Project Report Entitled

Design and Manufacturing of an Electric Bamboo Recumbent Bicycle

Submitted in partial fulfilment of the requirements for the award of degree of

Bachelor of Technology (B. Tech.)

In

Mechanical Engineering

SUBMITTED BY

Sakshi Shah (C22017551657) **Pranjali Joshi** (C22017551661)

Rucha Patil (C22017551658)

UNDER THE GUIDANCE OF

Prof. Nilesh Kolhalkar

DEPARTMENT OF MECHANICAL ENGINEERING

MKSSS's Cummins College of Engineering for Women, Pune

(An Autonomous Institute Affiliated to Savitribai Phule Pune University)

July 2021

Certificate

This is to certify that the Project/dissertation report entitled **"Design and Manufacturing of an Electric Bamboo Recumbent Bicycle"** submitted by

1. Sakshi Shah (C22017551657)
2. Pranjali Joshi (C22017551661)
3. Rucha Patil (C22017551658)

is record of bonafide work carried out by her, under my guidance, in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology (B.Tech.) in Mechanical Engineering of MKSSS's Cummins College of Engineering for Women, Pune, affiliated to Savitribai Phule Pune University.

Dr. Ravindra B. Ingle	**Dr. Ajit A. Bhosale**
Guide	Head
Department of Mechanical Engineering	Department of Mechanical Engineering

Dr. Madhuri B. Khambete

Principal

MKSSS's Cummins College of Engineering for Women, Pune - 411052

Date:

Place: Pune

Report Approval

Project Report Entitled

Title of Project, Can be used up to maximum two lines

By

Sakshi Shah (C22017551657) **Pranjali Joshi** (C22017551661)

Rucha Patil (C22017551658)

is approved for the degree of Bachelor of Technology

of

Department of Mechanical Engineering

MKSSS's Cummins College of Engineering for Women, Pune

(An Autonomous Institute Affiliated to Savitribai Phule Pune University)

Guide

External Examiner

DECLARATION

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke action from the sources which have thus been properly cited or from whom proper permission has not been taken when needed.

Sakshi Shah

Pranjali Joshi

Rucha Patil

Date:

ACKNOWLEDGMENT

First and foremost, I would like to express my sincere gratitude to my…

Sakshi Shah

Pranjali Joshi

Rucha Patil

ABSTRACT

Owing to the present scenario of industries, there is a sudden boom observed in the demand for bicycles around the globe. This has typically risen in this decade because there is an awareness of environmental impacts caused by human activities. To reverse these, people are choosing more sustainable and eco-friendly options. Governments are also taking initiatives in encouraging people to opt for sustainable substitutes. Keeping this in view, this is a right time for the revival of the more efficient recumbent bicycle, that can help the rider to travel long distances without much efforts and benefit him/her with ample exercising. When traveling longer distances a person can easily achieve respective higher speeds. To add to the sustainability an important feature of this bicycle is its material- Bamboo. An indigenous species named Dendrocalamus Strictus is used. This study is a blend of sustainability and design engineering in every possible way.

TABLE OF CONTENTS

Contents

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

E’	Storage modulus
E'_G	Storage modulus in the glassy region
E'_R	Storage modulus in the rubbery region
$\in$	Effectiveness
B	Interfacial strength indicator

ABBREVIATIONS

NFRC	Natural Fiber Reinforced Composite
GFRC	Glass Fiber Reinforced Composites
MMC	Metal Matrix Composites
CMC	Ceramic Matrix Composites

CHAPTER 1 INTRODUCTION

1.1 Introduction

1.1.1 Motivation

The primary sources of travel in the present day are two-wheeler and four wheeler vehicles. With the increasing pollution and waste generated, it is important to shift to more sustainable forms of transport. This project aligns with the six of the seventeen sustainability goals set forth by the United Nations, which are as follows.

1. Good health and well-being
2. Affordable and Clean Energy
3. Decent work and Economic growth
4. Sustainable cities
5. Responsible Consumption and Production
6. Climate Action

Health problems arising from the sedentary lifestyles affect a significant portion of the population today. According to the WHO, in 2016, 39% of adults aged 18 years and over (39% of men and 40% of women) were overweight [1]. Hence, inculcating exercise in our schedule via using human-powered vehicles can help improve health and fitness of the population. It also costs less to purchase, own and to operate than other type of vehicles [2].

To make long distance travel to workplaces more comfortable to people, we hence have suggested the use of a recumbent bicycle with an electric assist. A long wheel based recumbent bicycles is one of the safest and most comfortable bicycles made till date [2]. With the electric assist, a person will be able to travel long distances as well with ease.

By substituting bamboo as the cycle frame material, we can eliminate all the resources used in the manufacturing, procurement and processing making the manufacturing even greener. The bamboo being minimally processed and biodegradable can also be easily disposed of. It is considerably cheaper than the alternatives currently used in the industry. An in-depth analysis of the materials is conducted in the later chapters.

This project being sponsored by "Bamboochi Bicycle" shares the vision of the company to generate more employment in the rural areas as the bamboo frames need to be manually made.

1.1.2 Problem Statement

We need to develop a recumbent bicycle frame out of bamboo which will be able to sustain the weight of at least one person. The frame should be customised for the person riding it.

The problem can be approached using the design thinking that can allow us to understand what is needed currently in the society and empathise with it. We can then define it in the technical terms and then generate a solution. Validating, testing and ideating again developing the product continuously.

The key elements of the process include,

1. Design
2. Simulation
3. Manufacturing
4. Testing
5. Analysis
6. Validation

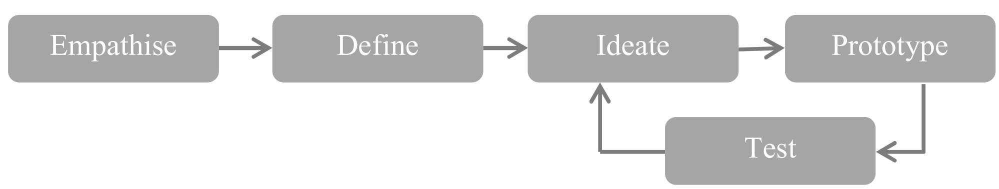


Figure 1. Design Thinking Approach

1.1.3 Aims and Objectives

The main objective of this project is to design an electrically assisted recumbent bamboo bicycle. The other specific objectives are as follows.

- The speed range obtained by the bicycle is within 25 Km per hour.

- The aim is to keep the efficiency higher than upright cycle.
- Carries a minimum load of a person.
- To obtain a substantial reduction in the frame weight in comparison to metallic frames.

1.1.4 Scope and Limitations

- The bicycle is made taking into consideration long distance travel
- Only the frame will be make of bamboo
- The time taken to manufacture the bicycle commercially is not taken into consideration.
- Mass production of these cycles is not taken into consideration.
- The study of this project does not cover the musculoskeletal analysis of the rider.

1.1.5 Deliverables and Outcomes

- Concept sketch
- Mechanical design of the bicycle
- CAD model of the bicycle
- Load Simulations
- Analysis of the cycle
- Validation of the design
- A working prototype

1.1.6 Organization of Chapters

The report consists of chapters distributed as follows

- Chapter 1- Introduction
- Chapter 2- Literature Review
- Chapter 3- Design Procedure and Methodologies
- Chapter 4-3D Modelling and Simulations
- Chapter 5- Results and Discussions

1.2 Recumbent Bicycle

1.2.1 What is Recumbent Bicycle

A recumbent bicycle term generally refers to, “A recumbent bicycle is a bicycle that places the rider in a laid-back reclining position.”[25]. However, no standardised definition is available.

1.2.2 Classification of Recumbent bicycles

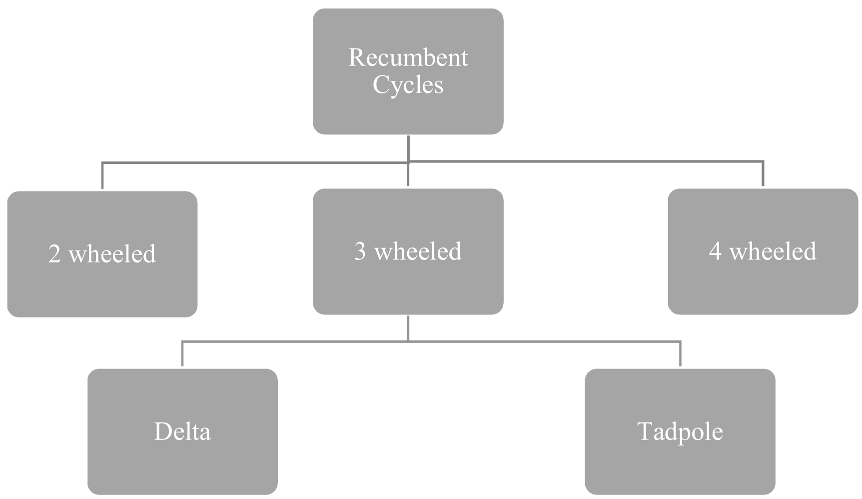


Figure 2. Classification of Recumbent Cycles

Recumbent Cycles can be classified initially based on the number of wheels they have. Two wheeled cycles are referred to as bicycles, three wheeled are called tricycles and four wheeled are called quadricycles. Recumbent tricycles can have two different types of configuration namely delta and tadpole. In the delta configuration, there is one wheel in the front and two in the rear. While in the tadpole configuration, we have two wheels in the front and one in the rear. Adding wheels tends to increase the stability of the bicycle. However, it results in the decrease of mobility and maneuverability.

1.2.2.1 Based on wheelbase

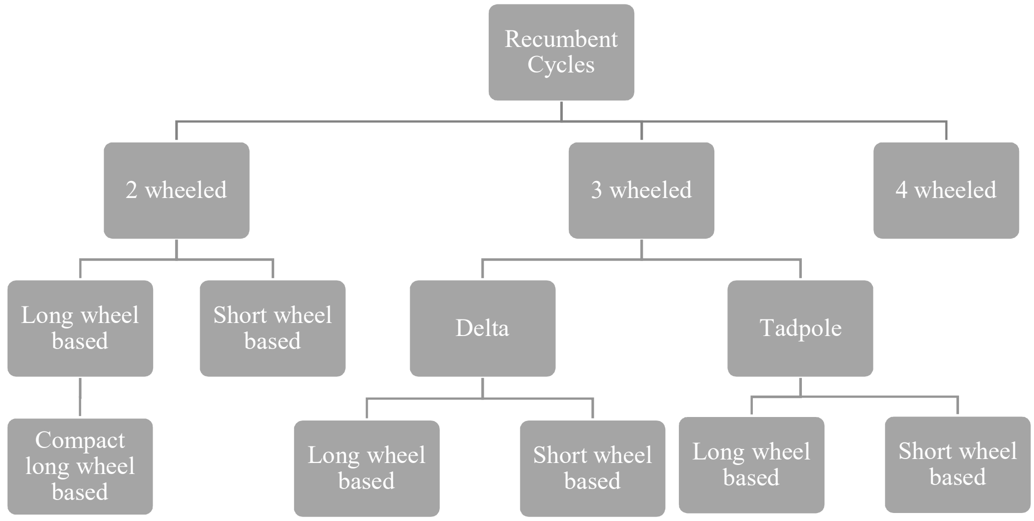


Figure 3. Classification of Recumbent Cycles based on Wheelbase

Recumbent Cycles can also be classified based on the wheelbase [15, 16]. Long wheelbase cycles have the front wheel in the front of the crank. In short wheelbase cycles, the crank is located ahead the front wheel. A comparison of the long wheelbased and short wheelbased cycles is as below [17].

	Long Wheel Base (LWB)	Short Wheel Base (SWB)
Advantages	• More stable • Faster stopping • Straight chain line • You can cross chain gears • Most long wheelbase recumbents use 20 inch or larger front wheels	• More maneuverability • More equal weight distribution between the front and rear wheels • Easier to transport
Disadvantages	• Less maneuverability • More cumbersome • Harder to transport	• Inefficient drive chain • Small front wheel • Danger of heel strike

Table 1 Comparison of long wheelbase and short wheelbase cycles

1.2.2.2 Based on height of seat

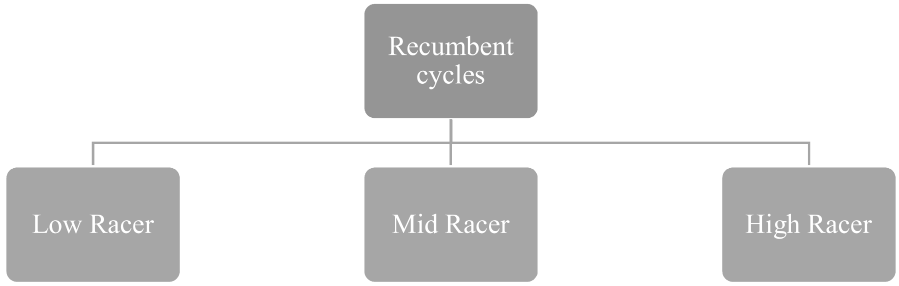


Figure 4. Classification of Recumbent Bicycles based on height of seat

Based on the height of the seat, the recumbent cycles can be classified as low racer, mid racer or high racer. Low racer cycles have the seat positioned slightly below the line that joins the centres of the front and rear wheels. Similarly, in mid racers the seat is inline with the centreline joining the front and rear wheels and higher in case of high racers. A more detailed comparison of them is given in the table below. [15, 16, 17, 18, 19, 20]

	Lowracer	Midracer	Highracer
Advantages	• Very Fast (Mostly for racing events) • Highly aerodynamic profile • Smooth on non-steep slopes or flat surfaces.	• Reasonably Fast • Better visibility than Lowracer due to higher positioning. But it is still low enough to reduce the air drag. • Moderately Aerodynamic. • Comfortable on hills and steep slopes • Mounting and dismounting is simpler than Lowracer and Highracer	• Very Fast • Very good visibility due to high positioning in traffic • Very aerodynamic. • Comfortable. • More maneuverability than the Lowracer. • Constructed with simple, lightweight frames. • Simple chain drive and straight

Disadvantages	• The seat angle is too horizontal • The seat is very close to the ground • Complicated frame • Complicated and twisted chain drive. • Since the pedal is located close to the front wheel, the riders legs may collide hence it has limited steering.	• Higher speeds like Highracer and Lowracer cannot be obtained • There may some handling issues at low speeds	• May be difficult to start and stop • The seat angle is too horizontal

Table 2 Comparison between Lowracer, Midracer and Highracer

1.2.2.3 Based on Steering Geometry

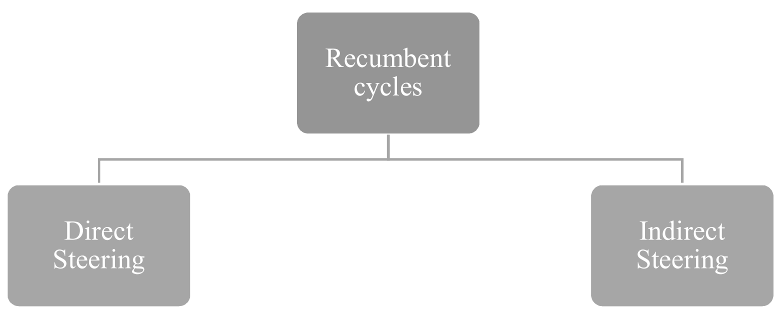


Figure 5. Classification of Recumbent Bicycles based on Steering

Prior to getting into direct and indirect steering, we define the overseat and underseat steering. The overseat steering is where the handlebar is located above the topmost part of the seat. This is generally the case in Lowracers and often leads to visibility issues. In underseat, the handlebar is below the top of the seat.

