DESIGN OF FRICTIONAL DRIVE UNIT FOR CONVERSION PROCESS OF STANDARD BIKE INTO ELECTRIC BIKE

HAMK
HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

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Pradip Khadka

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Degree Programme in Mechanical Engineering and Production Technology Abstract
Author Pradip Khadka Year 2021
Subject Design of frictional drive system to convert standard bike into electric bike
Supervisors Jaakko Vasko

The objective of this thesis project was to design a frictional drive unit for various types of conventional bicycles to convert them into electric bikes. The thesis project is commissioned by Hämeen ammattikorkeakoulu (HAMK). This report is effective for environmental purposes on basis of the public who is switching to electric bicycles. The main goal of this thesis project is to contribute to a reduction of carbon emissions during the production process for the new electric bikes.

Initially, the report explains the background of the electric bicycle users and the government policy to support them in switching to electric bikes. This indicates the market is moving towards electric bikes where there are lots of possibilities for converting conventional bikes into electric bikes.

After that, the report focuses on the commercially available different types of drive systems with their advantages and disadvantages to identify the most suitable drive system for this converting process. The compact design, material selection, and manufacturing process of a drive unit also need to be considered. Also, the drive unit must have to follow the regulation for motor assistance.

Furthermore, the report explains the design process for an appropriate solution for a frictional drive system. It covers the design method, the parts required for drive units, power supply, etc. The environmental impact is also briefly explained for recycling the conventional bikes. This report is based on web research for practical usage. With considering requirements for the design, calculation, 3D modelling, manufacturability has been done to have a practical solution.

Keywords drive system, bicycle, design, electric bike, conversion process.
Pages 29 pages and 4 appendices pages

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1 Introduction

1.1 Background

Electric bicycles' popularity is continuously growing in the Finnish market since they appeared a decade ago. Based on a report published by the Finnish Broadcasting Company Yle, there has been an over a 30% increase in electric bicycle users between 2018 and 2019, and the number is expected to grow in the future. However, the high price range of electric bikes has become the main reason to discourage potential buyers. The Finnish Ministry of Transport and Communications aims to promote electric cycling on longer journeys to reduce the number of journeys made by car (Yle, 2020). Instead of the purchasing a brand-new bike, we can convert our regular human-powered bike into a hybrid bike by installing a normal mechanism on it. It leads to the recycling of the old conventional bikes.

Figure 1. Electric bike user (Helsinki times, 2018)

1.2 Objective

This thesis aims to design a frictional drive system for a conventional bike to make an electric bike. Features like easy adjusting, compact design, and a low mass are strongly considered as well as the Finnish standard for a motor-powered bicycle.

The project is based on research for the product development of a drive system. The design process is explained for developing individual parts. The function of each part is considered. This report also describes mechanical aspects of the machine design, the problem identification, and the appropriate solution for producing a viable product for the current bike users who are shifting towards electric bikes. It includes the calculations for the power capacity, range, and speed of an electric bike. Recycling conventional bikes to convert them to electric bikes helps to reduce manufacturing costs and reduces the carbon footprint on the environment.

1.3 Project deliveries

To deliver a product that considers all factors like cost, weight, position, drive systems, the research has done as follows:

Table 1. Project deliveries

Research Description	Goals
Agreement and plan for thesis	To plan a road map for thesis work

Research on electric bicycle background	To summarize the process for electrification
Research on speed standards and safety standards for a motor-powered bike.	To design and analyze placement for motor and driven gear. power transmission and required power
Ideate for implantation of a motor hub, drive system, and power	To placement of battery and power calculation of source.
Finalization of idea for design and 3D modelling on Creo for a prototype.	To find suitable design, speed limit and follow safety for bike
Discussion with supervisor for modification	To approve the result
Final presentation and documentation	To finalize a thesis document

2 Current motor drive system for conversion process

In the current market, there are mainly three types of drive units based on their working principle. Namely hub drive unit, mid-drive, and frictional drive unit. Depending on their design, power transmission unit, price, weight, assemble time, and maintenance, all have certain advantages and disadvantages which are briefly described below.

2.1 Hub-drive system

The compact and independent design of a hub-motor drive system is the main advantage among other drive units. The motor stator is directly connected to the wheel which helps to increase the durability of the system, ensures high performance of a bike, and lessens the need for maintenance. This drive unit can be installed on both the rear and the front wheel of a bike in the desired position. Though, the rear hub drive unit is more stable than the front hub-drive unit.

Contrasting above positive side of a drive system, using the components on a hub motor-driven system makes it much heavier than other drive systems which reduces the suspension capability and shifts the centre of mass of a bike. It is also non-preferable for off-road riding. Because of the size limitation, this drive system cannot be installed on various types of bikes.

Figure 2. Hub motor drive conversion kits (Electrek, 2018)

2.2 Mid-drive motor system

The mid-drive motor system has a higher gear ratio than other drive systems. The power transmission occurs on the same junction of a chain and a gear of a bike. It produces huge torque which helps to increase the driveability on stiff roads as well. Light-weight, advanced drive gear design, low-centre of a mass, and pedal assistance are some other key features of it.

On the other hand, the advanced drive system needs the same level of reaction from the chain and a specified frame structure of a standard bike. The installation process is harder in comparison with other drive systems. It needs a higher level of maintenance regularly. The cost for this unit is higher than for other drive units.

Figure 3. Mid-drive unit (YAMAHA e-bike, 2021)

2.3 Frictional motor-drive system

Frictional drive system for a conversion process is the least popular among other drive systems. However, it is more practical, cheap, and sustainable for various types of bikes. The ordinary working mechanism and the design increase the weight efficiency ratio and reduce the installation process. The power is transmitted directly either to the front or rear wheel. Fewer components are used for manufacturing.

Though, output power efficiency reduces by drag on the wheel on the frictional motor-drive unit. The gear ratio of the wheel to the motor is large so high torque is required for acceleration.

Figure 4. Frictional drive power unit (Qiroll, n.d.)

