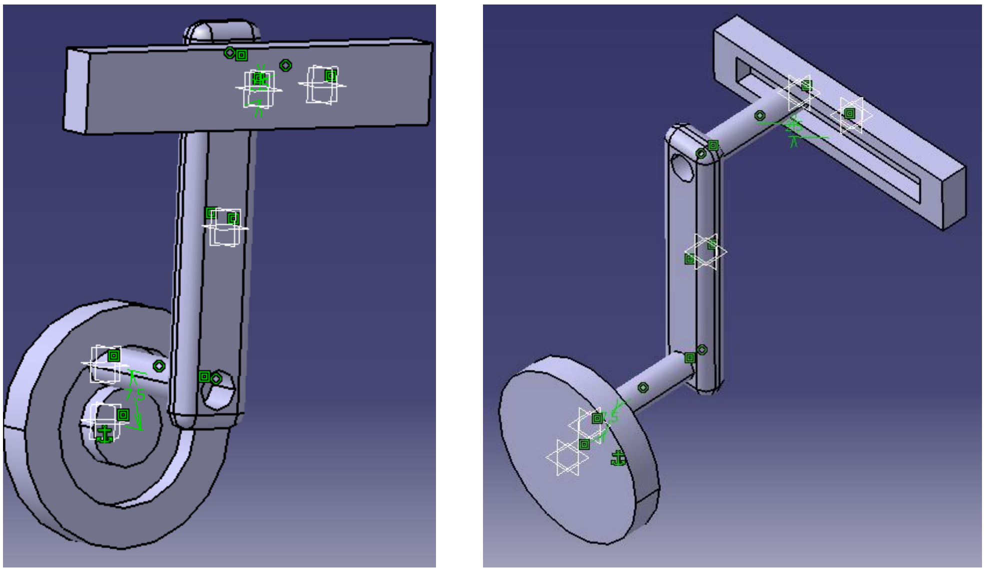

Fig 25. CATIA model of linkage sub assembly

4.9.Transmission Mechanism

Initially the power from the battery flows to the gear motor, which is arranged together with battery in an enclosed box. Now the gear motor rotates along with the shaft attached, with appropriately reduced RPM according to the specified reduction ratio of motor. Here ‘differential gears’ are used to transmit the motion from rotating shaft to the wheels with the flexibility for left and right wheels to move at different speeds. This accommodates turning of the wheelchair when required.

The differential gear has three jobs:

- To aim the engine power at the wheels.
- To act as the final gear reduction in the vehicle, slowing the rotational speed of the transmission one final time before it hits the wheels.
- To transmit the power to the wheels while allowing them to rotate at different speeds.

4.10. Detailed Design

The detailed design phase includes materials, manufacturing processes and digital mock up.

4.10.1. Materials

- Frames

  Power base chairs may have aluminium, stainless steel, cold-rolled steel, flat steel, tubular steel, or steel frames. The type of material used to construct the frame affects the weight of the frame, and therefore the overall weight of the wheelchair. The type of frame material also can affect the wheelchair's overall strength.

- Upholstery

  Upholstery for wheelchairs must withstand daily use in all kinds of weather. Consequently, manufacturers provide a variety of options to users, ranging from cloth to new synthetic fabrics to leather.

- Wheel

  Tires vary in size generally ranging from six to eight inches in diameter, although smaller sizes are also used and composition pneumatic, solid rubber, plastic, or a combination of these.