In direct steering kind of cycles, the handlebars are joined to the fork with a stem. This arrangement is similar to an upright bicycle. The overseat steering kind of recumbent cycles have their steering set up in this way.

In indirect steering, there is a pivot point in the centre of the bicycle to which the handlebar is connected with a linkage. In other words, the handlebar is connected to a connecting rod, which is then connected to the fork. There is a push and pull generated which is responsible for the turning of the vehicle. This type of steering is generally used in the under seat steering recumbent bicycles [21].

	Direct Steering	Indirect Steering
Advantages	• Provides precise steering • Simple construction • Cheaper • Lighter in weight	• Adjustable steering ratios • Provides better ergonomics • Fewer shocks and vibrations which results in a more stable handlebar
Disadvantages	• Less stable at high speeds	• More complex • More costly • Heavier in weight

Table 3 Comparison between direct steering and indirect steering

1.2.2.4 Based on Drive [21]

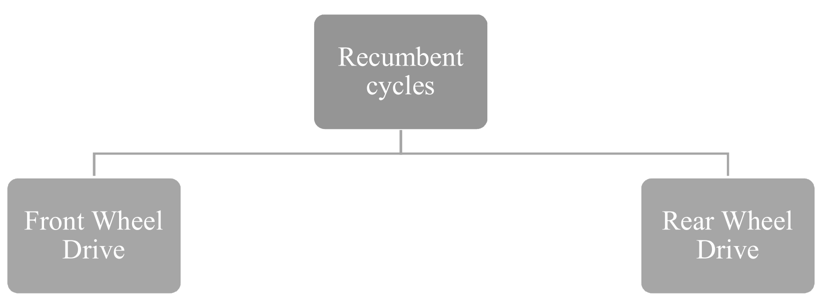


Figure 6. Classification of Recumbent Bicycles based on Drive

Based on the location where the power of the pedal goes, the cycle can be classified as a front wheel drive or rear wheel drive.

A rear wheel drive recumbent bicycles allows very good maneuverability at lower speeds. However at higher speeds, these bicycles are very unstable. A significant proportion of recumbents are rear wheel drives. A long chain connects the crank and the rear wheel. When employed in long wheelbase cycles, generally the chain is directly connected. But in case of short wheelbase cycles, there is an idler pulley connected in between. This pulley is required so that the chain doesn't get stuck between the front wheels. Multiple chains can also be used.

Since the crank is located close to the front wheel, it is more convenient to make recumbent bicycles front wheel drive. The challenge is doing so is that it hinders the turning of the cycle. The chain cannot bend much during turning and is subject to bending forces which may cause it to break.

Commonly a pivoting boom is used in front wheel drive recumbents. It includes a pivot placed behind the crank and fork. This makes the crank, chain and wheel one unit. It allows us to choose a larger wheel and help eliminate the problem of heel strike. The rider can pedal even when turning. In this case, it is also possible to steering using only feet, eliminating the need of handlebar.

The disadvantage of the front wheel drive recumbent is the wheelspin. As there is lesser amount of weight on the front wheel, it is prone to slipping on wet and gravel filled roads.

1.2.3 Seating Angle

The distinguishing feature of recumbent bicycles is the incline of the seat. The seat angle is the angle between the upper body and the line through hip joint and pedal axle. In an upright bicycle, the seat angle is generally less than 80 degrees. In a recumbent it general depends upon the type of the recumbent and generally varies from 105 to 150 degrees. In a review published in 2008, maximum power is generated when a person is seated at 105 degrees recumbent (mean hip angle at 77 degrees) [22]. This makes recumbent bicycles one of the most efficient bicycles which also generate very high exercise output. There is no standardization over what the seat angle is in recumbent bicycles and it completely depends on the riders comfort.

The seat can be either or foam type or mesh type. The mesh type seats are made by mesh stretched over a metal frame. It provides excellent breathability and allows sweat to evaporate. However foam seats are most common. Foam seats are simple cushion sewed or stapled on a hard base [23].

1.2.4 Bicycle Fairings[24, 25]

Bicycle fairings are basically body covers or windshields which can be attached on the bicycled to improve its aerodynamic properties. The drag force starts becoming noticeable at 17kmph (10mph). They can be made of carbon fibre, fibreglass or polymers. They improve the efficiency of the cycle by reducing the drag force acting on it. They can also provide some protection against the weather (i.e. during rain).

1.2.5 Analysis of Recumbent bicycles with respect to upright bicycles [21]

The benefits and drawbacks of the recumbent bicycle against the conventional upright bicycle are compared below

Advantages	Disadvantages
• Reduced neck, back, shoulder, butt, and joint pain • Faster • Better circulation • Better breathing • More comfortable • Higher Efficiency • More Safer (reduced probability of injury after crash) • Shorter braking distance • Better view of surroundings	• Poorer visibility than the upright bicycle • More costlier • Harder to ride on steep slopes • Difficult to turn • Harder to start from a stop • Larger and heavier

Table 4 Advantages and Disadvantages of recumbent bicycles over upright bicycles

1.2.6 Layout and components

The Basic layout of our recumbent bicycle is as shown in the figure below.

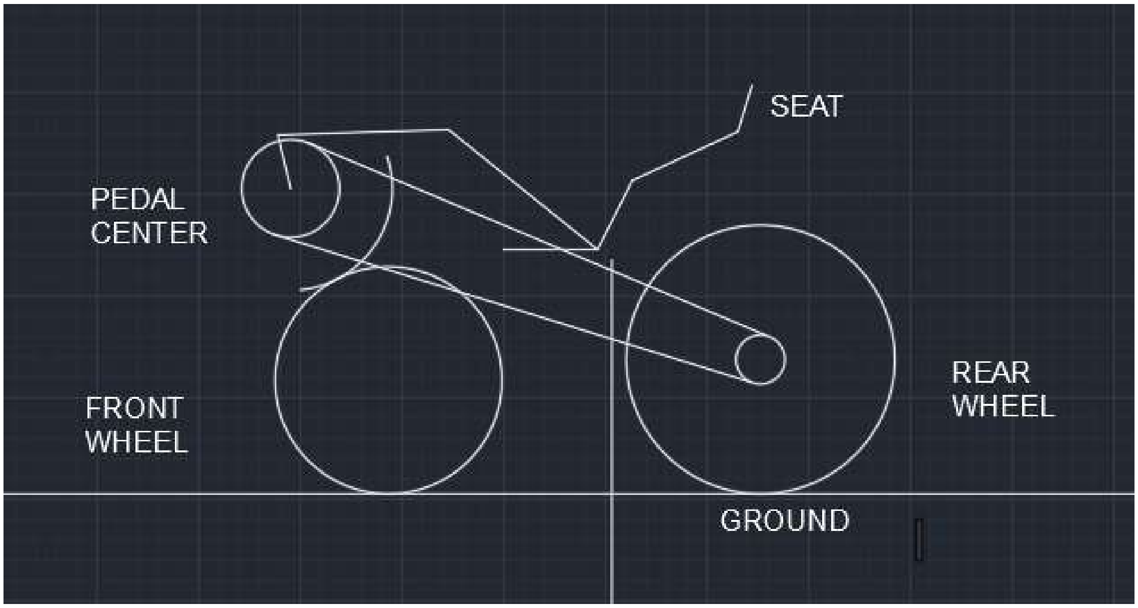
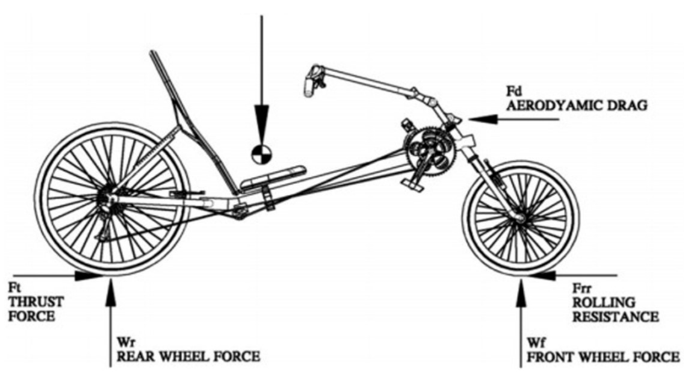


Figure 7 Recumbent bicycle layout

1.2.7 Forces acting on cycle

When in motion the main forces acting on a bicycle are the retarding forces which comprise the aerodynamic force due to air resistance and rolling resistance force due to friction between the tire contact patch and ground. The propulsive force is the thrust force provided by the drivetrain.



Img source: book

Thus net force acting on bicycle is given be the difference between propulsive and thrust force giving us the formula of maximum acceleration

a_x= (1/m)[P/V-(F_{aero}+F_{rr})]

Where

Aerodynamic force, F_{aero}=2.4783

Force due to Rolling resistance , F_{rr}=4.16925

Mass,m=85 kg

Bicycle Velocity, v= 25kmph=7 m/s

Wind velocity , v_w=10m/s

Power of motor, P= 250 W

Giving us

a_x=0.3496 m/s^2

We have only considered the motor power as we wanted to get an idea of acceleration provided by the electric drivetrain. We got a mean acceleration of 0.3496 m/s^2 against an expected mean of 0.231m/s^2 on a flat surface. (https://blog.decathlon.in/articles/cycling-benefits-for-the-urban-indian#:~:text=Regular%20commuter%20cyclists%20can%20have,1.5%20square%20meters%20(m2)

(https://www.indianclimate.com/show-data.php?request=AU1YRKPGRQ)

(https://www.researchgate.net/publication/223922575_Design_speeds_and_acceleration_characteristics_of_bicycle_traffic_for_use_in_planning_design_and_appraisal#:~:text=The%20power%20required%20to%20cycle,s%2C%20is%20approximately%20120%20W)

1.3 Material: Bamboo

Bicycle design depends mainly upon the application, which for an ordinary bicycle are endurance, speed, safety, and comfort. To satisfy these proper material selection is a must.

Any bicycle consists of a pair of wheels, a frame, drive train components, handles, and steering unit, carriages and holders, and seating. Each of these has a limited variety of materials to choose from, keeping a few aspects into account like- material properties, cost, availability, manufacturing considerations, and other physical aspects.

Wheels are made up of a hub, a rim, a tube, a tire, and spokes each of these may require different material. The bicycle industry uses the term “component” for everything except the wheel, frame, handlebar, and seat. A few examples of these components are cassette, derailleurs, crank, brake, chain, etc. The frame is the backbone of a bicycle, it acts as a complete functional unit. High strength to weight ratio is important in the frame material. The strength to weight ratio is also known as specific strength. The ideal frame would be light, strong, corrosion-resistant, fatigue-resistant, and inexpensive[1].

We have chosen standard components and wheels from the available options in the market. We now focus solely on the frame materials. As we consider making customized bicycles, rider’s style, weight, and sense of adventure also matter. The most widely used bicycle frame materials are high tensile carbon steel, Chromoly (Chrome Molybdenum) steel, Titanium, Carbon fibre, Aluminium alloy, Wood, Bamboo, Thermoplastics, etc.

1.3.1 Bamboo species

Bamboo is a naturally occurring lignocellulosic fiber; it is a combination of cellulose micro fibrils which is the reinforcement in the matrix of lignin and hemicellulose. Contrary to general belief, not the fiber but the matrix is responsible for strengthening the bamboo culm.[2] There are more than 1200 bamboo species around the globe. Fewer than 100 species have structural use. [3] The percentage of content of reinforcement and matrix varies according to the species.[4] We are using an indigenous bamboo species locally known as Mesh bamboo and have a scientific name as Dendrocalamus strictus. It is cultivated in a village named Bhor, located near Pune in Maharashtra, India. This bamboo is sturdy and scratch-resistant. The species of bamboo predominantly found in India is Dendrocalamus Strictus[5], this species shows different properties depending on the location where it is cultivated. The bamboo used in this study has not been tested yet. Therefore, the values of this species are taken into consideration from a source that has data available from a geographically similar area. Bamboo after proper chemical treatments gains more strength and durability when compared to naturally occurring material.[6] To process, it is harvested after 2.5 – 3 years, because it has higher values of elastic moduli and ultimate stress for both green and dry bamboo of this particular species[3], and then matured by heat treatment which is naturally drying it in shade for 5-6 months, later it is coated with boric acid and this process is termed Copper Chrome Boron (CCB) technique. This keeps the fungi or termites away from the culm. It is then clear-coated meaning covered with epoxy resin. This keeps the bicycle free from environmental damage, especially from moisture. Moisture badly affects bamboo if not taken proper care of. The primary properties that are affected by moisture content are dimension, weight, and strength.[7] The moisture content should always be lesser than the FSP (Fiber Saturation Point) for optimum mechanical properties.[3] In bicycle making, bamboo requires the least processing compared to any metallic or non-metallic material.[1]

1.3.2 Bending of bamboo

There are two most common techniques of bamboo bending they are [8]

1) *Hot bending*: It is subdivided into 2 methods
   a) *Immersion technique:* The bamboo poles are heated up to a temperature of more than 150°C by immersing them in lukewarm water for 12-24 hours depending on the thickness of the culm wall and other mechanical properties. It is then dried in open by bending it with the help of nails for 1-3 days. There is no alteration in bamboo properties with this method.
   b) *Combustion technique*: Directly and gradually heating the bamboo pole with a torch or other devices, this avoids splitting or pressure build-up in the culm. There are other techniques like small hole drills which help even heating the pole. Heating makes the bamboo flexible and can

be bent easily later. This technique doesn't alter the mechanical properties of bamboo.

