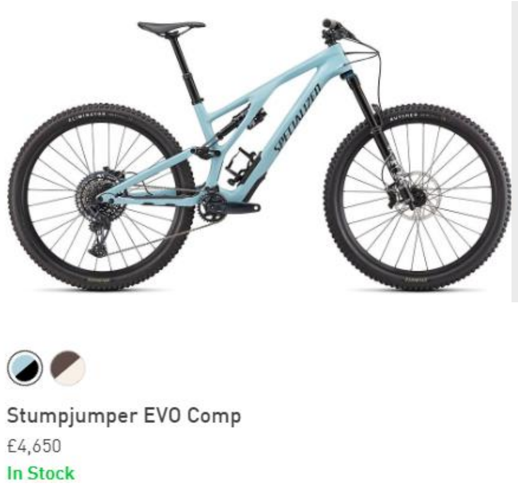
Contents

Research into MTB/Identifying a problem.

Mountain biking is becoming an increasingly popular hobby and form of exercise. Many teenagers and young adults choose to spend their weeks riding specially built bike parks. These bike parks are few and far between meaning there is usually quite a lengthy drive involved.

When I learnt to drive the idea of being able to drive to a bike park and ride with my friends sounded amazing however now I can drive I have come across some of the struggles of doing this and I have discussed with other young adults, and they appear to have similar issues. One of the biggest issues is simply down to the types of cars young adults are driving, because of the high price of cars most people chose a hatchback as their first car. Because hatchbacks are quite small transporting bikes is not the easiest task. It requires seats to be folded down and bikes to be partially dismantled to allow them to fit in. It also means you can only really fit 2 people and 2

Modern day high-end bikes are getting very expensive so consumers do not want to scratch any parts and especially not the frame as this both decreases its second hand value and also doesn't make the bike look nice. I believe that a lot of current bike rack solutions have not taken this into account as may solutions involve clamping the bike frame.



FRAME ONLY	TURQ	$4,700
C1		$6,600
C2		$6,900
T1	TURQ	$8,600
T2	TURQ	$9,500
T3	TURQ	$10,600

COMPARE KITS

E-biking is also becoming an increasingly popular hobby as it makes riding more accessible to people as they have a motor to assist them on their riding. Whilst this advance in technology has great advantages in does also limit how easy it is to transport them. Previous methods of transport such as a roof rack system become unusable as E-bikes are much heavier than standard bikes meaning lifting them onto the roof is incredibly difficult if not impossible for some users.

Some young adults also drive more 'sporty' cars or smaller 3 door cars. these cars don't have the option of having bikes stored on the roof as they may be convertible, or the roof is just too small or does not have compatible roof racks that fit.

Not only putting bike in a car time consuming and quite annoying but after a ride bike can often be very muddy and wet, if these bikes have to be put in a car it also covers the inside in mud. When the bikes are covered in mud using traditional bike racks can scratch the frame as the mud acts like sandpaper and rubs in between the frame clamp and frame.

Standard sizes/International standards

Within mountain biking there are several standard sizes for parts which I plan to use to my advantage when designing my bike rack and also incorporate so my bike rack will be compatible with a large variety of bikes, from road bikes to all mountain bikes.

Some standards on bikes include:

- Wheel sizes
- Seat post sizes
- Frame lengths
- Wheelbase lengths
- Bar widths

One standard on bikes is wheel size. On adult bikes there are 4 standard wheel diameters across mountain and road biking and several different widths.

The 4 sizes are: 27.5",29" & 700c.

There is a much larger variety of widths which range from 24c to 2.6" (there are exceptions of fat bikes which can have up to 5" tyres)

Another part of mountain biking is having to repair a bike due to either wear and tear or damage from a crash, when at these bike parks there it is often difficult to work on bikes as they usually have to be on the floor which makes it difficult to pedal them and check the bike over. Just a basic way to hold the bike off the ground is an incredibly useful asset. Most bike shops or repair options have a clamp to hold onto the bike seat post. This clamping mechanism is very commonly used as it doesn't damage or scratch the bike frame and is also a very similar part on every bike with only a couple of millimetres in deviation.