3 Design Process

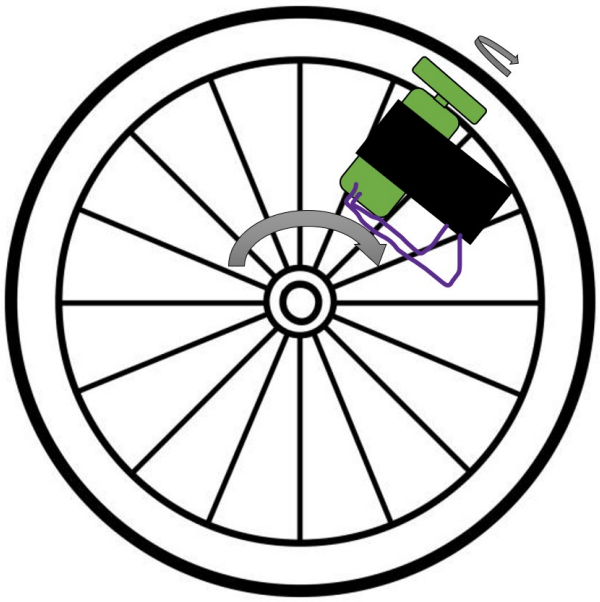
The initial point of the design process is demand on market or a new discovery of a product. To develop an idea for a product needs specified functions, working principles and an outline a structure. The process further goes on detailing materials, components, and design.

The design is consisting of several details like modelling, viability, analysis, simulation, production method, cost estimate, and manufacturability. It helps to design the product with more specified and detailed function. (Ashby, 2008)

3.1 Working principle

The frictional motor drive system can be divided into three main sections: a power supply and a controller (a battery), a circular motion generator (a BLDC motor) and a power output (a wheel).

Figure 5. Mechanism of frictional drive system



The lithium-ion battery provides sufficient power to the motor which creates circular motion. This motion is transferred to the bike's wheel rim with the help of a circular disc mounted on the motor shaft. By using drag force, the bicycle moves forward. The contact location is in a different location (normally it is located on outer part of the tyre) which is on the rim of a bicycle. This principle is similar to a dynamo for power generation. To produce drag force, the dynamo principle is reversed.

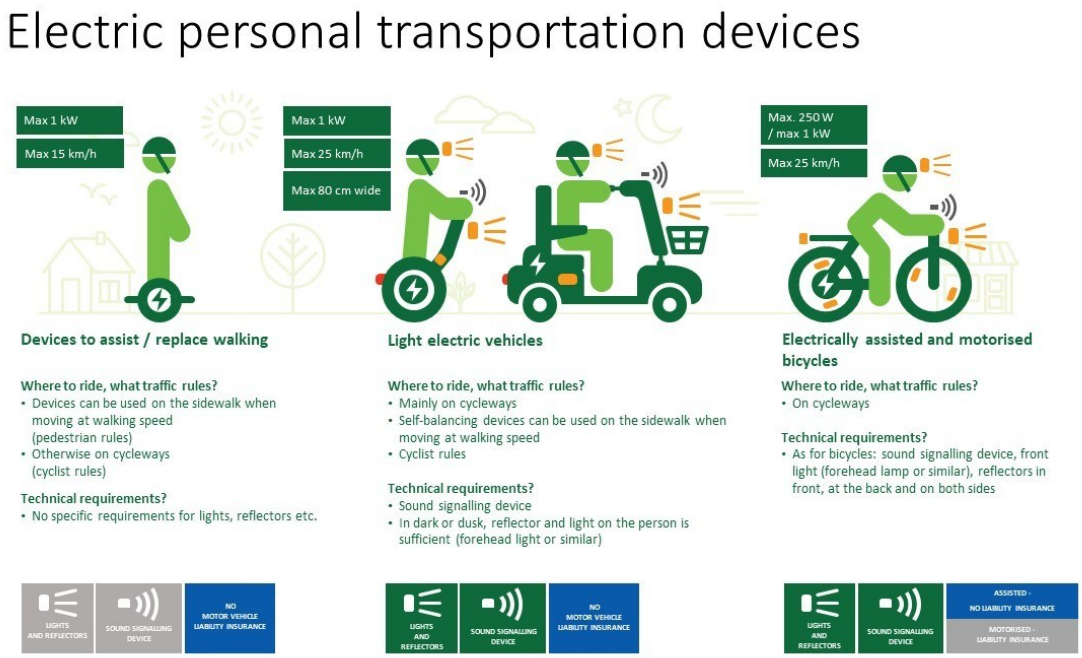
Figure 6. Dynamo attached on a bicycle (Pedalcell, n.d.)

3.2 Standards and regulations for motor-powered bicycle

According to the Finnish regulation for motor-assisted bicycles, a bike can reach a speed up to 25 km/hr with 250W power without having an insurance policy. Once it reaches 25km/hr power, it must have an insurance or the motor needs to be detached from the bicycle with an additional mechanism.

The frictional drive system is an electrically assisted conversion kit for a human power bike. (Traficom, 2021)

Figure 7. Electric personal transportation devices (Traficom, 2021)



3.3 Solution approach

With having several possible solutions for the conversion process, the frictional drive system is most suitable for a wide range of standard bikes. Direct power transmission on the wheel increases the compact design of a motor drive system. Although having low power output capability, the frictional drive systemmaintains safety standards by producing low speed for a bike.

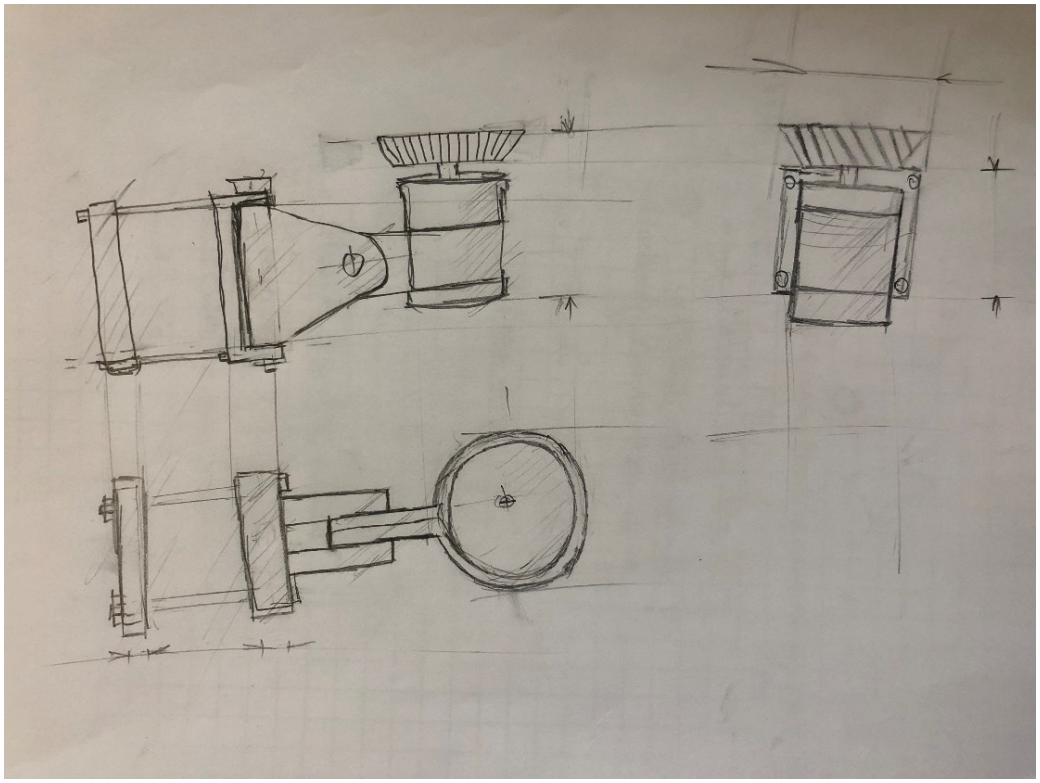
The front wheel has less traction and a weaker frame structure in comparison to the rear wheel. Also, there is a higher chance of accidents when a bike changes its orientation. The load distribution on the front side of a bike is less than on the rear side, which may cause slipping when moving the handle. So, the rear wheel area is more effective for the installation of a drive system.