2) <u>*Cold bending*</u>: It also is divided into 2 variations. These cause hindrance in the structural properties of bamboo in some or the other way and are thus, avoided.

   a) *Slashing technique*: A V-shaped narrow cut is given with a knife. This cut is with a depth of two-third of the diameter length. Either lashing or adhesive is used to secure the bend, the bend is achieved quickly and no tooling or processing is required. This method decreases the tensile strength of the bamboo.

   b) *Bundling technique:* The bamboo is split, bent and tied in bundles. This process isn't useful in bicycle making and reduces the material's compressive strength.[8]

1.3.3 Joining Materials

In order to strengthen the bamboo frame proper joining is necessary, for which Polyurethane acrylate (PUA) or Fiber-reinforced polymer (FRP) added to varnishes are used to seal the frame. A mixture of carbon fiber and Araldite or hemp reinforcement in Araldite is used as joining agents. Amongst which the former one is lighter and the latter is quite heavier. This process ensures there is no splitting, cracking, or joint defect. Making a trussed structure enhances the capacity and stiffness of the material on the whole and keeps it light in weight.[2]

1.3.4 Sustainability

It is a fact that bamboo is a grass, and it requires no care in the form of fertilizers, pesticides, irrigation,[6] grows at a very rapid pace because of which it can be harvested in 3-5 years, produces 35% more oxygen, and traps the excess CO2 produced by humans.[9] Unlike metals, alloys, or composites like carbon fiber, the process of procuring bamboo is much more cost-effective and has a minimal carbon footprint. This makes bamboo bicycles non-toxic and safe.

1.3.5 Testing and results

Bamboo is lightweight, tough, high-tensile, and inexpensive material.[5] This makes bamboo to be used as a material in automobile or transportation applications. There are various types of tests that we will consider

Firstly the component is classified into the material (the culm) and object, where the object is the frame. Then we can also think of destructive and non-destructive testing. We will discuss this further in detail as a future scope.

The table below gives a comparison between the conventional materials and bamboo, as mentioned earlier – specific strength is the main criteria to select a frame. Comparing to other materials except for carbon fiber and graphene bamboo shows phenomenal high specific strength. To add to this carbon fiber and graphene are not only denser but also 10 times more expensive than bamboo. This means the bamboo bicycle can achieve greater speed and comes at a lower price. The efficiency and acceleration in bamboo bicycles are similar to that of carbon fiber.

MATERIAL	TENSILE STRENGTH (MPa)	DENSITY (g/cm^3)	SPECIFIC STRENGTH (KNm/Kg)	BREAKING LENGTH (Km)
Bamboo	96	0.64	150	15.3
Titanium	344	4.51	76	7.75
CrMo Steel	560-670	7.85	71-85	7.27-8.70
Al Alloy	310	2.70	115	11.70
Carbon fiber	4300	1.75	2457	250
Graphene	130500	2.090	62453	6366

The wall thickness and internode length of bamboo are important characteristics to determine failure strengths.[4] A denser concentration of bamboo means higher cellulose concentration and is linearly in correlation with strengths, particularly flexural, tensile, and compressive. [3] As bamboo is a composite highlighting the fact that it has varied mechanical properties along the fiber length that is parallel to the fiber length and perpendicular to the fiber length. It is observed that bamboo can carry axial loads as these properties are noteworthy in the case of parallel fiber lengths;

whereas in the case of perpendicular to the fiber lengths, these properties have a very low or negligible value.

The averaged out values are a combination of nodal and intermodal values. The fibers are short along with the nodes and long along the internodes but as the density of fibers along the nodes is high it has lesser chances of breaking at the node. The nodes provide two purposes one, they prevent culm wall buckling and two, prevent the propagation of splitting from one internode to other.[10]

Other material properties of bamboo are[5]:

- Compressive Strength (Avg.)- 78 MPa
- Shear Strength (Avg.)- 85.3MPa
- Young's Modulus (Avg.)- 18 GPa
- Flexural strength (Avg.)- 177.14 MPa
- Poisson's Ratio (Avg.)- 0.32

Bamboo products have the advantage of advanced dimensional stability, more homogenous mechanical property, and better durability.[9]

CHAPTER 2 LITERATURE SURVEY

2.1 Introduction

This shall normally form Chapter 2 and shall present a critical appraisal of the previous work published in the literature pertaining to the topic of the investigation. The extent and emphasis of the chapter shall depend on the nature of the investigation

2.2 Literature review title

CHAPTER 3 DESIGN PROCEDURES AND METHODS

3.1 Design procedure of an HPV [14]

The steps to design a human powered vehicle (includes a recumbent bicycle is given in the following flowchart). One can choose the important steps relevant to the model and customize them to fit the project.

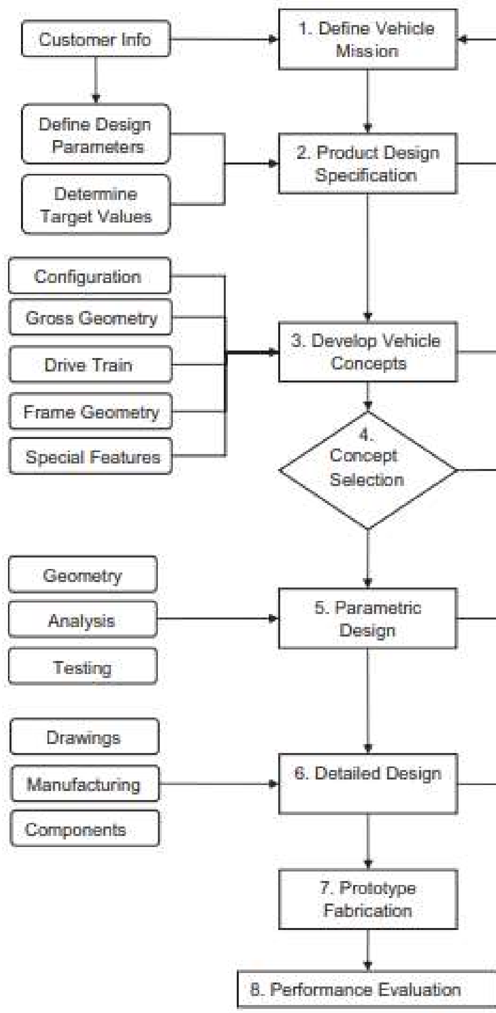


Figure 8 Procedure to design Human powered vehicles [14]

STEP 1. Define the mission of the vehicle

1. Obtain customer information

STEP 2. Develop vehicle design specifications

1. Information Sources

2. Design Parameters

  a. Design Control Variables

  b. Design Envelope Variables

  c. Performance metrics

3. Determine target values

CHECK: Before proceeding, go back to the mission statement for the vehicle and verify that all target values are consistent with it. If not, return to Step 2 and revise the values.

STEP 3. Develop vehicle concepts

1. Determine vehicle configuration

  a. CHECK: Before proceeding, check that the configuration is compatible with the mission statement.

2. Determine vehicle gross geometry

3. Design the drive train and establish chain line

4. Establish initial frame geometry

5. Special Features

STEP 4. Select optimal concept

1. Use rational decision-making techniques

2. Ensure each concept is compatible with mission and meets minimum design specification requirements

STEP 5. Complete parametric design

1. Validate vehicle geometry Preliminary performance analyses should be used to validate the vehicle gross geometry. (frame dimensions, hull shape)

  a. Use handling and performance analyses

  b. Verify top-level performance objectives are met, iterate as required

c. If performance objectives cannot be met with configuration, go back to Step 3

d. CHECK: Performance and handling must be consistent with mission

2. Complete Structural and other analyses and optimization

   a. Frame or shell type and structure (e.g., diamond frame vs. monotube)

   b. Member sizes/shapes

   c. Materials and conditions

   d. Processes

3. Determine testing needed to complete an optimal design

STEP 6. Complete detailed design

1. Complete detailed drawings of frame and all special-purpose parts

2. Complete manufacturing plans

3. Select components

STEP 7. Fabricate prototype

STEP 8. Complete functional and performance testing

1. Compare results with design specifications and analytical predictions

   a. Attempt to understand the cause of discrepancies

2. Test the following categories:

   a. Validate drive train

      i. Chain management and interference

      ii. Gearing requirements

      iii. Impedance match

   b. Determine load cases and loads

      i. CPSC Fork and frame test

      ii. Maximum Acceleration

iii. Road/water obstructions

iv. Hill climb

v. Maximum braking—front

vi. Maximum braking—rear

c. Validate frame/hull structure

i. Structural analysis (FEM, etc.)

ii. Optimization

iii. Modify and iterate as required

d. Review component compatibility

i. Modify and iterate as required

e. Complete details

i. CHECK: Interference, chain management

ii. Features—brake bosses, braze-ons, seats/saddles, etc.

iii. Cable/control routing and hardware

f. Complete drawings

i. Detailed SP part drawings

ii. Assembly drawings

iii. BOM

g. Prototype fabrication and testing

i. Fabrication and Assembly

ii. Functionality testing

iii. Performance testing

iv. Market testing

h. Modify and iterate or advance to production planning

3.2 Frame Design [26]

There is no standard methodology available to design the frame of a recumbent bicycle. The following sections contain the method we followed to design the bicycle frame.

3.2.1 Design Specifications

- Head tube angle, (90-β): 72°

  It is the angle made by the horizontal and the steering axis

- Rake, S: 42mm

  It is also known as fork offset. It is the distance of steering axis from an axis parallel to it passing through the center of the wheel

- Trail, T: 0.059 mm

  It is the horizontal distance between the tire contact patch and the point at which the steering axis meets the ground on being extended

- Seat height: 520mm

  It is the vertical distance between the sat and the ground

- Bottom bracket height: 690mm

  It is the Height of the pedal assembly from the ground.

- Wheel : standard wheel of size ISO-650c X 35 was selected for both front and rear
- Crank length: 160mm (Can range upto 170mm)

  It is the length of the crank arm to which the pedal is attached

- Wheelbase:1100mm

  It is the Center-to- center distance of wheels

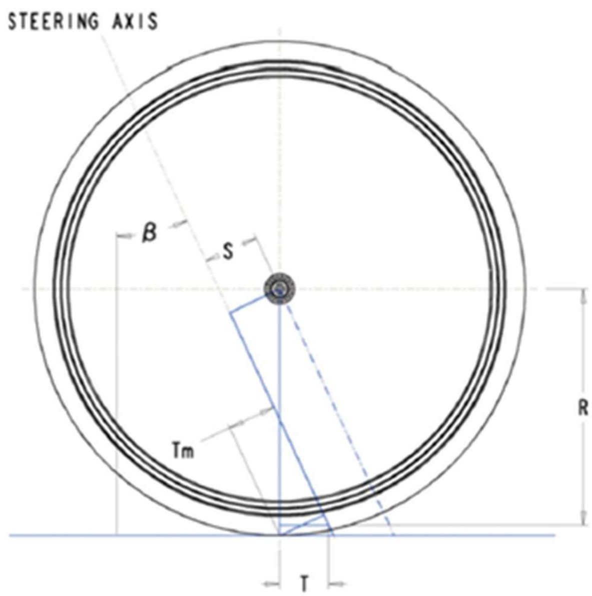


Image source-Design of Human Powered Vehicles

3.2.2 Design Parameters

Before starting the sketch of the cycle, we need to get some measurements from the rider as it is a customised model. The following measurements need to be taken.

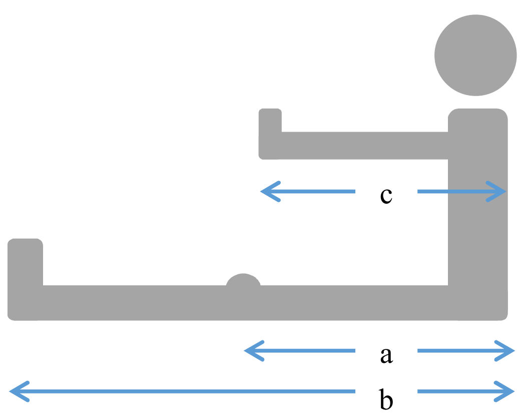


Figure 9 Measurements from the rider required for frame design

The rider is required to sit with back touching the wall and then raise the hands in an angle of 90 degrees. The values calculated are as given in the table below.

Variable	Value (cm)	Distance
a	66	The back to knee distance
b	117	The back to feet distance
c	80	The back to palm distance

The following parameters were selected for our rider based on the values of a, b and c

Sr No	Parameter	Value
1	Backrest-Angle	50 Degree
2	Backrest-Length	450mm
3	BB-BOS	970mm
4	BB-Clearance	320mm
5	BB-Height	400mm (min)
6	BB-Seat-Diff	170mm
7	CL (Crank Length)	160mm
8	HB-TOS	575mm
9	Saddle-Length	200mm
10	Seat-Height	520mm
11	TC (Turning Clearance)	150mm to 200mm

Based on the calculated values of a, b and c we can find the below values.

BB-BOS= b-CL-100*

HB-TOS= c-50*

BB-HB= CL+TC+600*

b-a = min seat height

Here,

BB- Bottom Bracket

BOS- Back of seat

TOS- Top of seat

HB- Handlebar

*These values are approximations

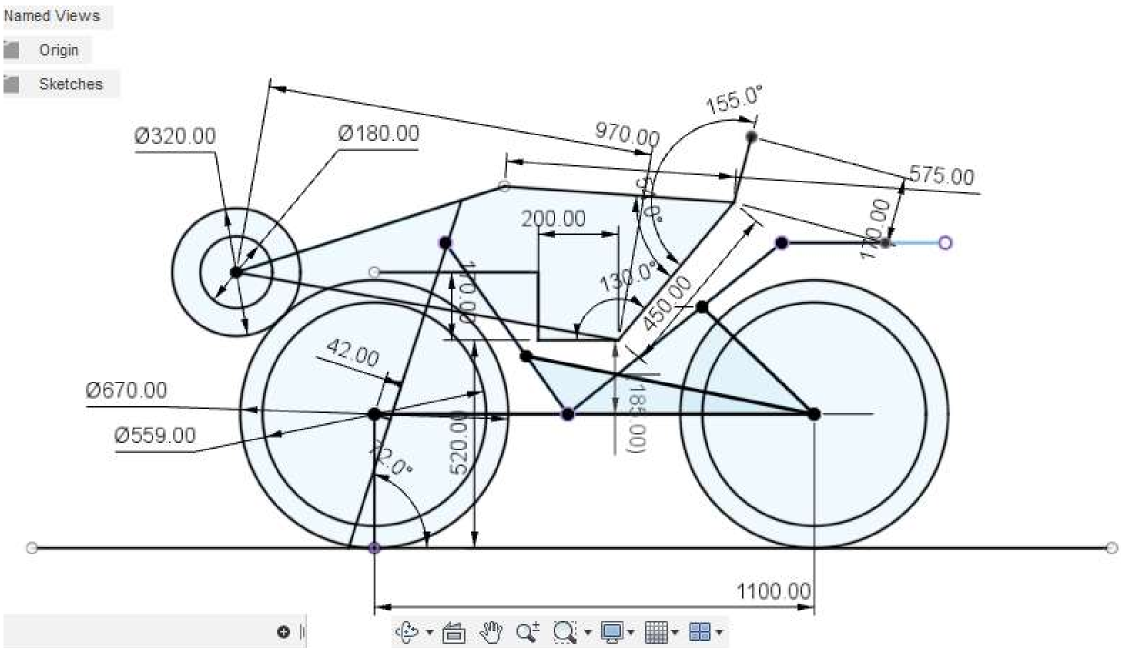
3.2.3 Design Methodology

Following methodology was followed to design the skeleton sketch of the cycle

1. Draw a seat with defined backrest angle and fixed saddle length
2. Draw a horizontal line taking perpendicular distance from saddle point as BB-seat difference(L1)
3. Draw an arc with BB-BOS value. Intersection of this arc and L1 is BB.(Bottom Bracket location)
4. With BB as center draw a circle with radius BB-Clearance
5. Select a Standard front wheel, tangential to the drawn circle. There must be sufficient distance between saddle and the wheel to accommodate the frame.
6. Mark the trail value from the contact of the front wheel and draw a line with the head tube angle. (L2)
7. Draw an arc from TOS with radius HB-TOS. The intersection of L2 and this arc is the location of the steering.
8. Validate the HB-BOS distance.
9. Determine your weight distribution on front and rear wheel. Assume a CG and calculate the distance of rear wheel from it using the ratio of weight distribution.
10. Determine the CG after fitting the frame in the geometry and building the model and validate its location. If different, modify the initial geometry till it coincides.
11. Validate the design – Patterson's method.