Because previous designers and companies have had to make their bike racks compatible with a large variety of bikes, I can use this to my advantage, I can research existing bike racks and designs, this will give me a good idea of ways to hod the bike and will also be a good starting point for development of a bike rack to help it meet my design specification.

Whilst using standards such as BSI and ISO are not always necessary, for my project I believe it could benefit me in terms of safety and also if my bike rack was to become commercially available it would help sell it if it complied with recognised standards.

One standard that will apply to my bike rack is ISO 11243. This is an international standard that outlines the requirements for a bicycle carrier that is attached to vehicles. It requires that the maximum weight and number of bikes that can be carried to be clearly displayed and any other relevant safety information. If my product was to become commercially available I would add a sticker or metal plate clearly displaying this information.

Another standard is EN 15194. Whilst this does not directly apply to bike carriers it covers the safety requirements for electric bikes including the design of compatible bike racks for E-Bikes. One of the main details is that the bike carrier is fire resistant and will also protect the user from electrical shocks incase of a short or electrical fault on the bike. My bike rack protects the user in 2 ways, for a start was the bike rack contacts the chassis of the car (via the tow ball) it is grounded to the car battery. The other feature will be that the bike is held by the tyres which are rubber and therefore insulate against electricity so wont let it travel into the bike rack.

Action Plan:

I can research & analyse existing bike racks to create an initial design specification.

Conduct a survey of users of bike racks to try and develop my design specification to the needs of others.

Survey of potential users' current solutions

After reviewing some existing designs, I decided to go to a bike shop and talk to people about how they transported their bikes and if they had any problems with it.

These were the results:

Name	How do they transport their bikes?	What do they like about it?	Problems/ what would they change?	What made them go with this option?	How many bikes can be transported?	How much did it cost?	Any other notes
Michael	Custom made 3 bike holders in van	Very secure, easy to load and unload. Bikes are held securely so don't get scratched or rub on each other. Doesn't prevent parking/ using drive throughs	Gets van incredibly muddy. Takes up most of the space in the van. First 2 bikes have to be taken out to get the 3rd one out.	Liked the security of a van and also how easy it is to load and unload	Mainly 3, 4 at a push	£50 for materials	Also uses van to sleep in when at bike parks or races far away.
Val	Puts in back of car (VW Polo)	Secure, doesn't need to buy additional rack	Very time consuming as wheels have to be taken off. Car gets very muddy inside. Limits space to only 2 seats in car Can only fit 2 bikes in Bikes rub and scratch each other	Hasn't decided on a better option yet as other options (roof rack and bike holder would cost £300+)	2 if both wheels are taken off and only 2 seats in the car used	Nothing (a lot of time)	
Tom	Sometimes puts in van or uses tow bar bike rack	Van is easy to fit 1 bike in Maxxraxx has an integrated locking system.	Bike makes van muddy if put inside. Bike rack attaches on frame so scratches them. Bikes have to be loaded and unloaded in a specific order (similar to Michael's problem) Can't get into boot of van if bike rack is on Bike rack sticks out quite far. Using on van means you don't fit in parking spaces	Wanted a bike rack to carry 5 bikes. Already had a tow ball fitted	4	£200	Bike rack is a Maxxraxx explorer, is supposed to take 5 bikes but fitting 4 on is a struggle. Did work with 2 adult bikes and 3 children's bikes

Liz	**Custom made trailer that uses Thule Pro Rides**	**Can transport 5 bikes easily. Bikes don't rub and can be securely locked. Has additional room in trailer for storage of tools and equipment**	**Has to tow around a trailer Was expensive. Bikes on the side have to be taken off first. Was expensive. Thule ProRides can scratch frames. Parking is a nightmare**	**Needed lots of storage and an easy way to transport 5 bikes when the family go to bike parks of the alps**	**5**	**£600 just for bike racks (already had trailer)**	
Archie	**Thule ProRide on roof racks**	**Fast to put bikes on Has integrated locking mechanism. Keeps inside of car clean**	**Has an E-Bike and is difficult to lift onto the roof as it is heavy. Girlfriend can't reach high enough to secure bikes. Can't use drive-through's**	**Didn't have a tow bar and got recommended by a friend**	**3**	**£400**	

I found this survey incredibly helpful, and it really helped me to learn the needs of users and other mountain bikers.