The maximum speed is 20km/hr for this solution without human power. The speed is producing by drag force on the wheel's rim which also helps to reduce the speed without

pedalling, so there is a low possibility of accidents by high speed. The one more benefit of this system is for braking, if power supply is cut off, it helps to reduce the speed gradually without braking.

The main idea of this design solution is that it is easily adjustable on various bikes. If a rider does not want to have this drive unit on the bike, it can be removed within a few minutes by disengaging some components. The following diagram can easily explain the idea for an drive unit.

Figure 8. Frictional motor-drive system sketch



4 Mechanical components

4.1 BLDC Motor

To gain a maximum speed of 20 km/hr and have a weight ratio, BLDC motor is suitable for a design solution. The BLDC motor is more efficient than a brushed DC motor. It does not have brushes, so it does not require maintenance. It also provides maximum torque continuously which helps to maintain a constant speed. The BLDC motor produces less heating during rotation compared to the traditional brushed DC motor.

The main disadvantage of BLDC motor is thehigh price. But having high durability and less need for maintenance reduces the operating costs. (Electricity shock, n.d.)

Figure 9. Working principle of a BLDC motor and a brushed DC motor (Magnetic innovation, n.d.)

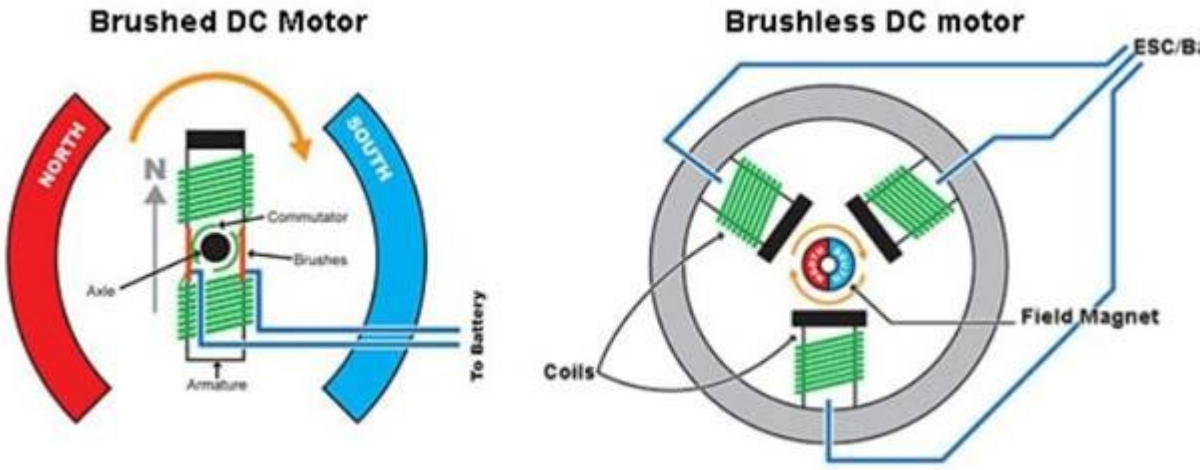
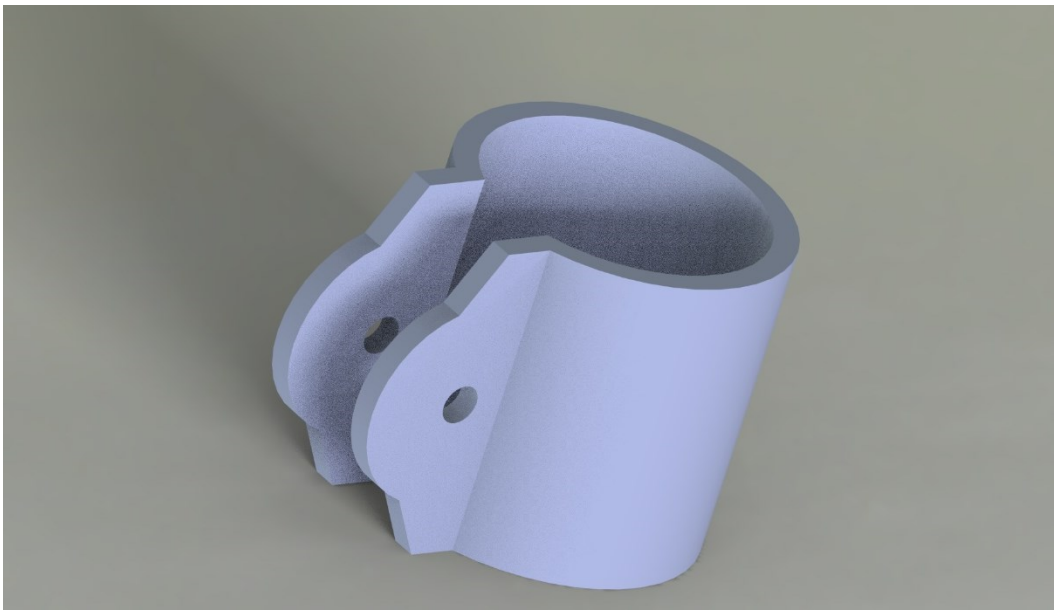


Figure 10. BLDC motor (Transmotec, n.d.)

4.2 Motor mounts

The motor mount is holding a motor with help of a connector to a bar mount. This part is directly exerting force produced by the motor. To adjust on bicycle rim there is 1 degree of freedom up to down. It is fastened to make it stable on the bicycle's side bar.