3.2.4 Skeleton Sketch

Made using fusion 360



3.3 The Electric Drivetrain

The global production of electric two-wheelers (mostly electric bicycles) drastically increased from 28 million to 40 million units from the year 2012 to 2014, respectively. More than 15 crore Electric Bikes have been sold in the past decade, most of them in China, India, Malaysia, and other Asian countries.[11] Electric bikes are also known as second cars in this decade. These are quieter, help the rider to achieve speed, and also make the ride physically less straining compared to normal human-powered vehicles. The motor power for a pedal-assist bicycle is lesser than that of a throttled- pure electric bicycle.

3.3.1 Components with specifications

3.3.1.1 Motor: 250 W, 36V.

This is a rear-wheel hub motor. A rear wheel hub motor does not source wheel slippage because its weight is distributed at the rear of the Electric Bike, as the front wheel hub motor does. However, keeping the motor on the rear wheel hub causes an imbalance between the rear and front of the Electric Bike, which can put enormous pressure on the rear wheel. Rear-wheel hub motors are available in a variety of range of power and control options.[11]

3.3.1.2 Battery: 10.4 Ah Li-ion battery

The important properties of an Electric Bike battery include long life, safety, lightweight, higher energy density, fast charging rate, lesser discharge loss, inexpensive, and sustainability, all of which are currently being researched and developed globally. Rechargeable batteries that could be used for Electric Bikes include nickel (NiCd, NiMH) batteries, lithium batteries, and lead-acid batteries, but nickel batteries seem to be rarely taken into account in Electric Bike studies because of their high expenses as well as environmental factors. Therefore, most Electric Bikes studies concentrate on lead-acid and lithium batteries[11]

3.3.1.3 Pedal-assist sensor: 5 Level

The rider is given the freedom to choose from 0-5 levels of pedal-assist, according to the chosen level the physical work reduces from 0 to 5.

3.3.1.4 Converter and electric display:

The converter balances voltage and current levels between the motor and the battery. The electric display helps in choosing the pedal assist levels and gives the speed data and shows charging levels of the battery, etc.

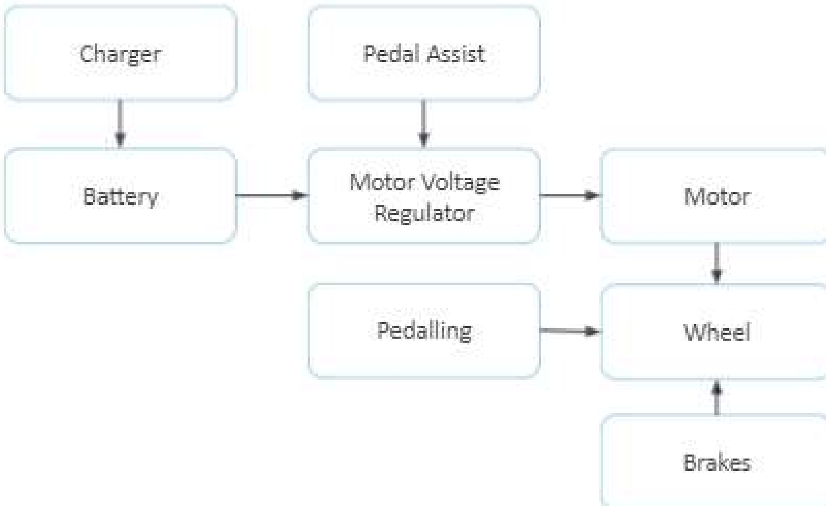
3.3.1.5 Charger

5A charger is quicker and charges the battery in 2 hours approximately
Better charging methods will demonstrate improving efficient utilization as well as later encourage the usage of Electric Bikes in the near future. In general, charging methods for Electric Bikes include constant voltage, constant current, and a blend of constant current and constant voltage[11].

3.3.2 Working

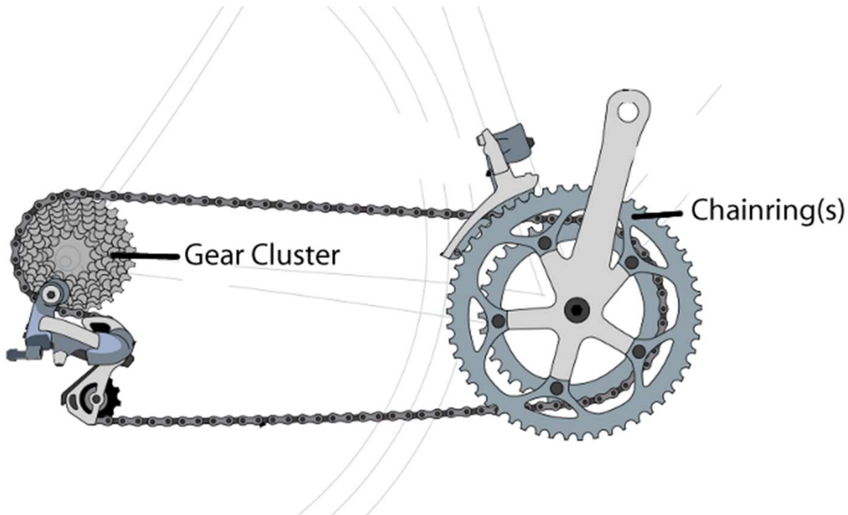
The power-assisted bicycle, which is also known as a pedelec, is a human-electric hybrid bicycle that assists the rider when pedaling, and it has a sensor to detect the pedaling speed (speed sensor), pedaling force (torque sensor) or both. When the rider starts to pedal a pedal-assist, the torque sensor will detect the force powered by pedaling and then send a voltage signal to an electronic control unit (ECU) to control an electric motor, which creates more power to assist the rider when pedaling. [11] When the raider pedals the bike pedal-assist speed sensor detects rotational speed in the crank axle and as a response engages the motor with the wheel. The torque sensor measures the physical force applied by the raider on the pedals and balances the speed to keep the power and speed constant. It manages the speed and brings maneuverability. These sensors work on the pre-described values given by the rider on the display and manage the speeds. If the speed limit is already achieved, then the motor is automatically disengaged and the crankset is locked. When brakes are applied the wheels are made to stop rotating by applying friction just like it is done in the case of normal geared or non-geared bicycles. The battery drives the motor and is charged with the help of the motor, the ECU, the converter manages and balances all the voltage and current levels in the battery and the motor.

3.3.3 Block Diagram:



3.4 Mechanical Drivetrain

It transfers power from the rider to wheels. For optimal performance cadence force and stroke has to be set correctly.



3.4.1 Components

- Chainring: It is a set of sprockets attached to the pedal mechanism. commercially available types are single double and triple chainring containing one, two and three sprockets respectively.
- Gear cluster/cassette/cog set: it is attached to the axle of the front wheel. It contains a number of sprockets with different numbers of teeth and aids in achieving different speed ratios.
- Gear shifting mechanism: it is a mechanism that is used to shift chain from one sprocket to another. It is categorised into three types internal hub gear, derailleurs, hybrid gear

3.4.2 Types of drivetrain based on speeds

Drivetrain can be simple drive or multi speed drives.

- Simple drives provide riders with a single speed i.e. it has a single velocity ratio between crack and wheel keeping speed of wheel rotation relative to crank rotation constant. This has the advantage of being simple, reliable, and having low cost but also leads to low performance levels as maximum speed is limited by rider's cadence.

- Multi speed drives are used where performance is a priority, because effective cadence range is much smaller than useful speed range.

3.4.3 Parameters

1. Gearing is the ratio of crank/power input speed to vehicle speed.
2. Gear development is the distance that the bicycle covers when the crank is turned one complete revolution. It is measured in meters.
3. Gear inches expresses gear ratio is the diameter of an equivalently driven wheel (https://en.wikipedia.org/wiki/Gear_inches)
4. Gain ratio: distance travelled by bicycle to the distance of revolution of pedal axle during one turn of crank. . It also takes into consideration the effect of length of crank arm on mechanical advantage. Usually a longer crank arm gives more mechanical advantage than a shorter crank arm. (https://en.wikipedia.org/wiki/Gear_inches)

Gear development and gear inches give us an idea of the mechanical advantage of the bicycle. For most general purpose riding it was recommended to have gear development of 3m-4m or 40-90 gear inches which is roughly equivalent to a speed of 3-11m/s.

s.no.	Parameter	Formula
1.	Gear development (m)	$\frac{N_{chainring}}{N_{flywheel}} \times D_{drive\ wheel} \times \pi$
2.	Gear inches	$VR*D_{DRIVE}$
3.	Speed (m/s)	Gear inches*π*cadence in rpm

3.4.4 Selection of number of teeth on cassette and chainring

Some factors taken into consideration for selecting gear sets are:

- Higher gears require higher pedal forces thus increasing the gear development only increases the bicycle speed upto a certain level after which it tends to remain constant.

- Larger chainrings are harder to turn but moves the bicycle larger distances per revolution whereas smaller chainrings are easier to turn but move the bicycle smaller distances per revolution.
- More gear transitions lead to interruptions in power transfer

We wanted 10 speed ratios in our bicycle as per the commercial requirement

And thus had an option for selecting a double chainring system with 5 sprocket cog or a single chainring system with 10 sprocket cog

As wider cassettes are comparatively difficult to mount we choose a 5 speed cassette with even number of teeth

We analysed our options of chainring cassette gears system using MATLAB program to give us the gear pairs best suited for our requirements of gear development range.

42t/28t with 10t-18tcasette gives gear development range from 8.844m suitable for high speed or downhill conditions to 3.2756m suitable for slightly steep hill riding without load and normal riding conditions as listed below. This gives us a max speed of 11.792m/s for open roads and a max speed of 7.37 m/s and min speed of 2.2422m/s for city roads

The speeds obtained for various gear ratios for cadence ranging from 50-80 rpm are listed in

chainring_e	**casette_e**	**dev_e**	**speed_ine**	**speedmax_e**
42	10	8.844	7.37	11.792
42	12	7.37	6.1417	9.8267
42	14	6.3171	5.2643	8.4229
42	16	5.5275	4.6063	7.37

42	18	4.9133	4.0944	6.5511
28	10	5.896	4.9133	7.8613
28	12	4.9133	4.0944	6.5511
28	14	4.2114	3.5095	5.6152
28	16	3.685	3.0708	4.9133
28	18	3.2756	2.7296	4.3674

3.4.5 Drivetrain configurations

We have selected the front wheel drive with the pivoting crank configuration

- Simple chain with centerline rear wheel drive
- Complex chain drive with centerline rear wheel drive
- Front wheel drive with fixed crack
- Front wheel drive with pivoting crank
- Dual wheel rear wheel drives

3.4.6 Gear shifting mechanism

3.4.6.1 Internal hub gear (https://wheretheroadforks.com/internal-gear-hub-vs-derailleur-my-pros-and-cons-list/)

(https://www.youtube.com/watch?v=XkjH4mHFO9M)

(https://en.wikipedia.org/wiki/Hub_gear)

It makes use of epicyclic gears and has 3 basic speeds. It is heavier than derailleur and also resistant to damage due to impacts and foreign particles. It does not require the rider to adjust the chain as the chain never comes off the gears. It is more expensive than derailleurs and less commonly used. They enable the rider to shift gears even when the rider is not pedaling, but suffer when the rider tries to shift gear under load as release of pressure is required for gear change. Changing the wheel without changing the hug gear is not possible as internal hub gear forms an integral part of the wheel itself.

3.4.6.2 Derailleurs

It makes use of a mechanism which mounts the chain on a small fixed sprocket like structure and shifts laterally to enable chain shifting. Rear derailleurs shift between sprockets of cog and front derailleurs shift between chainrings. They give higher speed ratios and the rider can only change the gear while pedaling.

3.4.6.3 Hybrid gearing with derailleurs (https://en.wikipedia.org/wiki/Hub_gear)

It makes use of internal hub gears and derailleurs both leading to a wider range of gear ratios but with increased weight and complexity. It is advantageous if used in recumbent as it makes starting from a stop after breaking hard easier.