The main problems I wanted to tackle were:

- **Bikes rubbing against each other/getting scratched.**
- **Bikes having to be loaded & unloaded in a specific order.**
- **Bikes should be easy to load (suitable for E-bikes which are significantly heavier)**

Some features I wanted to include as the target market clearly liked:

- **Integrated locking system**
- **Quick loading and unloading of bikes.**
- **Cheap price**
- **Ability to still use drive-through's & easily park.**

Initial Design Brief

Purpose:

- **The purpose of this project is to design a durable, secure, and easy-to-use mountain bike rack for use on cars. The rack should be able to accommodate a variety of bike frame sizes and styles and should be easy to install and remove.**

Target Audience:

- **The target audience for this rack is mountain bikers who regularly transport their bikes to trailheads, bike parks and other outdoor locations. The rack should be designed with the needs of this audience in mind, with an emphasis on durability and ease of use.**

Design Requirements:

- **The rack must be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes.**
- **The rack must be easy to install and remove, with minimal tools required.**
- **The rack must be able to securely hold the bikes in place during transport, with minimal movement or sway.**
- **The rack must be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel.**
- **The rack must be lightweight and compact, taking minimal space on the car.**
- **The rack must be easy to use, with clear instructions and intuitive design.**
- **The rack should be made of high-quality materials, such as aluminium or steel, for durability and corrosion resistance.**
- **The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.**
- **The rack must not damage or scratch any parts of the bikes.**
- **The rack should have a way of holding a bike in a way to allow repairs.**

Design Constraints:

- **The rack should be designed to be compatible with most car tow balls/hitches.**
- **The rack should not exceed a weight of 30kg.**
- **The rack should not exceed the dimensions of the rear of an average car: 1.65mx1.49m**

Timeline:

- **The manufacturing should be completed by January 2023 with a final design ready by October 2022**

Budget:

- **The budget for this project is £500, this budget only covers materials as if this was to become a commercial product the manufacturing & labour time/cost would be greatly reduced.**

Overall, the design brief for a mountain bike rack should focus on creating a durable, secure, and easy-to-use rack that will appeal to mountain bikers and meet their specific needs. The rack should be designed with an emphasis on ease of use, durability, and compatibility with standard car roof racks and hitch mounts. The project should be completed within a specific timeline and budget, with a prototype ready for testing within the first 2 months.

Initial Design Specification

Materials:

The rack should be constructed primarily of aluminium or steel, with plastic or rubber components as needed. These materials will provide durability and corrosion resistance, while also keeping the weight of the rack to a minimum.

Dimensions:

The rack should be designed to be compatible with most standard car roof racks and hitch mounts. The rack should not exceed a dimension of 1.65x1.49x1m

Capacity:

The rack should be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes. It should be able to hold a minimum of 5 bikes securely.

Mounting:

The rack should be easy to install and remove, with minimal tools required. The rack should be designed to be mounted on the roof of a car or on a hitch mount.

Security:

The rack should be able to securely hold the bikes in place during transport, with minimal movement or sway. It should come with a locking mechanism to prevent theft.

Durability:

The rack should be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel. It should be designed to resist rust and corrosion.

Weight:

The rack should be lightweight and compact, taking minimal space on the car. It should not exceed a weight of 30kg.

Aesthetics:

The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.

User-Friendly:

The rack should be easy to use, with clear instructions and intuitive design.

Safety:

The rack should be designed to ensure that the bicycles are secured in a stable manner, to prevent them from falling off while in motion.