5. Digital MockUp

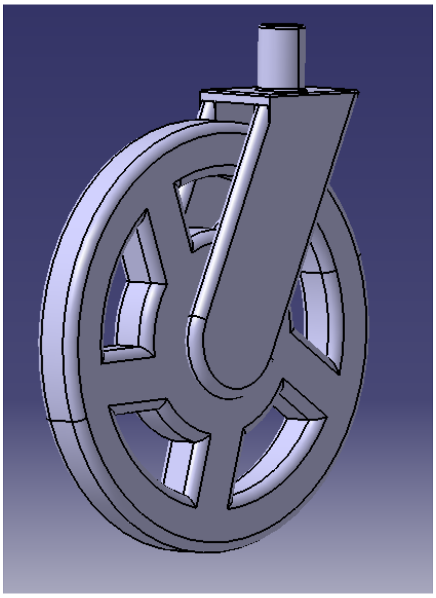

Fig26. Front Caster

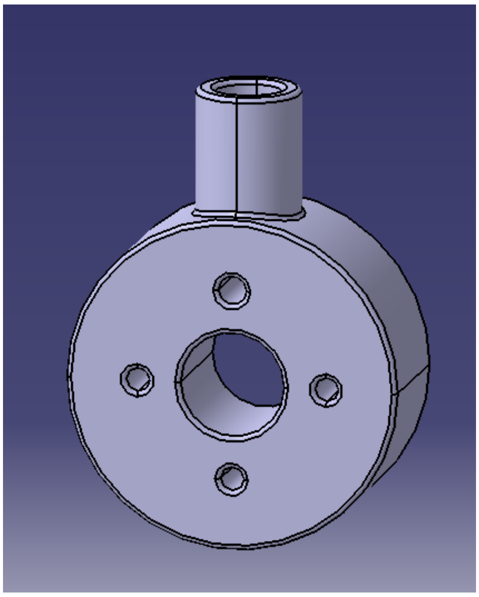

Fig 27. Hub for holding motor with chassis

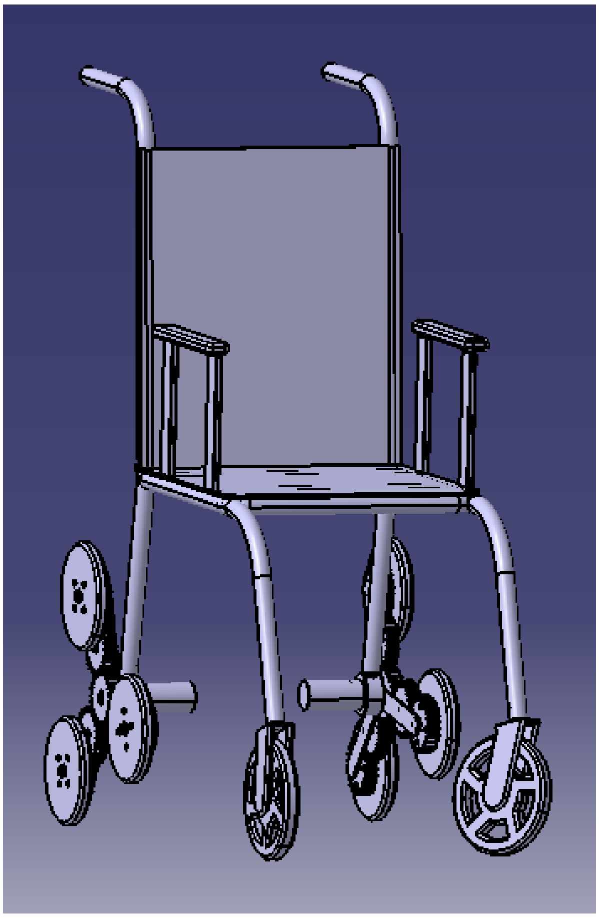

Fig 28. Final Assembly of Product Model

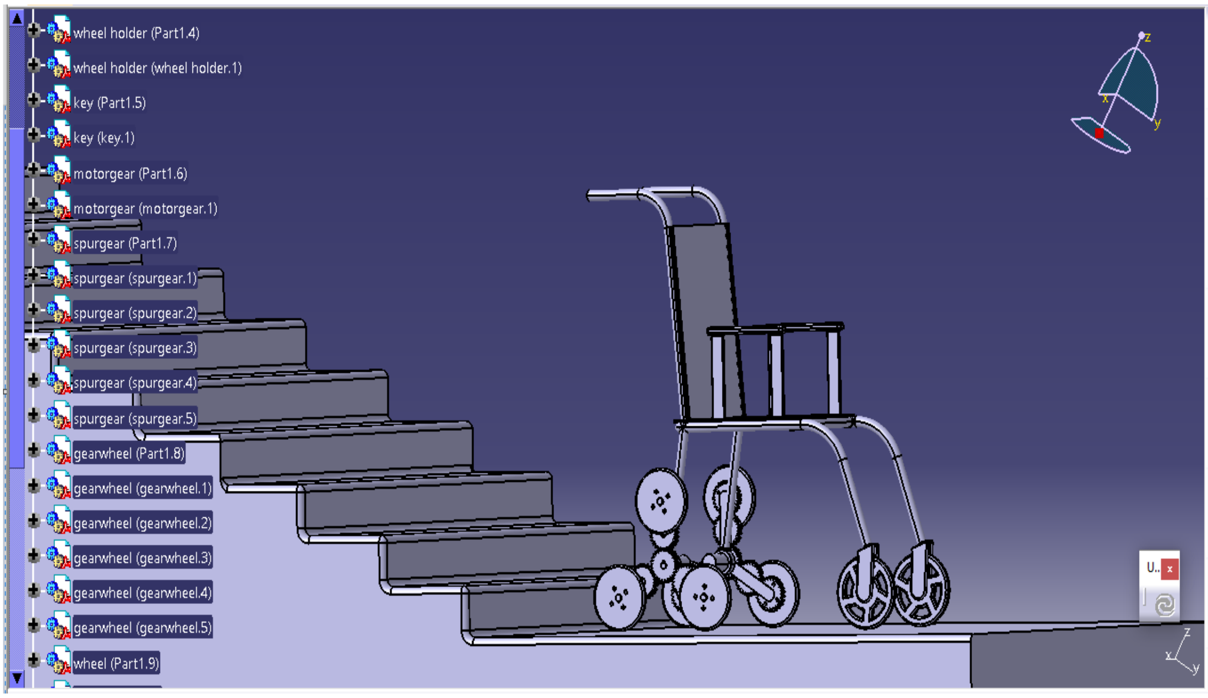