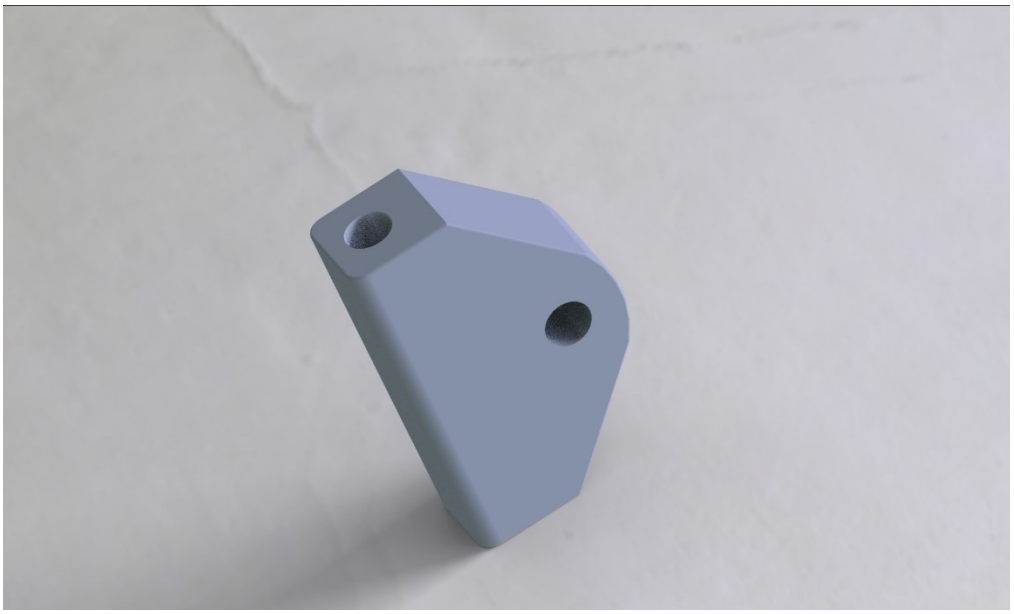
Figure 11. Motor mount



4.3 Connector

The main function of a connector is joining bar mount and motor mount together. There are two degrees of freedom on it, so that it can move both on the X-axis and Y-axis. It helps to adjust the position of the motor for contacting the surface which is the bicycle wheel's rim.

Figure 12. Connector



4.4 Bar mount

The bar mount is attached to a bicycle bar for stability of the whole drive unit. It is fixed on the surface so that it holds all systems on it. It consists of two parts which arebolted and screwed together. To fit on various types of bicycles this is a crucial part of the design. The contact surface is shaped elliptical and set not to touch the two parts together by leaving a certain gap between them. It helps to fit and adjust it on different types of bicycle bars.

Figure 13. Bar mount(a)

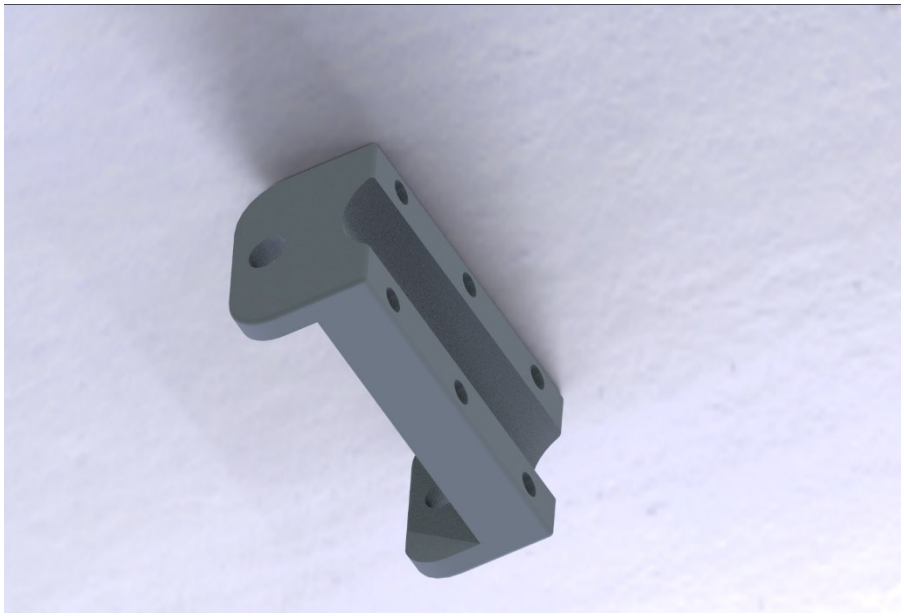
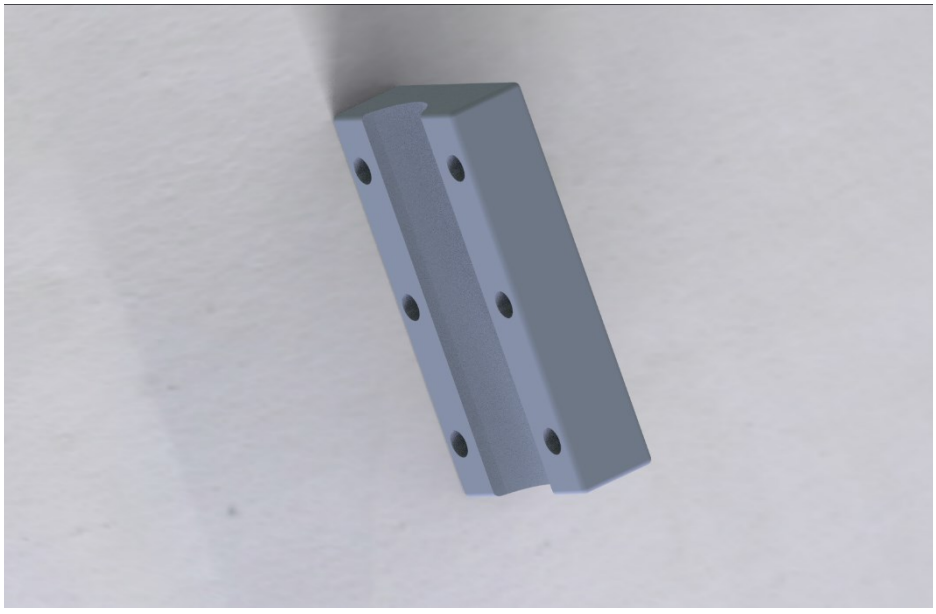


Figure 14. Bar mount(b)



4.5 Rotor

The rotor is assembled on the top of the motor to contact the surface of the rim. This part transmits power on the wheel. There is a rubber insert on a grove of a rotor that lies between the rim and the rotor. It produces drag on the wheel so that it wheels.