Overall, the design specification for a mountain bike rack should focus on creating a durable, secure, and easy-to-use rack that will accommodate various types of mountain bikes, will be compatible with most standard car roof racks and hitch mounts, be light weight, easy to install, and have a sleek and modern aesthetic. It should also have a locking mechanism to prevent theft.

Initial sketches can be found on page 6 in my sketchbook.

Action Plan:

Conduct further research into existing users' requirements and develop design brief.

To conduct further research into my design specification and check the feasibility of all points (specifically the ability to carry 5 bikes)

To start making my own initial sketches inspired by existing designs and improving on them.

Wheel Cage Development

Sizing

Because the wheel cage is such a crucial part which interacts with the bike, I wanted to test how it would fit. I had initially designed its size using a simple drawing, I planned for it to be 600mmlong and 60mm wide. To test if this would fit a created a quick prototype out of cardboard.

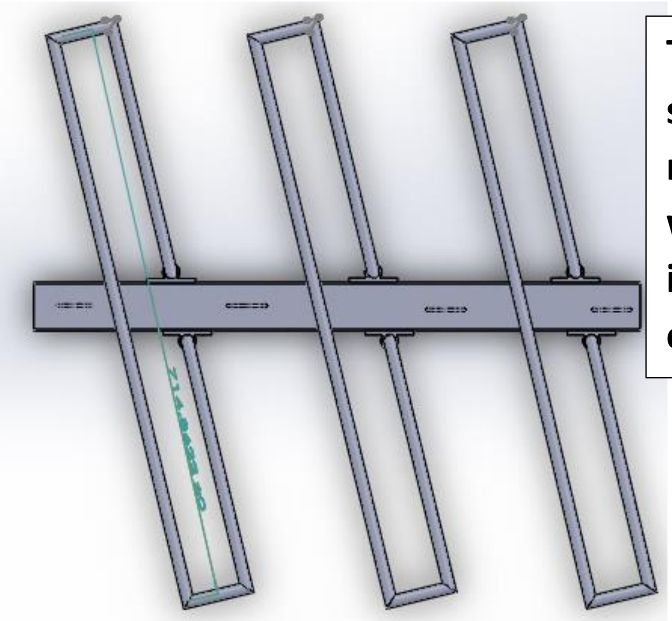
I then enlarged the holder so that it was 700mm long (a 100mm increase). As you can see the problem with it being this big is that it hits the brake rotor, this is a problem as it stops the bike sitting all the way in and would also damage the brake rotor.

From this photo we can see that whilst the wheel does fit in the holder whilst it is this size it is only actually sat into it by about 10cm, this test was also done on the smaller wheel size I want my product to work with, because of this I decided I wanted the wheel to sit into the holder more to give it extra support.

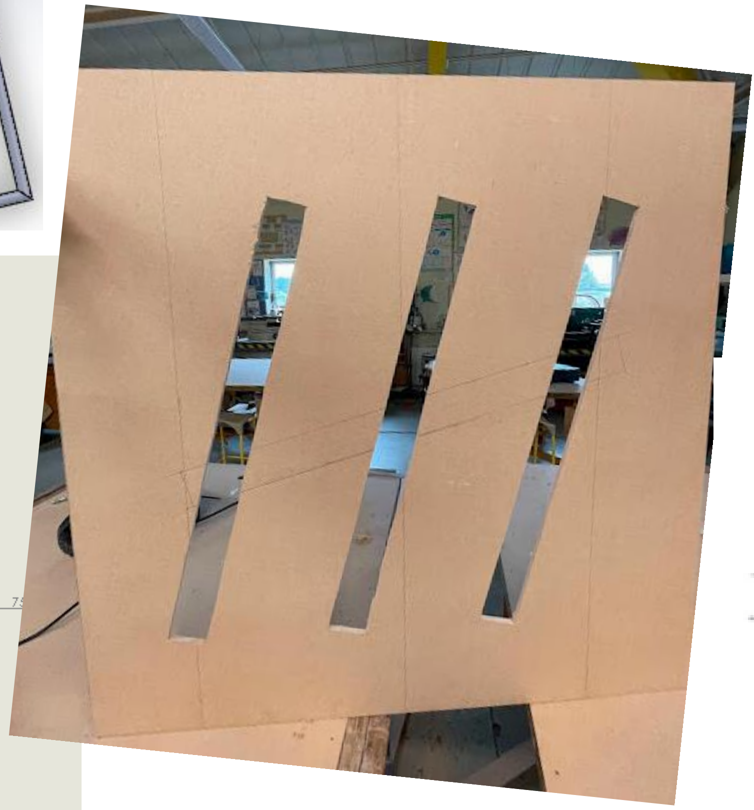
I settled on the length of the holder being 650mm as this left adequate clearance for the brake rotor whilst also meaning the wheel sat deep enough into the holder.