We decided to use a front and rear derailleur system considering the number of speeds that we wanted to achieve and its lower cost and weight , ease of availability of replacements, and simplicity

3.4.7 Drivetrain Program

3.4.7.1 MATLAB Program

```
clear all;
clc;
%taking gear developmment in range of 2.6-9m
geardevmin=input('enter the minimum value of gear
development required')
geardevmax=input('enter the maximum value of gear
development required')
wheeldia=input('enter the drive wheel diameter')
lowgearratio=geardevmin/(wheeldia*(22/7))
highgearratio=geardevmax/(wheeldia*(22/7))
i=1;
```

```
v=28:2:50;
  for i=1:12
     Nchainring(i)=v(i);
  end
e=10:2:50;
   for i=1:21
       Ncassette_e(i)=e(i);
   end
o=11:2:51;
   for i=1:21
       Ncassette_o(i)=o(i);
   end
Nchainring;
Ncassette_e;
Ncassette_o;
r_e=Nchainring./Ncassette_e';
r_o=Nchainring./Ncassette_o';
%considering cadence range from 50-80
cadencemin=input('enter the min cadence value in rpm')
cadencemax=input('enter the max cadence value in rpm')
%for odd number of teeth cog
location_o=r_o>lowgearratio & r_o<highgearratio;
ratio_o=r_o(location_o);
dev_o=ratio_o*wheeldia*(22/7);
speedmino=dev_o*cadencemin/60;
speedmaxo=dev_o*cadencemax/60;
[Nfl Ncl]=find(r_o>lowgearratio & r_o<highgearratio);
chainring=Nchainring(Ncl)';
casette_o=Ncassette_o(Nfl)';
T_o=table(chainring,casette_o,dev_o, speedmino,
speedmaxo)
%for even number of teeth cog
location_e=r_e>lowgearratio & r_e<highgearratio;
```

```
ratio_e=r_e(location_e);
dev_e=ratio_e*wheeldia*(22/7);
speedmine=dev_e*cadencemin/60;
speedmaxe=dev_e*cadencemax/60;
[Nfle Ncle]=find(r_e>lowgearratio &
r_e<highgearratio);
chainringe=Nchainring(Ncle)';
casette_e=Ncassette_e(Nfle)';
T_e=table(chainringe,casette_e, dev_e, speedmine,
speedmaxe)
%plotting graphs
figure (1)
plot(dev_e, speedmaxe, '-r', dev_e, speedmine, '-g')
axis([0 15 0 15])
title('speed ranges versus gear development')
xlabel('gear development in m')
ylabel('speed in m/s')
legend({'y = spped for min cadence','y = speed for max
cadence'},'Location','southeast')
grid on;
```

3.4.7.2 Output

enter the minimum value of gear development required

2.6

geardevmin =

2.6000

enter the maximum value of gear development required

9

geardevmax =

9

enter the drive wheel diameter

0.67

wheeldia =

0.6700

lowgearratio =

1.2347

highgearratio =

4.2741

enter the min cadence value in rpm

50

cadencemin =

50

enter the max cadence value in rpm

80

cadencemax =

80

T_o =

127×5 **table**

chainring	casette_o	dev_o	speedmino	speedmaxo
28	11	5.36	4.4667	7.1467
28	13	4.5354	3.7795	6.0472
28	15	3.9307	3.2756	5.2409
28	17	3.4682	2.8902	4.6243
28	19	3.1032	2.586	4.1375

28	21	2.8076	2.3397	3.7435
30	11	5.7429	4.7857	7.6571
30	13	4.8593	4.0495	6.4791
30	15	4.2114	3.5095	5.6152
30	17	3.716	3.0966	4.9546
30	19	3.3248	2.7707	4.4331
30	21	3.0082	2.5068	4.0109
30	23	2.7466	2.2888	3.6621
32	11	6.1257	5.1048	8.1676
32	13	5.1833	4.3194	6.9111
32	15	4.4922	3.7435	5.9896
32	17	3.9637	3.3031	5.2849
32	19	3.5465	2.9554	4.7286
32	21	3.2087	2.6739	4.2783
32	23	2.9297	2.4414	3.9063
32	25	2.6953	2.2461	3.5938
34	11	6.5086	5.4238	8.6781
34	13	5.5073	4.5894	7.343
34	15	4.773	3.9775	6.3639
34	17	4.2114	3.5095	5.6152
34	19	3.7681	3.1401	5.0242
34	21	3.4093	2.841	4.5457
34	23	3.1128	2.594	4.1504
34	25	2.8638	2.3865	3.8184
34	27	2.6516	2.2097	3.5355
36	11	6.8914	5.7429	9.1886
36	13	5.8312	4.8593	7.7749
36	15	5.0537	4.2114	6.7383

36	17	4.4592	3.716	5.9455
36	19	3.9898	3.3248	5.3197
36	21	3.6098	3.0082	4.8131
36	23	3.2959	2.7466	4.3945
36	25	3.0322	2.5269	4.043
36	27	2.8076	2.3397	3.7435
36	29	2.614	2.1783	3.4853
38	11	7.2743	6.0619	9.699
38	13	6.1552	5.1293	8.2069
38	15	5.3345	4.4454	7.1126
38	17	4.7069	3.9224	6.2759
38	19	4.2114	3.5095	5.6152
38	21	3.8103	3.1753	5.0805
38	23	3.479	2.8992	4.6387
38	25	3.2007	2.6672	4.2676
38	27	2.9636	2.4697	3.9515
38	29	2.7592	2.2993	3.6789
40	11	7.6571	6.381	10.21
40	13	6.4791	5.3993	8.6388
40	15	5.6152	4.6794	7.487
40	17	4.9546	4.1289	6.6062
40	19	4.4331	3.6942	5.9108
40	21	4.0109	3.3424	5.3478
40	23	3.6621	3.0518	4.8828
40	25	3.3691	2.8076	4.4922
40	27	3.1196	2.5996	4.1594
40	29	2.9044	2.4204	3.8726
40	31	2.7171	2.2642	3.6227

42	11	8.04	6.7	10.72
42	13	6.8031	5.6692	9.0708
42	15	5.896	4.9133	7.8613
42	17	5.2024	4.3353	6.9365
42	19	4.6547	3.8789	6.2063
42	21	4.2114	3.5095	5.6152
42	23	3.8452	3.2043	5.127
42	25	3.5376	2.948	4.7168
42	27	3.2756	2.7296	4.3674
42	29	3.0497	2.5414	4.0662
42	31	2.8529	2.3774	3.8039
42	33	2.68	2.2333	3.5733
44	11	8.4229	7.019	11.23
44	13	7.127	5.9392	9.5027
44	15	6.1768	5.1473	8.2357
44	17	5.4501	4.5417	7.2668
44	19	4.8764	4.0637	6.5019
44	21	4.412	3.6766	5.8826
44	23	4.0283	3.3569	5.3711
44	25	3.7061	3.0884	4.9414
44	27	3.4315	2.8596	4.5754
44	29	3.1949	2.6624	4.2598
44	31	2.9888	2.4906	3.985
44	33	2.8076	2.3397	3.7435
44	35	2.6472	2.206	3.5296
46	11	8.8057	7.3381	11.741
46	13	7.451	6.2092	9.9347
46	15	6.4575	5.3813	8.61

46	17	5.6978	4.7482	7.5971
46	19	5.098	4.2484	6.7974
46	21	4.6125	3.8438	6.15
46	23	4.2114	3.5095	5.6152
46	25	3.8745	3.2288	5.166
46	27	3.5875	2.9896	4.7834
46	29	3.3401	2.7834	4.4535
46	31	3.1246	2.6038	4.1661
46	33	2.9352	2.446	3.9137
46	35	2.7675	2.3063	3.69
46	37	2.6179	2.1816	3.4906
48	13	7.7749	6.4791	10.367
48	15	6.7383	5.6152	8.9844
48	17	5.9455	4.9546	7.9274
48	19	5.3197	4.4331	7.0929
48	21	4.8131	4.0109	6.4174
48	23	4.3945	3.6621	5.8594
48	25	4.043	3.3691	5.3906
48	27	3.7435	3.1196	4.9913
48	29	3.4853	2.9044	4.6471
48	31	3.2605	2.7171	4.3473
48	33	3.0629	2.5524	4.0838
48	35	2.8878	2.4065	3.8504
48	37	2.7317	2.2764	3.6423
50	13	8.0989	6.7491	10.799
50	15	7.019	5.8492	9.3587
50	17	6.1933	5.1611	8.2577
50	19	5.5414	4.6178	7.3885

50	21	5.0136	4.178	6.6848
50	23	4.5776	3.8147	6.1035
50	25	4.2114	3.5095	5.6152
50	27	3.8995	3.2496	5.1993
50	29	3.6305	3.0255	4.8407
50	31	3.3963	2.8303	4.5284
50	33	3.1905	2.6587	4.254
50	35	3.0082	2.5068	4.0109
50	37	2.8456	2.3713	3.7941
50	39	2.6996	2.2497	3.5995

T_e =

132×5 **table**

chainringe	**casette_e**	**dev_e**	**speedmine**	**speedmaxe**
28	10	5.896	4.9133	7.8613
28	12	4.9133	4.0944	6.5511
28	14	4.2114	3.5095	5.6152
28	16	3.685	3.0708	4.9133
28	18	3.2756	2.7296	4.3674
28	20	2.948	2.4567	3.9307
28	22	2.68	2.2333	3.5733
30	10	6.3171	5.2643	8.4229
30	12	5.2643	4.3869	7.019
30	14	4.5122	3.7602	6.0163
30	16	3.9482	3.2902	5.2643
30	18	3.5095	2.9246	4.6794

30	20	3.1586	2.6321	4.2114
30	22	2.8714	2.3929	3.8286
30	24	2.6321	2.1935	3.5095
32	10	6.7383	5.6152	8.9844
32	12	5.6152	4.6794	7.487
32	14	4.8131	4.0109	6.4174
32	16	4.2114	3.5095	5.6152
32	18	3.7435	3.1196	4.9913
32	20	3.3691	2.8076	4.4922
32	22	3.0629	2.5524	4.0838
32	24	2.8076	2.3397	3.7435
34	10	7.1594	5.9662	9.5459
34	12	5.9662	4.9718	7.9549
34	14	5.1139	4.2616	6.8185
34	16	4.4746	3.7289	5.9662
34	18	3.9775	3.3146	5.3033
34	20	3.5797	2.9831	4.773
34	22	3.2543	2.7119	4.339
34	24	2.9831	2.4859	3.9775
34	26	2.7536	2.2947	3.6715
36	10	7.5806	6.3171	10.107
36	12	6.3171	5.2643	8.4229
36	14	5.4147	4.5122	7.2196
36	16	4.7379	3.9482	6.3171
36	18	4.2114	3.5095	5.6152
36	20	3.7903	3.1586	5.0537
36	22	3.4457	2.8714	4.5943
36	24	3.1586	2.6321	4.2114

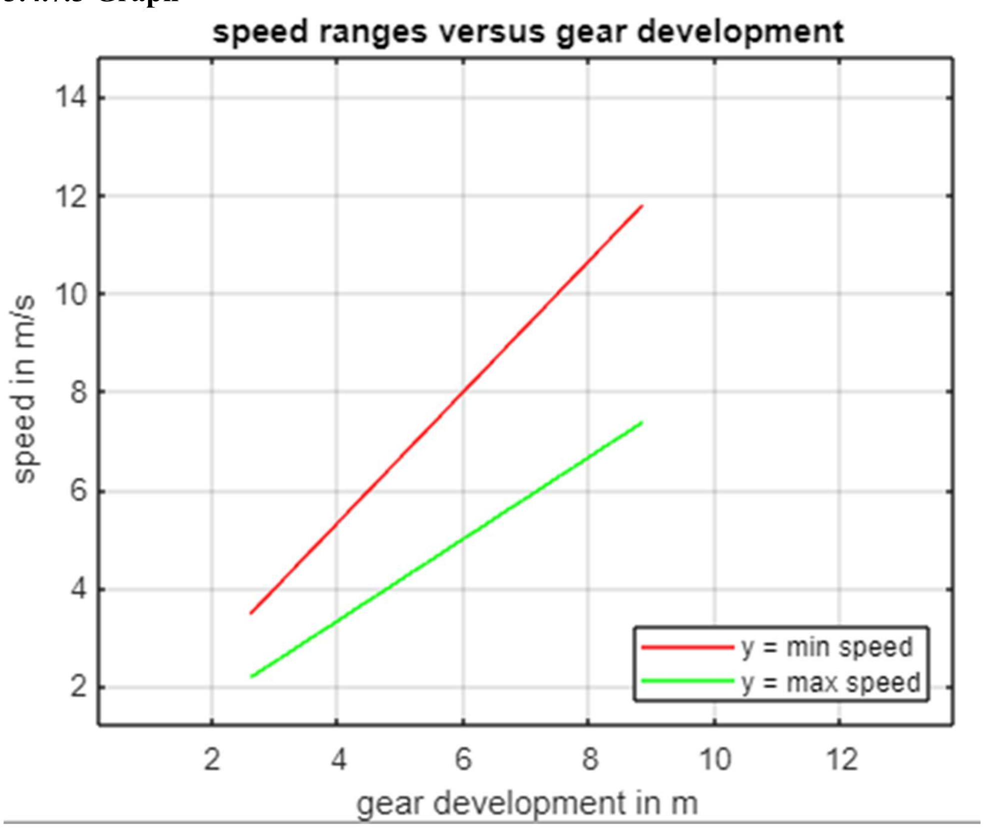
36	26	2.9156	2.4297	3.8875
36	28	2.7073	2.2561	3.6098
38	10	8.0017	6.6681	10.669
38	12	6.6681	5.5567	8.8908
38	14	5.7155	4.7629	7.6207
38	16	5.0011	4.1676	6.6681
38	18	4.4454	3.7045	5.9272
38	20	4.0009	3.334	5.3345
38	22	3.6371	3.031	4.8495
38	24	3.334	2.7784	4.4454
38	26	3.0776	2.5647	4.1034
38	28	2.8578	2.3815	3.8103
38	30	2.6672	2.2227	3.5563
40	10	8.4229	7.019	11.23
40	12	7.019	5.8492	9.3587
40	14	6.0163	5.0136	8.0218
40	16	5.2643	4.3869	7.019
40	18	4.6794	3.8995	6.2392
40	20	4.2114	3.5095	5.6152
40	22	3.8286	3.1905	5.1048
40	24	3.5095	2.9246	4.6794
40	26	3.2396	2.6996	4.3194
40	28	3.0082	2.5068	4.0109
40	30	2.8076	2.3397	3.7435
40	32	2.6321	2.1935	3.5095
42	10	8.844	7.37	11.792
42	12	7.37	6.1417	9.8267
42	14	6.3171	5.2643	8.4229

42	16	5.5275	4.6063	7.37
42	18	4.9133	4.0944	6.5511
42	20	4.422	3.685	5.896
42	22	4.02	3.35	5.36
42	24	3.685	3.0708	4.9133
42	26	3.4015	2.8346	4.5354
42	28	3.1586	2.6321	4.2114
42	30	2.948	2.4567	3.9307
42	32	2.7637	2.3031	3.685
42	34	2.6012	2.1676	3.4682
44	12	7.721	6.4341	10.295
44	14	6.618	5.515	8.8239
44	16	5.7907	4.8256	7.721
44	18	5.1473	4.2894	6.8631
44	20	4.6326	3.8605	6.1768
44	22	4.2114	3.5095	5.6152
44	24	3.8605	3.2171	5.1473
44	26	3.5635	2.9696	4.7514
44	28	3.309	2.7575	4.412
44	30	3.0884	2.5737	4.1178
44	32	2.8954	2.4128	3.8605
44	34	2.725	2.2709	3.6334
46	12	8.0719	6.7266	10.763
46	14	6.9188	5.7656	9.225
46	16	6.0539	5.0449	8.0719
46	18	5.3813	4.4844	7.175
46	20	4.8431	4.036	6.4575
46	22	4.4029	3.669	5.8705