Figure 15. Rotor

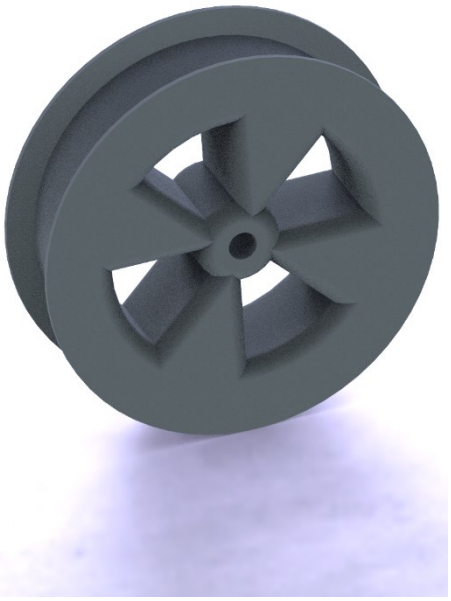


Figure 16. Rotor rubber insert.

4.6 Power supply and controller

The required power is supplied by a lithium-ion battery pack which is attached to the bicycle bottle cage position. The controller is included in the same package so that there is no separate box required for holding it.

4.6.1 Battery Pack

To set a continuous power supply, a battery pack for the required range of bicycles, there must be consideration of the current, weight and voltage of a battery pack. There are several companies that supply a required set of battery packs alongside a controller for the power supply.

Figure 17. Battery cell pack

4.6.2 Throttle

Throttle is used to control the speed with help of a potentiometer-knob to change single which is attached to the handle bar of a bicycle. This helps riders with smooth speed changes.

Figure 18. Throttle for accelerate motor (Ebay, n.d.)

5 Manufacturing process

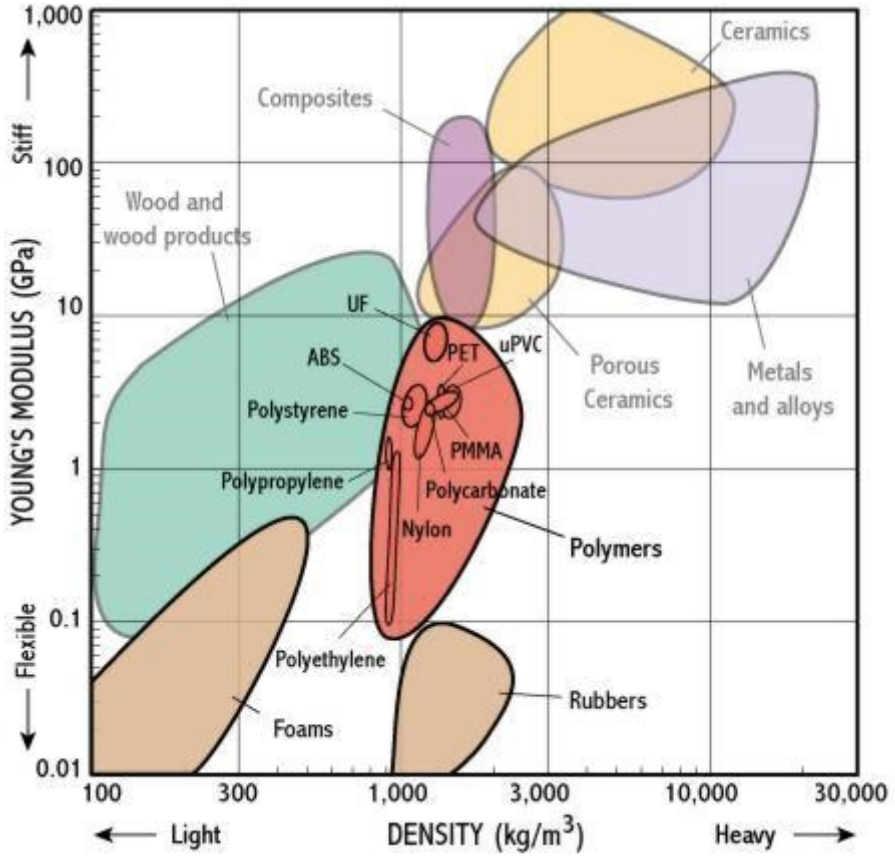
5.1 Material

To manufacture motor mounts, bar mounts and battery packages for the drive system, 3D printing polymers and aluminium are used because of their low weight ratio and non-magnetism properties. These materials are low in cost and have versatile usage. The required level of strength can be also provided by these materials.

5.1.1 3D printing materials

There are various types of materials available for 3D printing withvarious properties of strength, impact resistance, cost effectiveness, flexibility, heat resistance, fatigue resistance, etc. Prototyping and a permanent solution of the drive system can be made by using high-strength polymers, for examples ABS (acrylonitrile butadiene styrene), TPU (thermoplastic polyurethane), PA (polyamide), and PP (polypropylene). (BCN3D, n.d.)

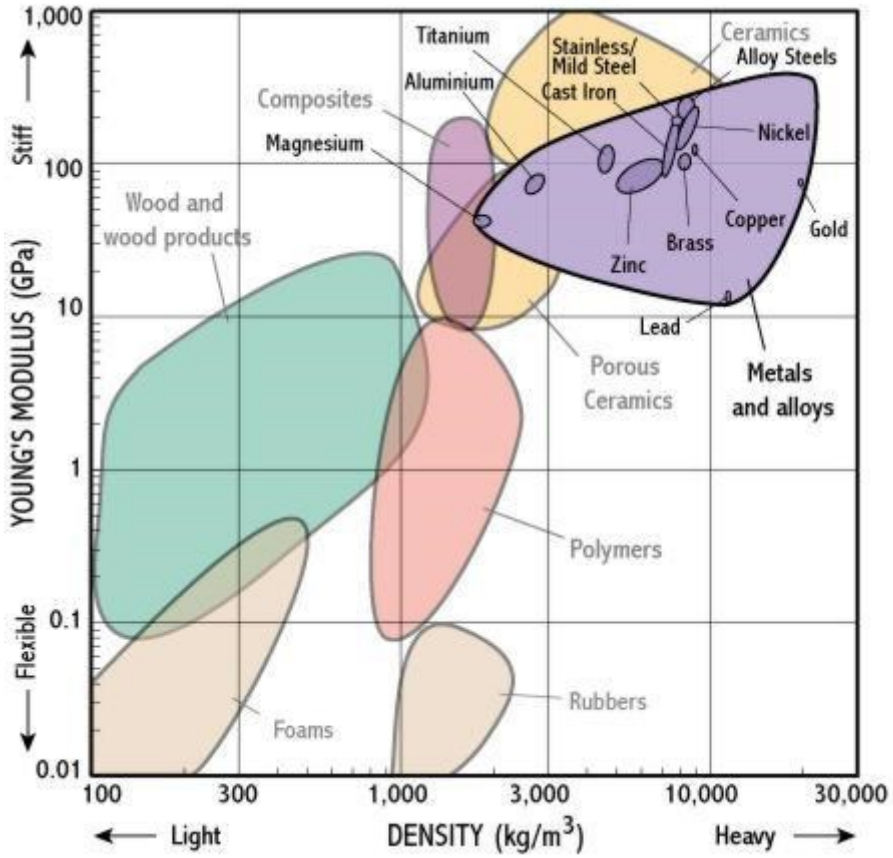
Figure 19. Young modulus-density chart for polymer(a) (Materials , n.d.)