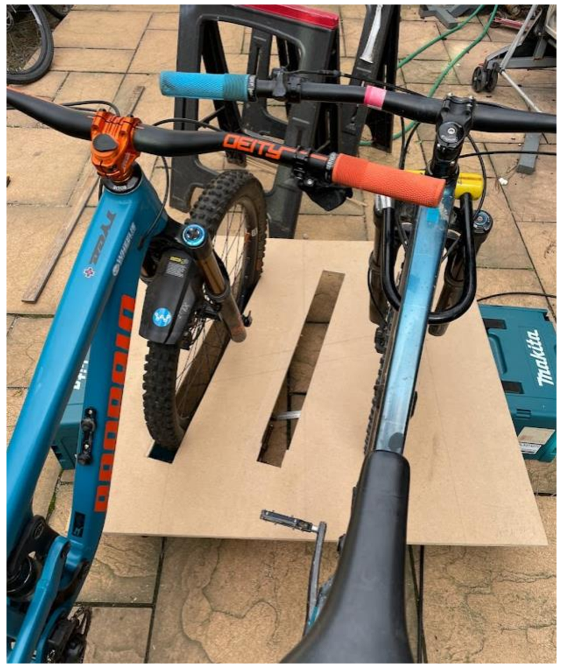
When I made the prototype out of MDF the slots were actually too narrow, I'm assuming this wasn't a problem with the cardboard because it could bend however the MDF couldn't.