Fig 29. Wheelchair while climbing stairs

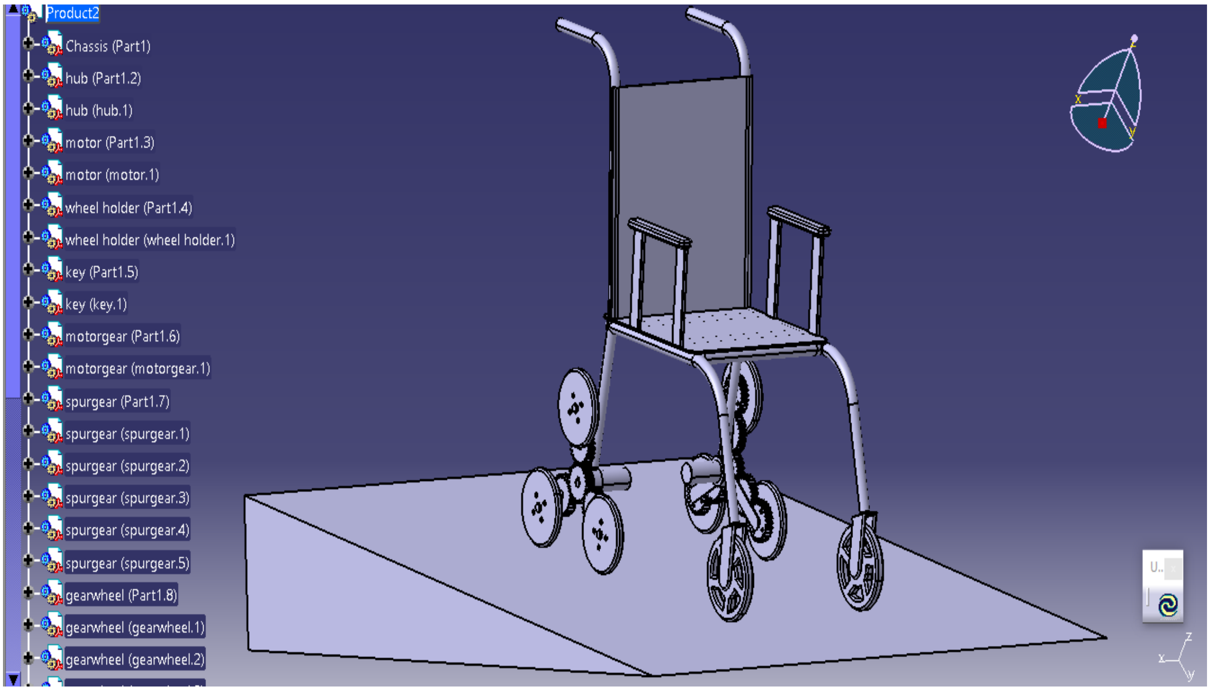

Fig 30. Wheelchair on Inclined Surface

6. Results and Discussion

By choosing the material, adding the load and setting the boundary conditions into the simulation function of Inventor, the analysis result can be obtained as below