5.1.2 Aluminium sheet

The circular disc (a rotor) can be manufactured with aluminium. It has higher tensile strength than polymers and less weight ratio than steel. The non-magnetic properties of aluminium also help to rotate the motor without any disturbance. The rotor is directly placed on the wheel so that the heat will be produced during rotation. The metal has a higher heat resistance than the polymer.

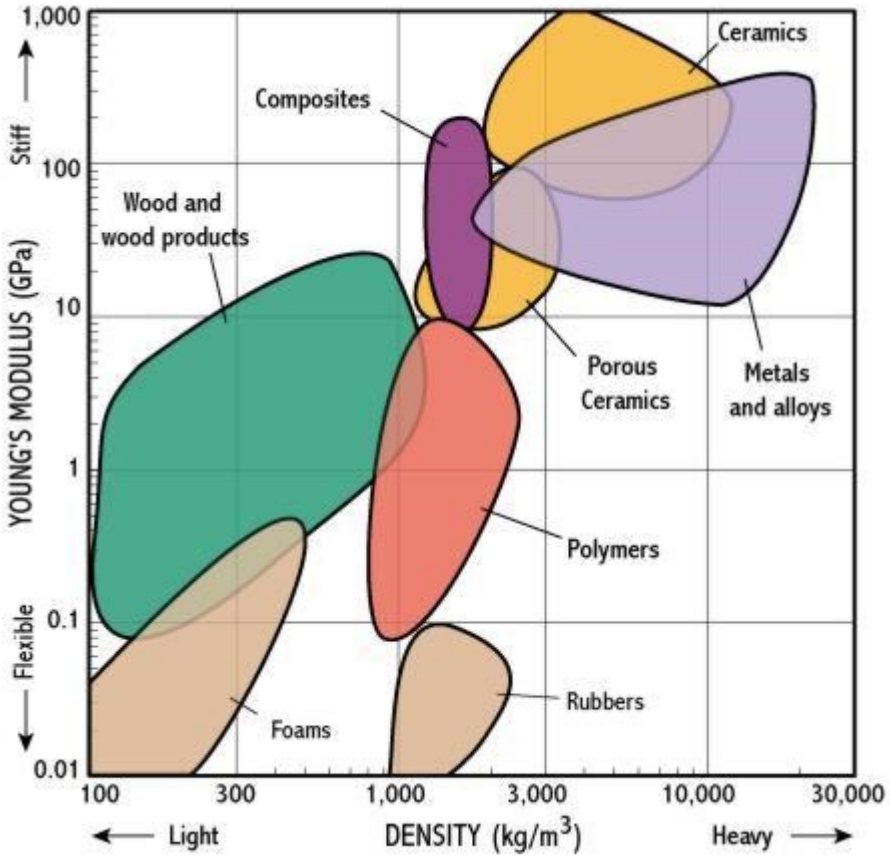
Figure 20, Young modulus-density charts(b) (Materials, n.d.)



5.1.3 Rubber inserts

Rubbers are good material to produce drag without wearing a bicycle rim. It is a bad conductor of heat which reduces transferring heat to the motor's shaft. Light weight, high stiffness, and high elasticity are also some common properties of rubbers.

Figure 21. Young modulus-density chart (c) (Materials, n.d.)



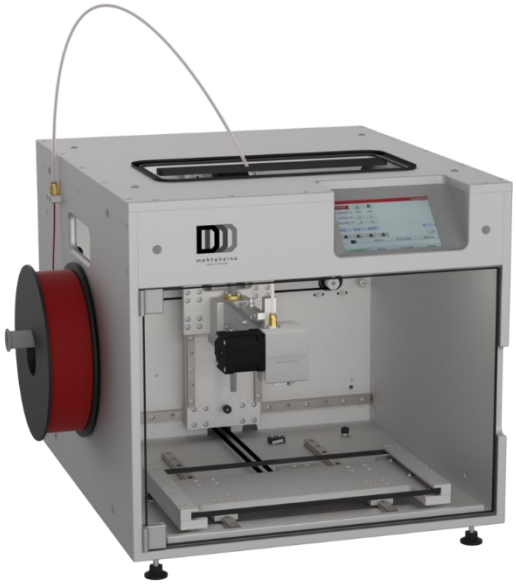
5.2 Production method for mechanical parts

5.2.1 Additive manufacturing method

To produce a prototype of the frictional drive unit, an additive manufacturing method is the most relivable and cost-effective production way. There might be a technical default regarding structure, design, and materials. To overcome the above-mentioned problems during production this manufacturing method helps.

There are also possibilities to produce some parts like the bar mount and the motor mount by 3D printing method. It is more cost-effective than other production methods.

Figure 22. 3D printer (mehtaheino oy, n.d.)



5.2.2 Machining

The rotor is a crucial part of the frictional drive unit to transfer torque into the wheel's rim. To produce good quality rotor disc, turning and milling are the common high precision methods for production. The disc needs the following operations by CNC turning.

- Facing
- Grooving
- Drilling

And to remove unwanted material from the disc, CNC milling needs to be done. Chamfering is also done by CNC milling.

Figure 23. CNC turning machine (technox machine and manufacturing Inc, n.d.)

5.3 Production cost calculation

For the production of the frictional drive unit as p lanned above, price is estimated by the commercial way and might fluctuate with different factor like supplier, manufacturing methods, labour cost, and time. This price estimation is for a single unit of a fictional drive system so there is a higher price than expected. However, the price estimation is as follows.