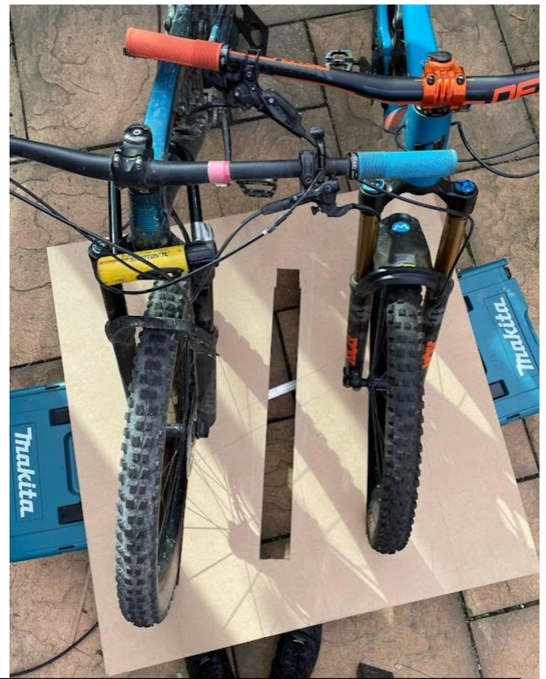
Initial wheel cage design test

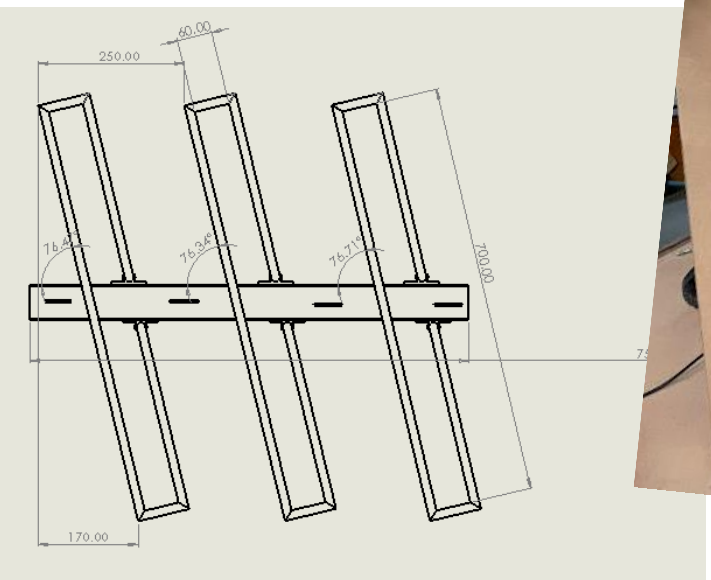


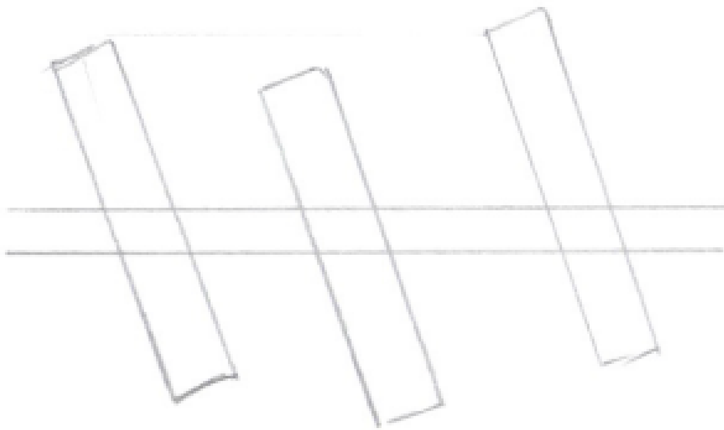
To test the size of the bike rack and to make sure the cages were far apart and would not mean the parts would clash I decided that I would cut this profile out of MDF or another inexpensive wood before ordering steel and other materials.











After making this prototype and testing it I immediately realised that this layout would not work as the bars and brakes of the bikes collided with only 2 bikes so definitely wouldn't work with 3.

I realised I needed to redesign this portion of my bike rack.

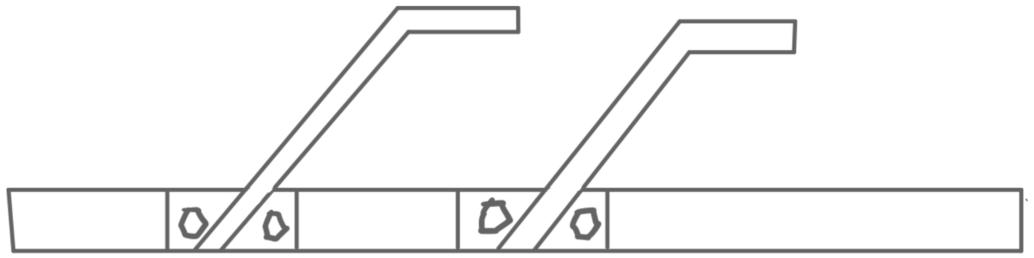
My first idea was to offset the wheel cages from each other (see drawing to the left)