46	24	4.036	3.3633	5.3813
46	26	3.7255	3.1046	4.9673
46	28	3.4594	2.8828	4.6125
46	30	3.2288	2.6906	4.305
46	32	3.027	2.5225	4.036
46	34	2.8489	2.3741	3.7985
46	36	2.6906	2.2422	3.5875
48	12	8.4229	7.019	11.23
48	14	7.2196	6.0163	9.6261
48	16	6.3171	5.2643	8.4229
48	18	5.6152	4.6794	7.487
48	20	5.0537	4.2114	6.7383
48	22	4.5943	3.8286	6.1257
48	24	4.2114	3.5095	5.6152
48	26	3.8875	3.2396	5.1833
48	28	3.6098	3.0082	4.8131
48	30	3.3691	2.8076	4.4922
48	32	3.1586	2.6321	4.2114
48	34	2.9728	2.4773	3.9637
48	36	2.8076	2.3397	3.7435
48	38	2.6598	2.2165	3.5465
50	12	8.7738	7.3115	11.698
50	14	7.5204	6.267	10.027
50	16	6.5804	5.4836	8.7738
50	18	5.8492	4.8743	7.7989
50	20	5.2643	4.3869	7.019
50	22	4.7857	3.9881	6.381
50	24	4.3869	3.6558	5.8492

50	26	4.0495	3.3745	5.3993
50	28	3.7602	3.1335	5.0136
50	30	3.5095	2.9246	4.6794
50	32	3.2902	2.7418	4.3869
50	34	3.0966	2.5805	4.1289
50	36	2.9246	2.4372	3.8995
50	38	2.7707	2.3089	3.6942
50	40	2.6321	2.1935	3.5095

3.4.7.3 Graph



Available chainring tooth numbers:

28 30 32 34 36 38 40 42

https://enduro-mtb.com/en/gear-ratios-mtb-drivetrain/

Standard cassette sizes

https://bike.bikegremlin.com/3573/bicycle-cassette-rear-chainrings-standards/#3

3.5 Patterson's method

It is the gyroscopic effect of wheels that make the bicycle stable. The wheels have 6 degrees of freedom, the one in vertically downward direction is eliminated due to ground, and the freedom in left and right direction is restricted due to lateral friction of wheel, but not totally as it is a non-holonomic constraint.

Lateral forces produce a moment about the steer axis, and mechanical trail acts as a moment arm creating steering torque, which along with changing the steering angle and also cause the cycle to lean or roll on one side because vertical roll and steering are coupled. The coupling is due to the effect of lateral ground forces at tyre contact patch and gyroscopic effect of wheels. If the bicycle leans to the left, the fork rotates to steer to the left. If the bicycle is initially straight and is steered to the left, it leans to the right. This makes the bicycle wave back and forth to oscillate between steer and lean, making the bicycle stable only above certain speeds.

Patterson's method gives us an idea about bicycle handling qualities. It was developed by Bill Patterson.

Bicycle handling qualities relate rider's action to bicycle's responses. The "bicycle handling characteristics" give us an idea of the nature, magnitude and quickness of bicycle responses when the handlebar is pushed or moved. The desirable characteristics of a bicycle are that it should be easy to balance, it should be responsive and sporty, and it should be stable during cruise.

3.5.1 Parameters

The basic parameters that provide us information regarding this are:

1. *Roll Control Authority*: It gives an idea of responsiveness ie agility of the bicycle. Change in roll rate w.r.t. distance the handlebar is moved. Roll Rate is the rate of rotation about the longitudinal (horizontal) axis.

   $$\frac{dW_x}{R_H d\delta} = KV \quad \text{Where } K = \left(\frac{b}{hL}\right)\left(\frac{coscos\,(\beta)}{R_H}\right)$$

2. *Torsional Spring Constant*: Change in torque on steering column w.r.t. change in steer angle. A positive value means that the rider would have to apply force in a direction opposite to the direction of steer, making the bicycle not rideable. As the speed of the

bicycle increases the Torsional Spring Constant becomes more negative providing a torque that opposes disturbances and makes the bicycle more stable.

$$\frac{dQ}{d\delta} = K_1 - K_2V^2$$

3. <u>*Control Sensitivity*</u>: it gives an idea of the feel of a bicycle, ie whether it feels light or heavy while maneuvering. It is the change in roll rate w.r.t rider's intentions. Intension is the weighted sum of handlebar motion and handlebar force Increased control sensitivity makes the bicycle difficult to control as the rider will tend to over control the bicycle.

$$\frac{dW_x}{d\ \ _{INT}} = \frac{K_4 \times V}{R_H + (\frac{K_3}{R_H})(-K_1 + K_2V^2)}$$

4. Fork Flop: there is a moment on fork assembly that produces rotation when the bicycle is lead. The change in this moment on the steering column w.r.t. Change on roll angle is called fork flop. It helps in providing feedback to the rider. It helps in providing riders feedback. Reducing the trial value to zero leads to zero fork flop, which destabilizes the bicycle any force that causes lean of bicycle will not be felt at the handlebar. The fork flop force should be kept below 225N/rad

$$\frac{dQ}{d\theta} = -T \times cos(\beta) \times (\frac{mgb}{L})$$

3.5.2 Equations used

Nomenclature

1. **L** Wheelbase
2. **b** Horizontal distance from rear axle to center of gravity
3. **h** Vertical distance from ground to center of gravity
4. **If** Mass moment of inertia of the front tire about the wheel axis
5. **Ir** Mass moment of inertia of the rear tire about the wheel axis
6. **kx** Radius of gyration about the centroidal x-axis (longitudinal axis)
7. **K** Roll Control Authority constant
8. **K1–K5** Patterson's constants (see text for explanation and interpretation)
9. **m** Combined mass of bicycle and rider
10. **Q** Moment about the head tube axis
11. **Rf** Front wheel radius, measured from axle to mid-point of tire

12. **Rr** Rear wheel radius, measured from axle to mid-point of tire
13. **RH** Handlebar radius, measured from steering axis to center of hand
14. **S** Fork offset
15. **T** Trail
16. **Tm** Mechanical trail
17. **V** Velocity of the bicycle
18. **Wx** Roll rate (rate of rotation about the longitudinal axis)
19. **Wz** Yaw rate (rate of rotation about the vertical axis)
20. **b** Compliment of the head tube angle, measured from the vertical
21. **d** Steering angle
22. **Ɵ** Roll angle

Sr no	Parameter	Formula	Calc. Value	Typical Values	Significance
1	T(Trail)	$T=\frac{Rsin(\beta)-S}{cos(\beta)}$	0.059m	-	
2	Tm (Mechanical Trail)	$T_m=Tcos(\beta)-R_f sin(\beta)$	-0.0615m	-	
3	K1 http://www.bicycle.tudelft.nl/Proceedings	$K1=m*g*\left(\frac{b}{l}\right)*T*\cos(90-\beta)*\sin(90-\beta)$	8.1348N m/rad	<10- Best Upto 25- ok	"Trim" force on handlebars during a steady turn

	BMD2010/papers/patterson2010application.pdf				
4	K2	$K_2 = T_m(\frac{m \times b \times cos(\beta)}{L^2})(\frac{k_x^2}{k_x^2+h^2})$	0.88kg	0.3kg	Torsional spring constant: TSC = K1 – K2V2
5	K3	$K_3 = \frac{1}{1500}$	Const.	Const.	Patterson's recommendation.
6	K4	$K_4 = K \times R_H$	0.7876 /m	.15–.5 /m	Lower K4 reduces max sensitivity. Used in max control sensitivity
7	Fork Flop-	$\frac{dQ}{d\theta} = -T \times cos(\beta) \times (\frac{mgb}{L})$	150.4278 N/rad	50–225 N/rad	Adequate fork flop makes the bike easy to control—the rider can sense

					roll error and make corrections without conscious effort.
8	Max Control Sensitivity	$\frac{dW_x}{d_{INT\ (MAX)}} = \frac{K_4}{2\sqrt{K_3 K_2}}$	16.2579 rad/ms	Less than 18 rad/ms	Bikes with higher K4 and better low speed capability should have larger K2 and give more 'feel' at the handlebar.
9	K	$K=(\frac{b}{hL})(\frac{cos(\beta)}{R_H})$	4.5m^{-2}	>3m^{-2}	Roll control authority=K*v

3.5.3 MATLAB Program

3.5.3.1 Input variables

Distance of center of gravity ahead of rear wheel, b=0.501;

Total design mass with rider, m=105;

Height of center of gravity=0.550;

Radius of gyration about centroidal x axis, k=0.4;

Wheel base,l=1.1;

Handlebar radius from steer axis to hands,r=0.175;

rake,S=0.042;

K3=1/1500;

gravity,g=9.81

Drive wheel radius, rw=0.3175

Thickness of tire, rt= 0.0175

Compliment of head tube angle, x= 18^0, 19^0, 20^0 (we selected 18^0 for our design)

3.5.3.2 Program

```
clear all;
close all;
clc;
b=0.5;m=75;h=0.7;k=0.4;l=1.64;r=0.29;S=0.025;
K3=1/1500;
g=9.81
rw=0.223
rt=.02
x=19:1:32
for j=1:14
fprintf('\n the value of x=%d',x(j))
trail=((rw*sind(x(j)))-S)/cosd(x(j))
trailmech=((trail*cosd(x(j)))+(rt*sind(x(j))))
K1=m*g*(b/l)*trail*cosd(x(j))*sind(x(j))
K2=(trailmech)*(m*b*cosd(x(j))/l^2)*((k^2)/((k^2)+(h^2)))
KS= (b*cosd(x(j)))/(h*l*r)
K4(j)=KS*r
FF= -(trail*cosd(x(j)))*(m*g*b/l)*(1/r)
CSmax(j)= K4(j)/(2*((K3*K2)^(1/2)))
```

```
K=(b/(h*l))*(cosd(x(j))/r)
K5(j)=(K3/4)*((CSmax(j))^2)
fprintf('--------------------------------------------------
-----')
%------------------------------------------------------------
------
v=1:1:30;
for i=1:30
%standard formulae
RCA(i)=K*v(i);
TSC(i)=(K1-(K2*(v(i)^2)));
n(i)=K4(j)*v(i);
d(i)=r+(K3/r)*(-K1+K2*(v(i)^2));
CS(i)=n(i)/d(i);
end
RCA;
TSC;
CS;
%for plotting graphs with speed on x axis
figure(1)
plot(v,RCA,'-r');
title('RCA vs v')
grid on;
figure(2)
plot (v,TSC,'-k');
title('TSC vs v')
grid on;
figure(3)
plot (v,CS,'-k');
title('CS vs v')
grid on;
end
figure(4)
```

```
plot (x,K4, '-og')
grid on;
title('K4 vs x')
```

3.5.3.3 Output

x =

18   19   20

the value of x=18

trail =

0.0590

trailmech =

0.0615

K1 =

8.1348

K2 =

0.8800

KS =

4.5004

K4 =

0.7876

FF =

-150.4278

CSmax =

16.2579

K =

4.5004

K5 =

0.0441

----

the value of x=19

trail =

0.0649

trailmech =

0.0671

K1 =

9.3732

K2 =

0.9537

KS =

4.4742

K4 =

0.7876   0.7830

FF =

-164.5154

CSmax =

16.2579   15.5260

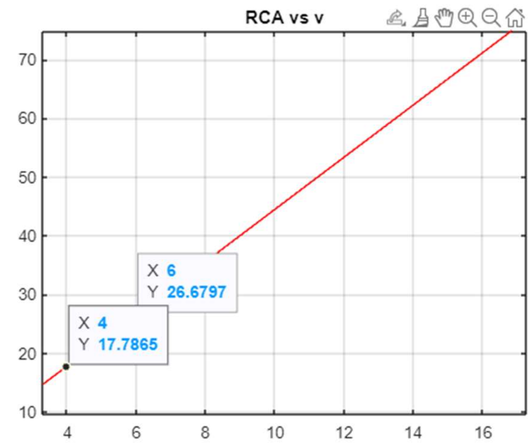
K =

4.4742

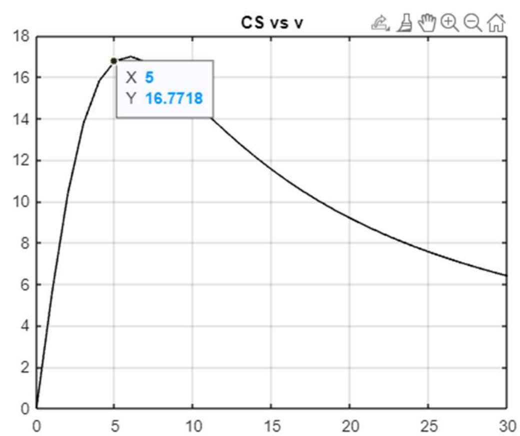
K5 =

```
   0.0441    0.0402

----------------------------------------------------------

the value of x=20

trail =

   0.0709

trailmech =

   0.0726

K1 =

  10.6850

K2 =

   1.0257

KS =

   4.4466

K4 =

   0.7876    0.7830    0.7782

FF =

-178.5186

CSmax =

  16.2579   15.5260   14.8788

K =

   4.4466

K5 =

   0.0441    0.0402    0.0369
```

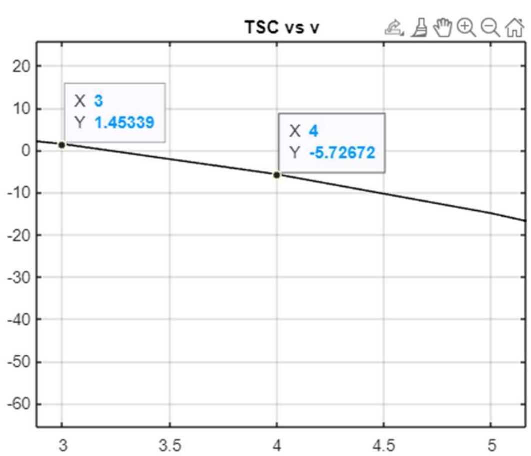
3.5.3.4 Graphs



Graph 1



Graph 2



Graph 3

3.5.4 Results

1. At high speeds the force applied on handlebars becomes important as roll control authority increases and the fork rotates through a very small angle. At low speeds due to low roll control authority the fork has to be rotated through larger distances. K is the slope of Roll Control Authority (RCA) v/s speed curve. It has a value of 4.5m^-2. As it is recommended that K should be greater than 3m^-2 for higher low speed control authority, we have an acceptable value
2. Control Sensitivity (CS) helps give a feel of the handlebar. Higher control sensitivity makes an inexperienced rider overcontrol the bicycle as it will have a large and quick response to the handlebar inputs. The max value of Control Sensitivity (CS) is 16.2679 rad/ms, which is less than the maximum acceptable value of 18 rad/ms for nimble bicycles. The maximum limit of value of control sensitivity is subjective depending on the rider's experience.
3. The Torsional spring constant (TSC) is the stiffness of a torsional spring equivalent to the total moment produced about the steering axis. Negative values provide torque that opposes the disturbances. A positive value of torsional spring constant would mean that the rider has to apply force in direction opposite to the steer direction, and is thus not desirable.