Table 2. Estimated cost calculation

Parts	**Price per unit(euros)**	**Supplier**
BLDC motor	70	Magnetic innovations
3D printed parts	30	-
Battery	8.9*	Pro-akku
Rotor	15	-
Rubber inserts	7.5	Bikester
Fastens	5	Beltema
Labor cost	80	-
Total estimation	296.5	

6 Environmental effect

To produce single new bicycle, 96 kg of carbon is emited into the atmosphere by the bike industry. And this could vary by bikes. Also, there is some impact on water pollution, air pollution, landfill waste by production of a new bike. To reduce the bicycle's carbon footprint, recycling an old standard bike is a good solution for sustainable cycling. And converting process into an electric bike does not have that much an impact on the environment as most of the required part are already manufactured for other purposes. Utilizing already produced parts is one of the key goals of this thesis.

Figure 24. Bicycle to reduce carbon footprint. (Stott, 2020)

The electric bike produces less carbon in comparison to the conventional bike with food related factors and manufacturing factors. (Stott, 2020)

7 Conclusion

The main aim of this thesis was to recycle a conventional bike by modifying it into an electric bike and by designing a suitable drive unit that can fit in various types of bikes

The necessary research was done during all the stages to support finding a design solution approach for conversion process. All types of drive systems have advantages and disadvantages. However, to support the objective of this thesis, the frictional drive system has more necessary and vital advantages.

Firstly, the solution for the design of a frictional drive system was approached and the designing was done in Creo for 3D modelling, analysing the solution. Features like easy adjustability, compact size, and low mass density were strongly considered during the design process. To assemble a mount that fits various types of bikes was a challenge. The positioning of the drive unit should not affect regular cycling. After having a testing prototype, the case study was done on different bikes in hämeenlinnan seudun opiskelija-asuntosäätiö building's bicycle storage room.

In conclusion, thesis has shown that there is a huge potential to develop sustainable bicycling without producing new electric bicycles. The design can be improved to have a good electric bike for power transmission efficiency and higher range.