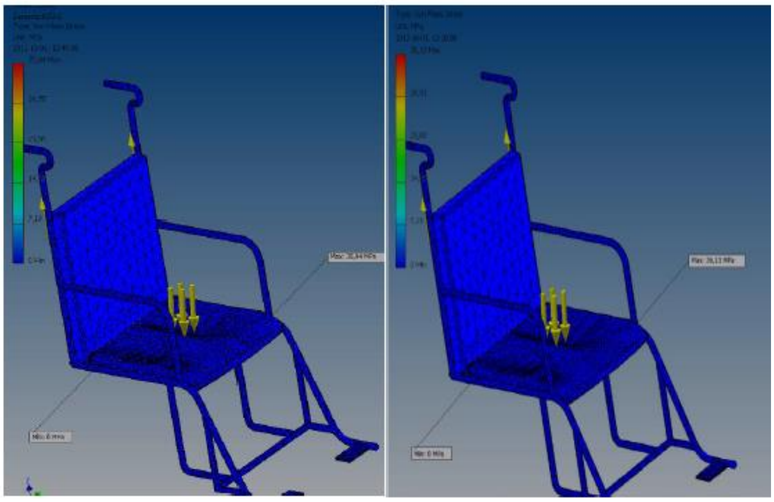

Fig 31. Von Mises Stress of the framework

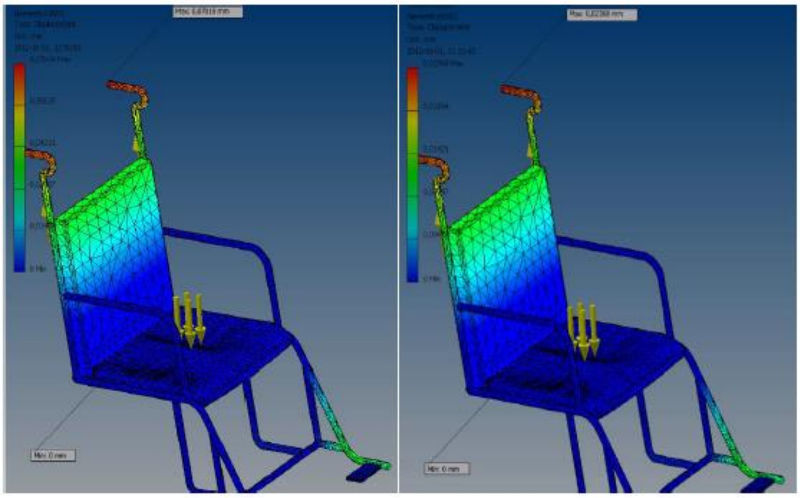

Fig 32. Displacement

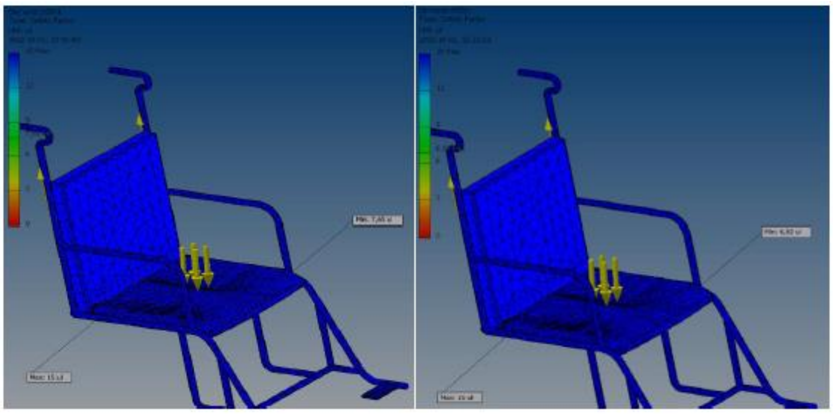

Fig 33. Safety Factor

	Maximum		Minimum	
	Aluminium-6061 HAC	Alloy Steel	Aluminium-6061 HAC	Alloy Steel
Von Mises Stress (MPa)	37.44	39.45	0	0
	76.48	81.42	0	0
	31.19	33.8	0	0
	45.59	48.40	0	0
	79.06	80.22	0	0
Displacement (mm)	0.07018	0.02368	0	0
	0.07141	0.03649	0	0
	0.0925	0.03884	0	0
	0.06005	0.02022	0	0
	0.05865	0.01958	0	0
Factor of Safety	1.5	1.5	7.65	6.92
	1.5	1.5	3.21	2.8
	1.5	1.5	8.93	8.09
	1.5	1.5	6.3	5.68
	1.5	1.5	3.13	2.83

From the conclusion above, the mechanical properties of both materials are closed to each other: alloy steel have less displacement, but it is more heavy and the safety factor is a little lower, so considering the light weight, more comfort and safety, Aluminum-6061 HAC is very reasonable. So Aluminum-6061 HAC can be selected as the material of the framework of the wheelchair.

Dimensions of Components in modelling

i. <u>Seat</u>

- Backrest

  Length = 650 mm

  Width = 460 mm

- Armrest

  Length = 260 mm

  Width = 80 mm

- Base

  Depth = 150 mm

  Width = 460 mm

- Thickness = 50 mm

ii. Frame

- Dimension of tubular section = 30 mm
- Height of frame = 560 mm
- Width of Frame = 460 mm

iii. Wheel Carrier

- Centre to centre Distance = 175 mm
- Wheel Diameter = 180 mm

iv. Gear motor and battery box

- Length = 300 mm
- Width = 450 mm
- Thickness = 100 mm