CHAPTER 4: 3D MODELLING AND SIMULATIONS

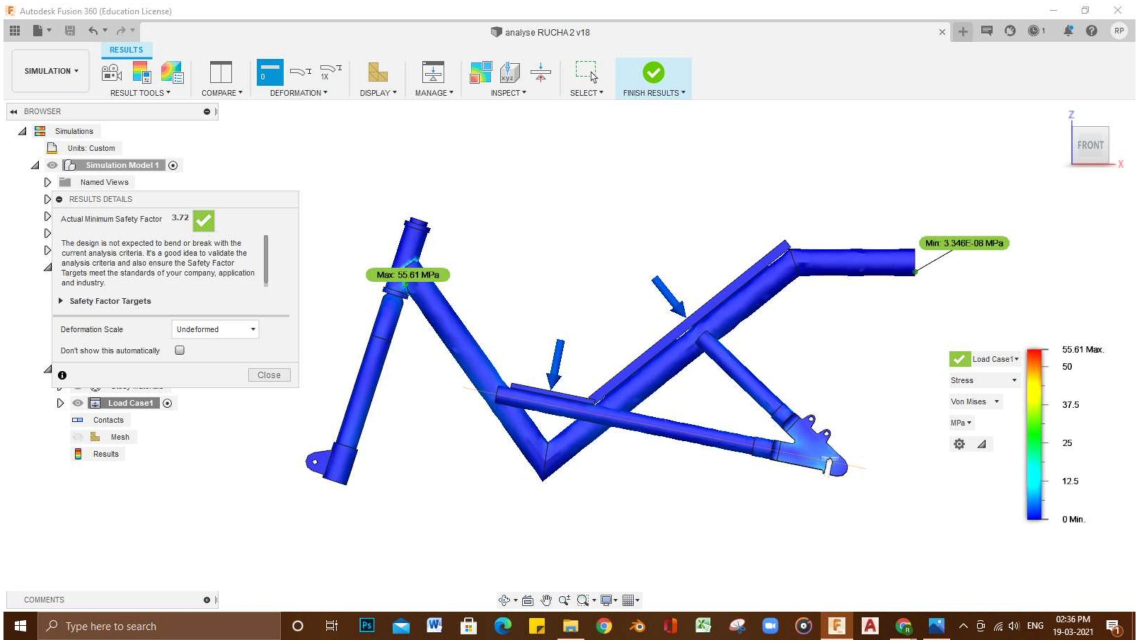
4.1 Introduction

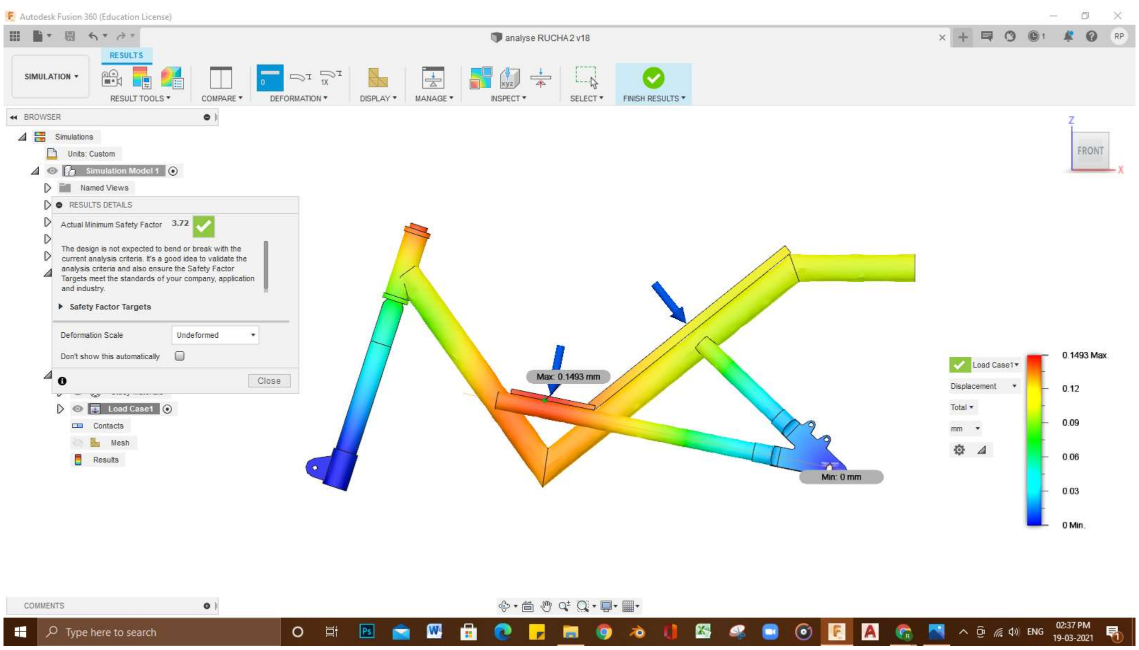
In this chapter, we cover the renders of the solid model made along with the finite element analysis of the model.

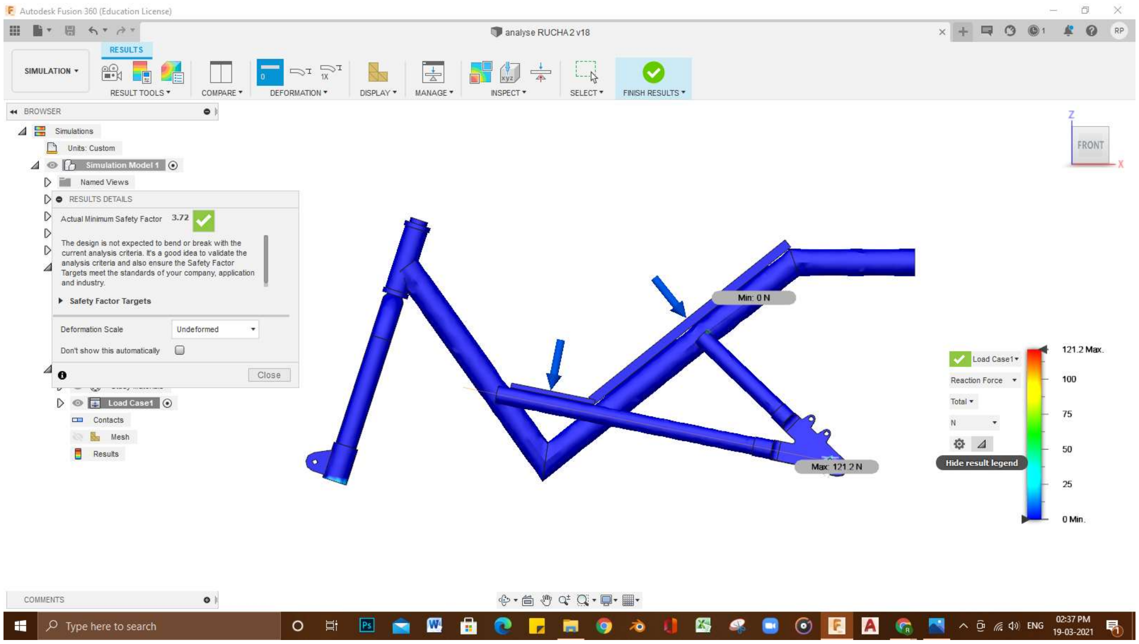
4.2 3D model

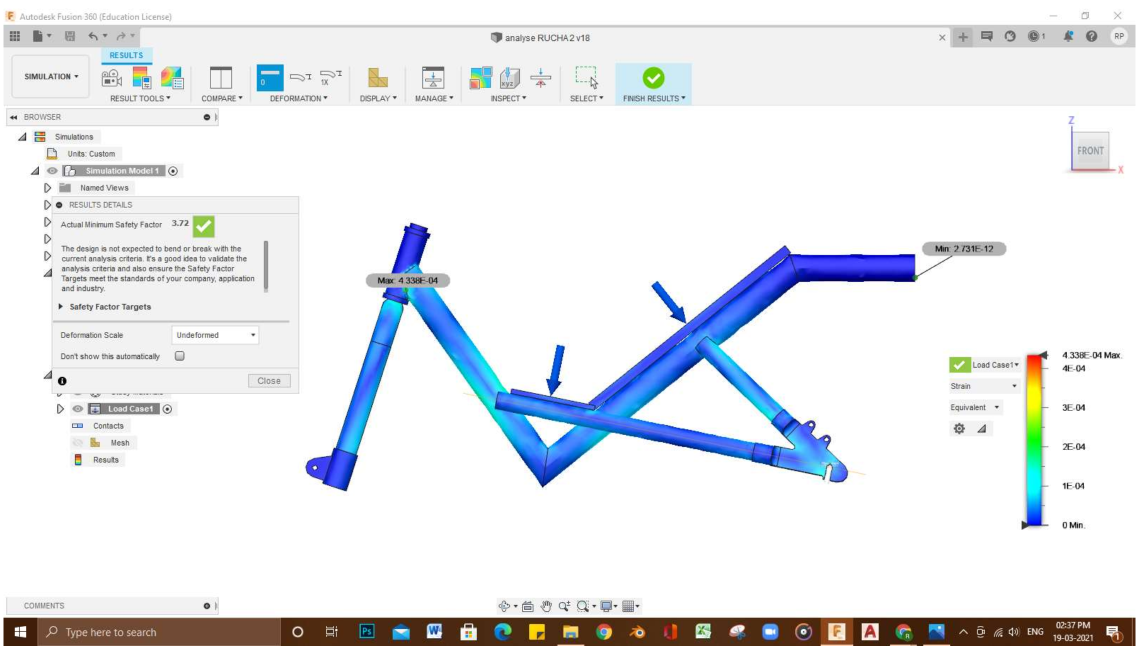
The model was designed using fusion 360.

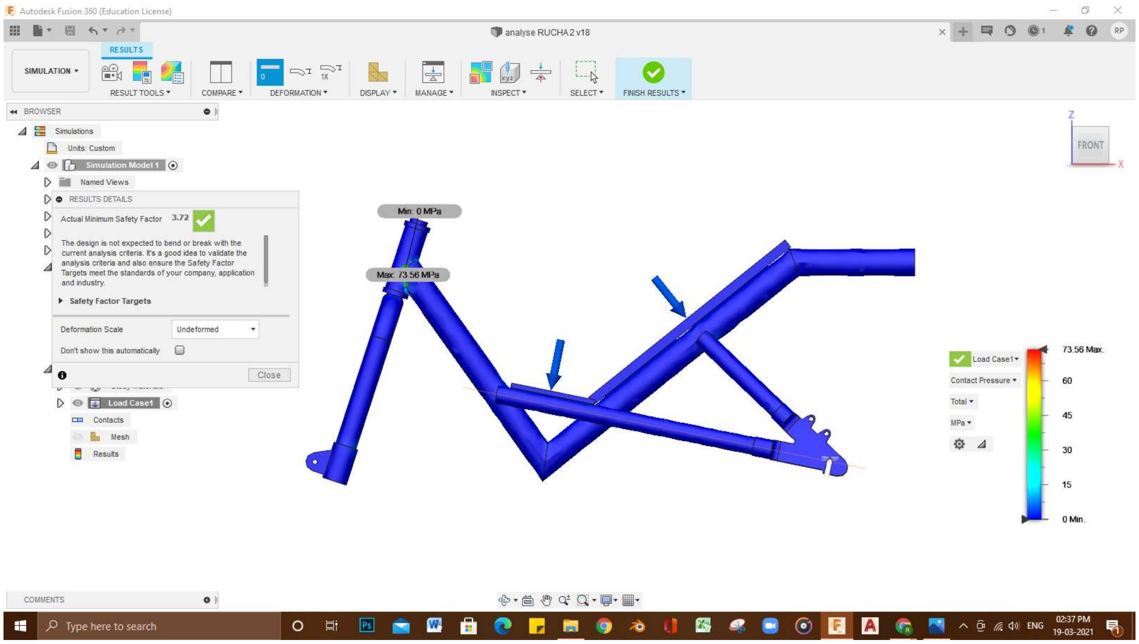
4.3 Analysis

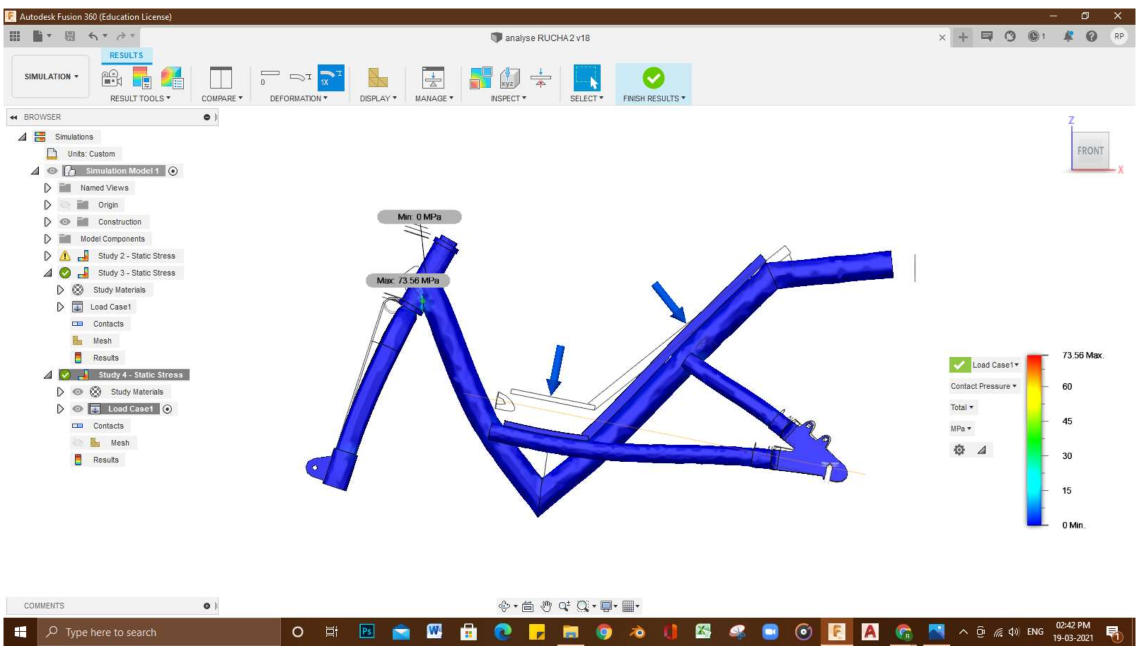

Autodesk Fusion 360 (Education License)
analyse RUCHA2 v18
Actual Minimum Safety Factor 3.72
The design is not expected to bend or break with the current analysis criteria. It's a good idea to validate the analysis criteria and also ensure the Safety Factor Targets meet the standards of your company, application and industry.
Safety Factor Targets
Deformation Scale
Undeformed
Max: 55.61 MPa
Min: 3.346E-08 MPa
Load Case1
Stress
Von Mises
MPa
55.61 Max.
50
37.5
25
12.5
0 Min.