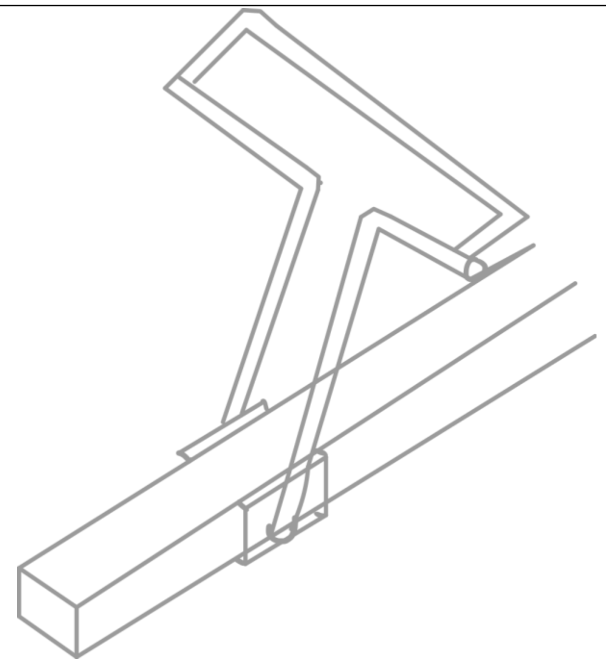
Initially I thought this adaptation would solve my problems however I realised the 2 outside bikes would still clash, on top of this it would mean that the wheel cages needed to be designed and manufactured individually as they would have different dimensions to allow for the offset. This would also eliminate the use of a jig and increase manufacturing time.

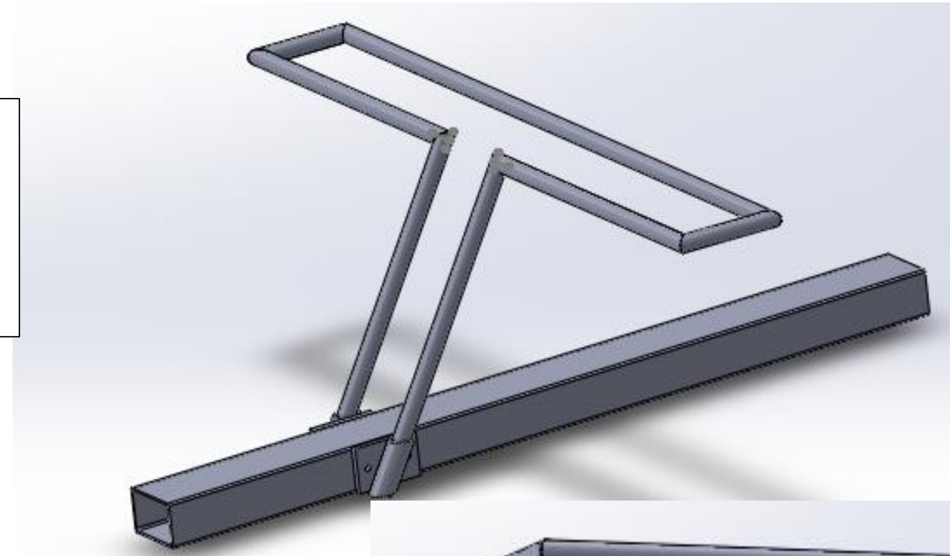
Re-Design after first test

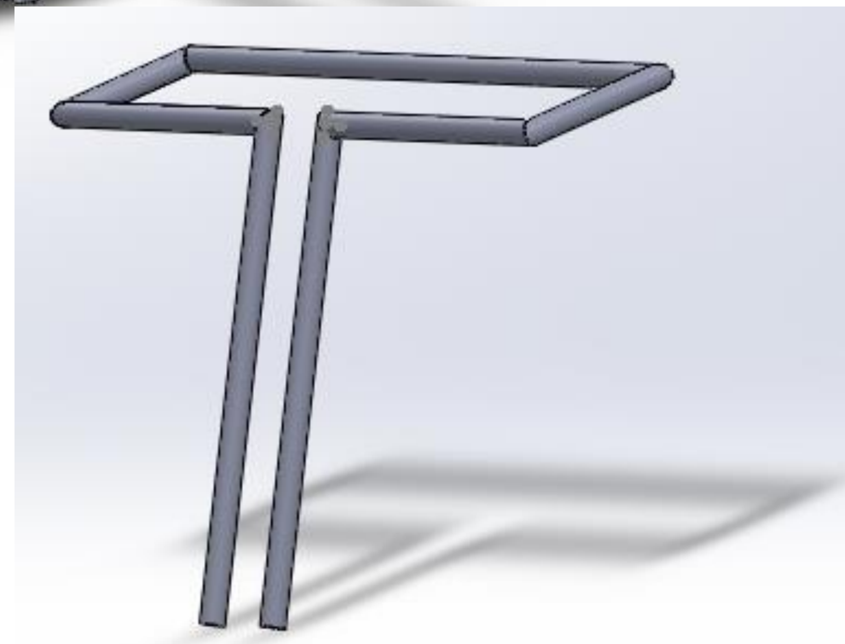
After looking at my previous designs I was really stumped with what to do.