In the designed model, there are variations in proportional dimensional scaling. These are due to the different percentiles of anthropometric parameters considered in the design of individual features of chair. These percentiles to be considered are based on subjective perceptions arrived at by subjective analyses. Also the design of wheels and wheel carrier are suitable to limited range of staircase dimension variations. As the product is targeted for domestic use, the regularity in staircases are assumed. The mechanism for engagement and disengagement of shaft to the sun gear and the wheel carrier are to be developed further, to accommodate the switching between stair climbing mode and moving on flat ground mode. This could be provided either manually or automatically by setting the maximum limit for torque in flat ground mode.

7. Conclusions

In this project we designed a stair climbing wheelchair, which has compact structure, can cope with flat or inclined terrain, stairs and obstacles. All parts of the wheelchair were modelled in CATIA AND AutoCAD, then simulation analysis to make sure the strength of the framework, gear shaft, etc. The results are:

- Design the walking mechanism and the transmission system for our stair-climbing wheelchair, according to the calculations which decide the structure of the wheelchair, then model all parts of the wheelchair.
- The seat backrest adjusting mechanism adopts manual operation, which is not only energy saving, but also reduces the weight of the wheelchair by not installing the motor.
- User can adjust the seat backrest system to make sure the seat of the wheelchair is parallel to the level ground when it climbs up and down stairs.
- Assembling simulation is carried out in CATIA in order to avoid interference between different parts of the wheelchair.

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