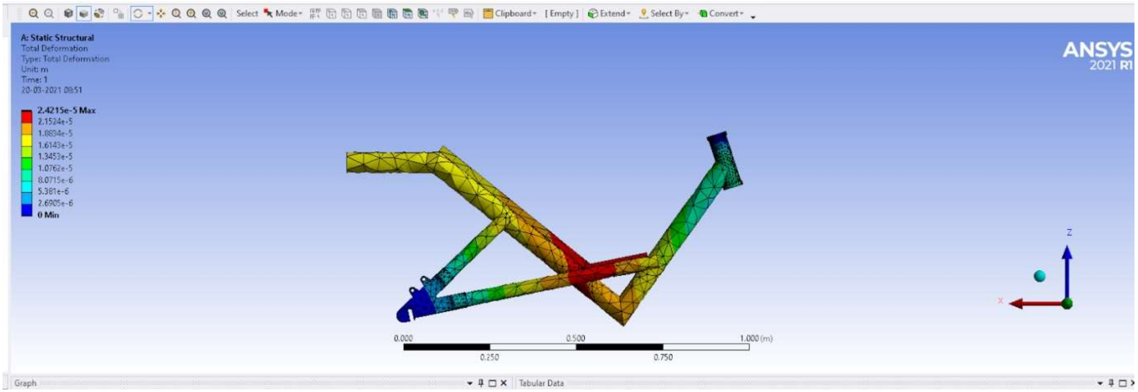

Autodesk Fusion 360 (Education License)
analyse RUCHA2 v18
Actual Minimum Safety Factor 3.72
The design is not expected to bend or break with the current analysis criteria. It's a good idea to validate the analysis criteria and also ensure the Safety Factor Targets meet the standards of your company, application and industry.
Safety Factor Targets
Deformation Scale
Undeformed
Max: 0.1493 mm
Min: 0 mm
Load Case1
Displacement
Total
mm
0.1493 Max.
0.12
0.09
0.06
0.03
0 Min.

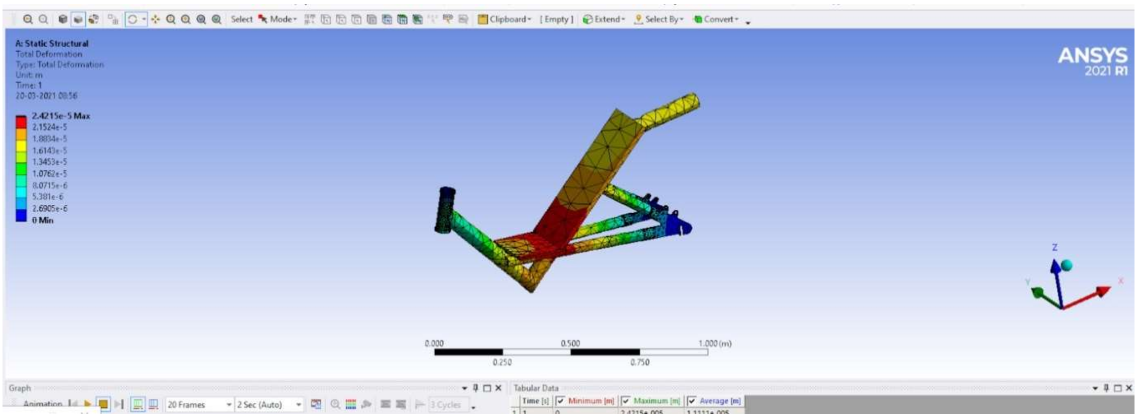

Autodesk Fusion 360 (Education License)
analyse RUCHA2 v18
RESULTS
SIMULATION
RESULT TOOLS
COMPARE
DEFORMATION
DISPLAY
MANAGE
INSPECT
SELECT
FINISH RESULTS
BROWSER
Simulations
Units: Custom
Simulation Model 1
Named Views
RESULTS DETAILS
Actual Minimum Safety Factor 3.72
The design is not expected to bend or break with the current analysis criteria. It's a good idea to validate the analysis criteria and also ensure the Safety Factor Targets meet the standards of your company, application and industry.
Safety Factor Targets
Deformation Scale
Undeformed
Don't show this automatically
Close
Load Case1
Contacts
Mesh
Results
FRONT
Min: 0 N
Max: 121.2 N
Load Case1
Reaction Force
Total
N
Hide result legend
121.2 Max.
100
75
50
25
0 Min.
COMMENTS
Type here to search
ENG
02:37 PM
19-03-2021

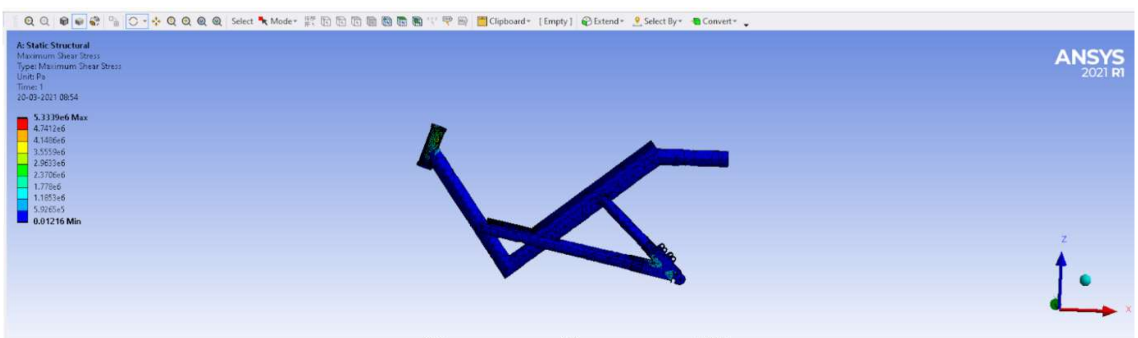

Autodesk Fusion 360 (Education License)
analyse RUCHA2 v18
RESULTS
SIMULATION
RESULT TOOLS
COMPARE
DEFORMATION
DISPLAY
MANAGE
INSPECT
SELECT
FINISH RESULTS
BROWSER
Simulations
Units: Custom
Simulation Model 1
Named Views
RESULTS DETAILS
Actual Minimum Safety Factor 3.72
The design is not expected to bend or break with the current analysis criteria. It's a good idea to validate the analysis criteria and also ensure the Safety Factor Targets meet the standards of your company, application and industry.
Safety Factor Targets
Deformation Scale
Undeformed
Don't show this automatically
Close
Load Case1
Contacts
Mesh
Results
FRONT
Max: 4.338E-04
Min: 2.731E-12
Load Case1
Strain
Equivalent
4.338E-04 Max.
4E-04
3E-04
2E-04
1E-04
0 Min.
COMMENTS
Type here to search
ENG
02:37 PM
19-03-2021






A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
2.4215e-5 Max
2.1524e-5
1.8834e-5
1.6143e-5
1.3453e-5
1.0762e-5
8.0715e-6
5.381e-6
2.6905e-6
0 Min
ANSYS
2021 R1
0.000
0.500
1.000 (m)
0.250
0.750
Graph
Tabular Data


A: Static Structural
Total Deformation
Type: Total Deformation
Unit: m
Time: 1
2.4215e-5 Max
2.1524e-5
1.8834e-5
1.6143e-5
1.3453e-5
1.0762e-5
8.0715e-6
5.381e-6
2.6905e-6
0 Min
ANSYS
2021 R1
0.000
0.500
1.000 (m)
0.250
0.750
Graph
Tabular Data
20 Frames
2 Sec (Auto)


A: Static Structural
Maximum Shear Stress
Type: Maximum Shear Stress
Unit: Pa
Time: 1
5.3339e6 Max
4.7412e6
4.1486e6
3.5559e6
2.9633e6
2.3706e6
1.778e6
1.1853e6
5.9265e5
0.01216 Min
ANSYS
2021 R1
0.000
0.500
1.000 (m)

CHAPTER 5 RESULTS AND CONCLUSIONS

5.1 Bill of Materials

5.2 Conclusions

5.3 Future Scope

5.3.1 Bamboo testing

As mentioned, earlier bamboo testing is a must in order to know the exact material properties which will further enhance and widen the scope of applications of the material.

5.3.1.1 Destructive testing:

The presently available tests particularly for the material, in this case, the culm is newly revised by the International Organization for Standardization (ISO) model standard, ISO 22157: 2019 Bamboo structures- Determination of Physical and Mechanical Properties of bamboo culms. This standard tests for mechanical properties that are compression parallel to fibers, tension parallel to fibers, tension perpendicular to fibers, shear parallel to fibers, flexural bending parallel to fibers, and flexural bending perpendicular to fibers, These tests come with their own limitations and thus are continuously renewed with time.[10]

Because we are using an indigenous species, using a local or national standard seems inevitable. Thus, the latest edition of the Bureau of Indian Standards (BIS), method of tests for bamboo- IS. 6874.2012 – Determining the physical and mechanical properties of round bamboo. It tests physical properties namely Moisture content, Basic mass per volume of density, and shrinkage. The mechanical properties that can be tested are the Static bending test, Compressive strength parallel to the grain, tensile strength parallel to the grain, and shear strength parallel to the grain.

These tests require different accessories like grippers and triangular blocks etc.

An ample amount of bamboo culms for different strength and density tests, their moisture, and lengths also need to be taken care of according to the description. Most tests ask for 12% of moisture content in the specimen.

5.3.1.2 Non-Destructive testing

We have chosen destructive testing for the material as it is available in large numbers but once a bicycle frame is made by maturing and processing the bamboo and joining it with all the dimensional accuracies, it is arduous and not feasible to use destructive testing. Thus, non-destructive testing helps in determining the flaws in the object (frame) if any.

This also acts as a mark of surety for the usage of the bicycle. As carbon fiber frame is analogous to bamboo frame in many ways, hence we can use similar non-destructive testing for both with minimal exceptions.

Infrared thermography- This is a non-invasive technique, where the inspected material is not altered or affected in any way and the processes can be repeated several times for better result data.[12] The infrared thermography process is simple; here an external thermal stimulus is applied to the inspected material using an optical flash lamp, heat lamp, or other devices. The thermal waves penetrate the material surface producing a thermal contrast in areas with subsurface anomalies, during the transient phase, which makes subsurface defect detection possible.

Pulse-thermography, step-heating-thermography, lock-in thermography, and ultrasound thermography are a few widely used simulation methods [12]. A few American Society for Testing and Materials committee (ASTM) standards, particularly the ASTM E-7 have various non-destructive testing mentioned in it. They can be used for material property inspection also.

Some other tests include Pulse thermography, X-ray thermography, Ultrasonic thermography, Acoustic, and tap testing.[12]

Finite Element Analysis can be done to simulate and calculate all the frame tests and the material tests as well. This gives a confirmation of the data obtained by the above-defined methods.

5.3.2 Other Customizations and accessories

1) *Customization in electric drive train according to the distance,* This will reduce the expenses of the bicycle, if the person expects to travel a shorter distance than the available range, he or she can ask for a lesser-powered motor and a 2 level pedal assist, etc.

2) *Modification in electric drivetrain by adding throttle and a super-capacitor*, for a longer range of 50 Km/hr. in a single charge and reusing the kinetic energy from regenerative braking.[13]

3) *Solar panels*- A trailer with attachable and detachable clamps can be made to make the bicycle more sustainable and this will enable long-distance daytime traveling easier and would save battery charging time making this bicycle worthy of traveling for a longer distance. There can be further modifications like a tracker system for more efficient sun tracking and power-producing. A foldable solar panel could act as a shed that will keep the raider at ease in the high scorching heat. This brings an addition of some small improvisation in the circuitry of the electric drive train. Like an Arduino, MPPT, etc. This might sound expensive but in the long run, will be a cost-effective alternative.

4) *Seat materials*- Recumbent bicycle seats are generally made up of FRP (Fiber Reinforced Polymer) this has fiberglass as the fiber and a polymer material. With a view of making this bicycle more and more sustainable, with some more research we can switch to a composite made out of bamboo fibers, which will be procured from leftover bamboo parts and a biodegradable matrix-like PLA (Polylactic acid), Thermoplastic Starch, Polyhydroxyalkanoate (PLHAs), etc. This will also reduce the cost of the bicycle drastically. There can be other alternatives of natural fibers and biodegradable matrices commonly known as Green Composites.

5) *Fairings and carriages*- Fairings are a good gear in protecting the raider from dust and cold winds; these again can be made up of PLA or any other sustainable and light material. Carriages help the person carry excess loads; these can be attached above the rear wheel behind the seat. Although a simulation test is necessary to determine the maximum loads and exact positions of these accessories, these if used will be an asset for sure.

REFERENCES

This should follow the Appendices, if any, otherwise the Summary and Conclusions chapter. The candidates shall follow the style of citation and style of listing in one of the standard journals in the subject area consistently throughout his/her report, However, the names of all the authors along with their initials and the full title of the article/monogram/book etc. have to be given in addition to the journals/publishers, volume, number, pages(s) and year of publication. Citation from websites should include the names(s) of author(s) (including the initials), full title of the article, website reference and when last accessed. Reference to personal communications, similarly, shall include the author, title of the communication (if any) and date of receipt.

Sample book chapter style

[1] P.K. Mallick, "Fiber Reinforced Composites: Materials, Manufacturing, and Design," in Chapter 2 Materials, Taylor & Francis Group, LLC., 2007, pp. 1–88.

Sample articles style

[2] P. Sahu and M. K. Gupta, "Sisal (Agave sisalana) fibre and its polymer-based composites: A review on current developments," *J. Reinf. Plast. Compos.*, vol. 36, no. 24, pp. 1759–1780, 2017.