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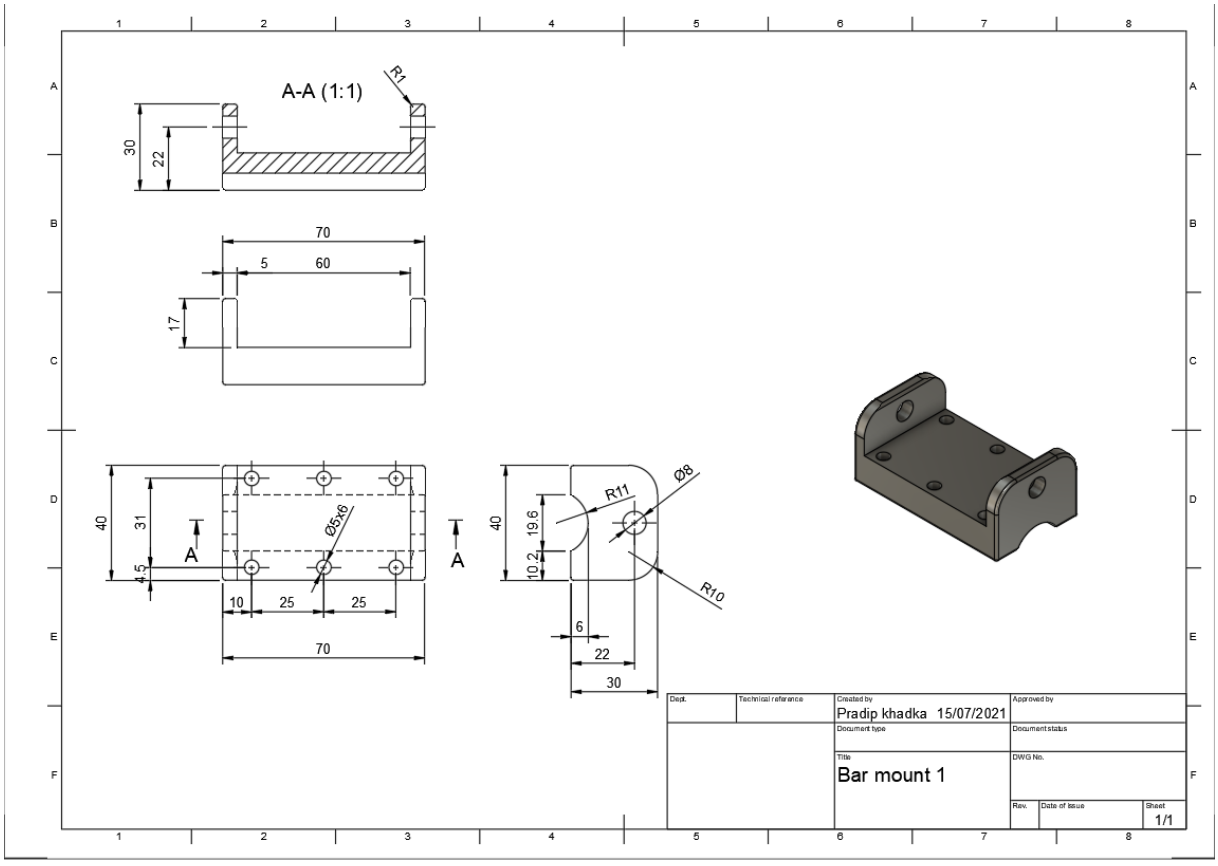
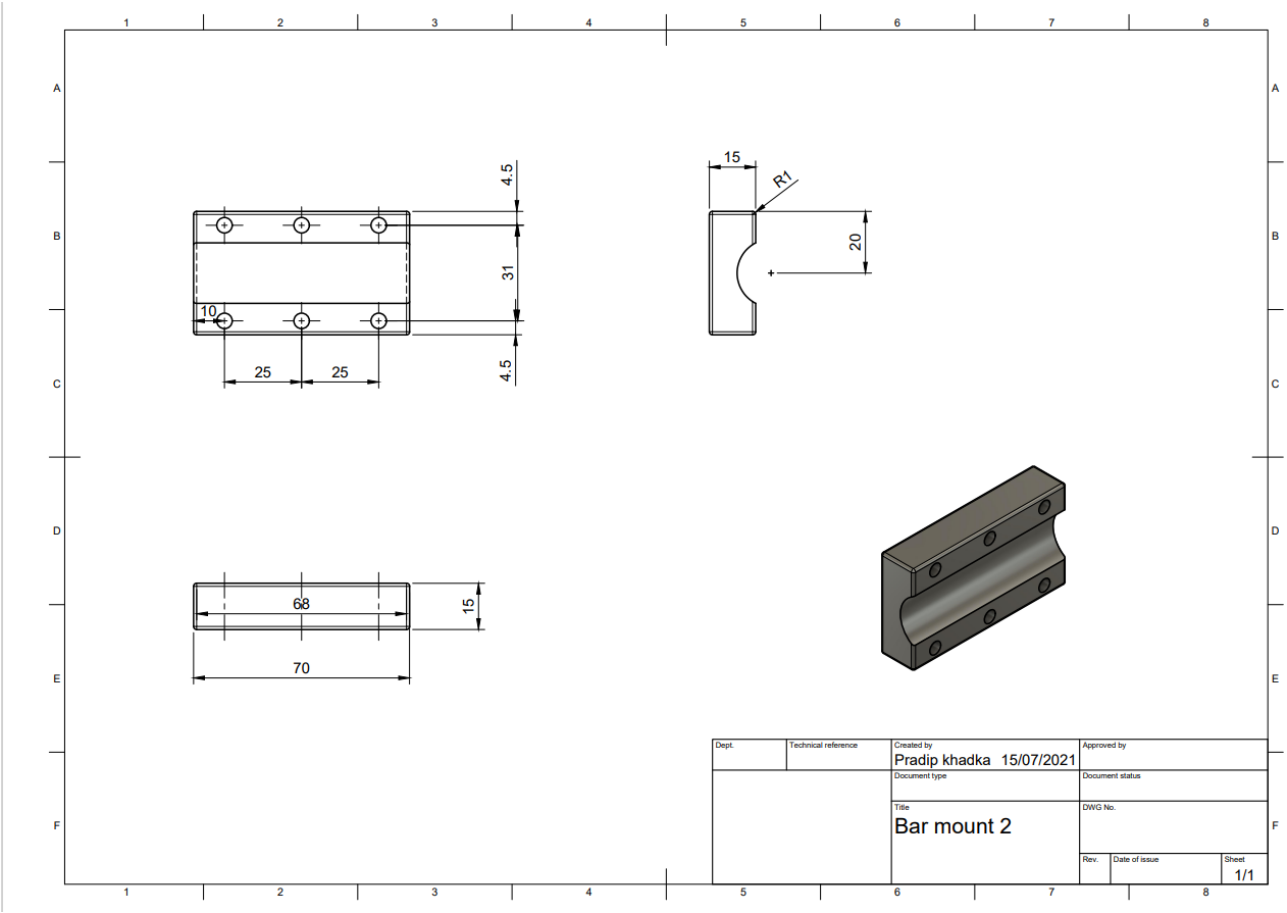
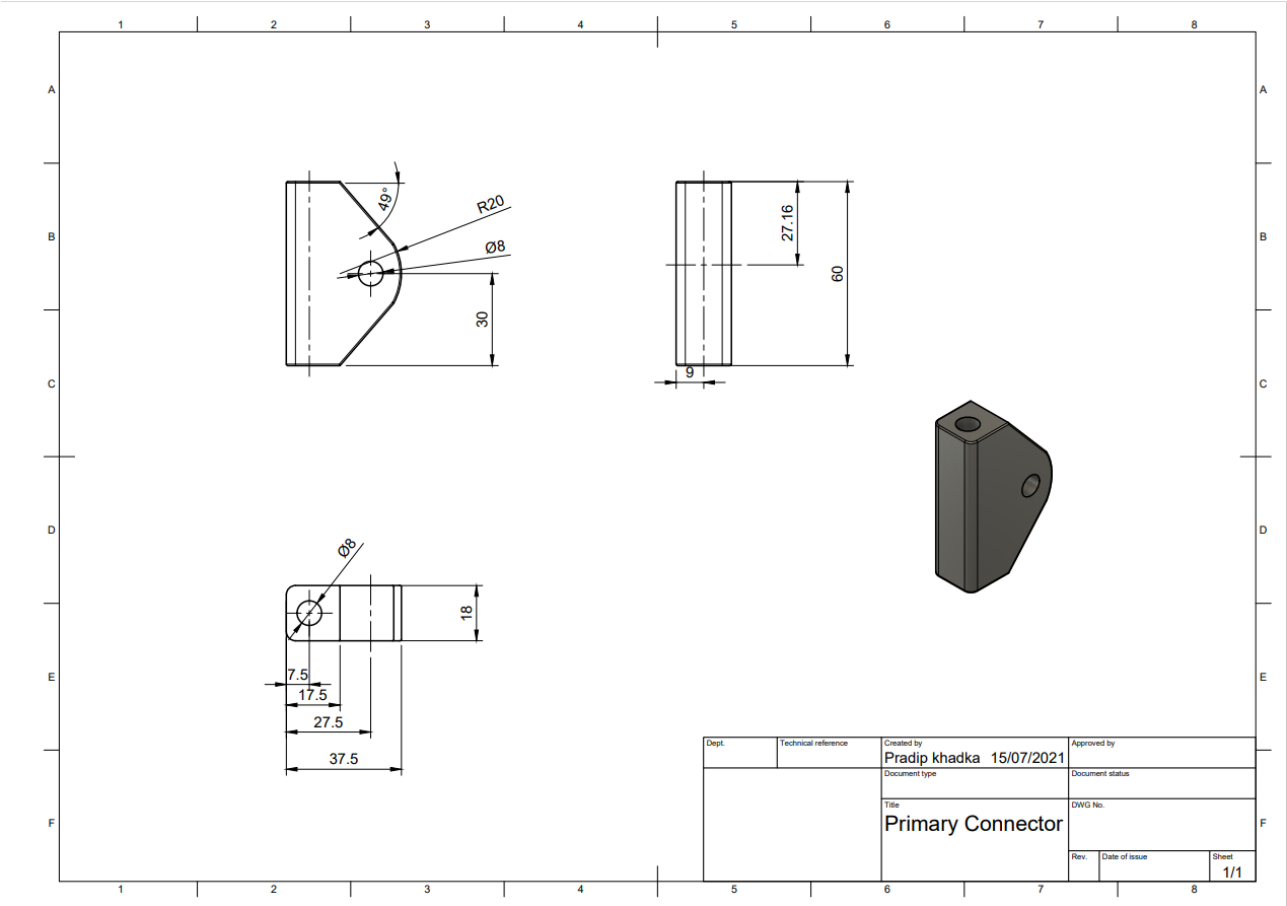
Appendix 1: Technical drawing of bar mount 1



Appendix 2: Technical drawing of bar mount 2



Appendix 3: Technical drawing of a connector



Appendix 2: Prototype testing on different types of a bicycles