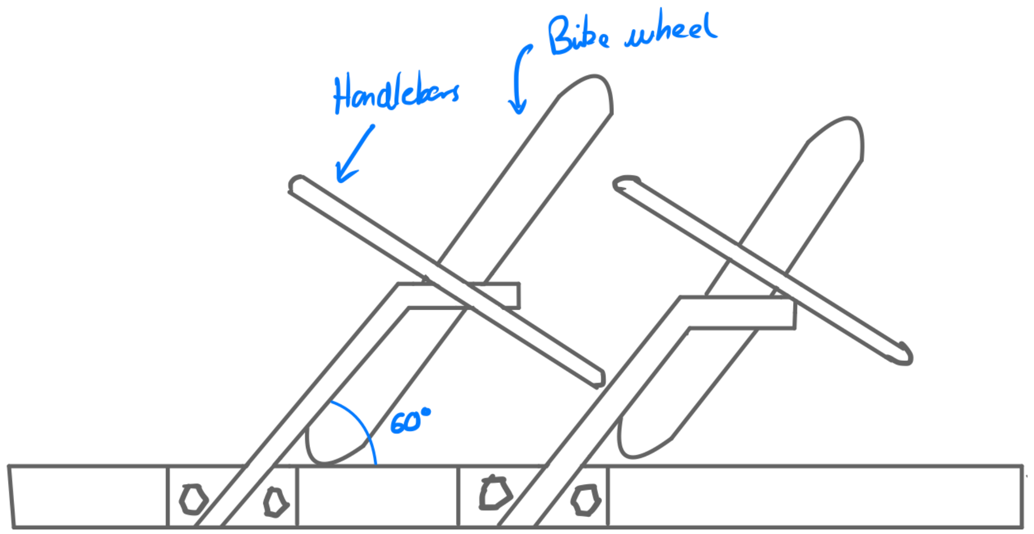
I realised I might have just been orientating my wheel cages at the wrong angle. If I could have the bikes slanted from a front on view instead of a top-down view they shouldn't collide.







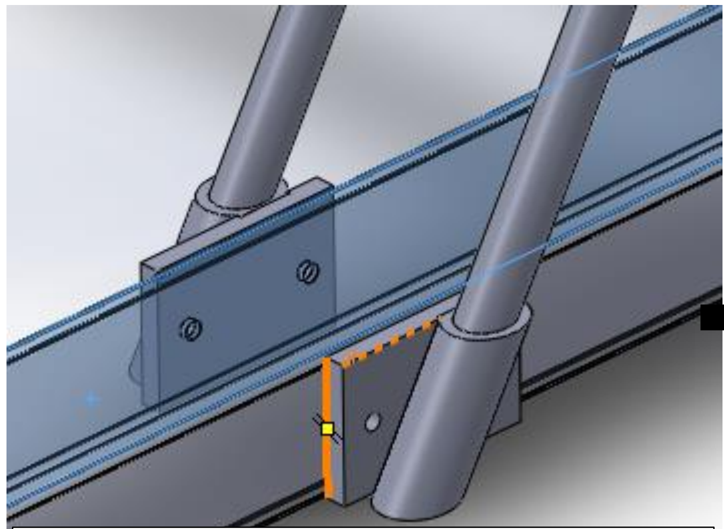




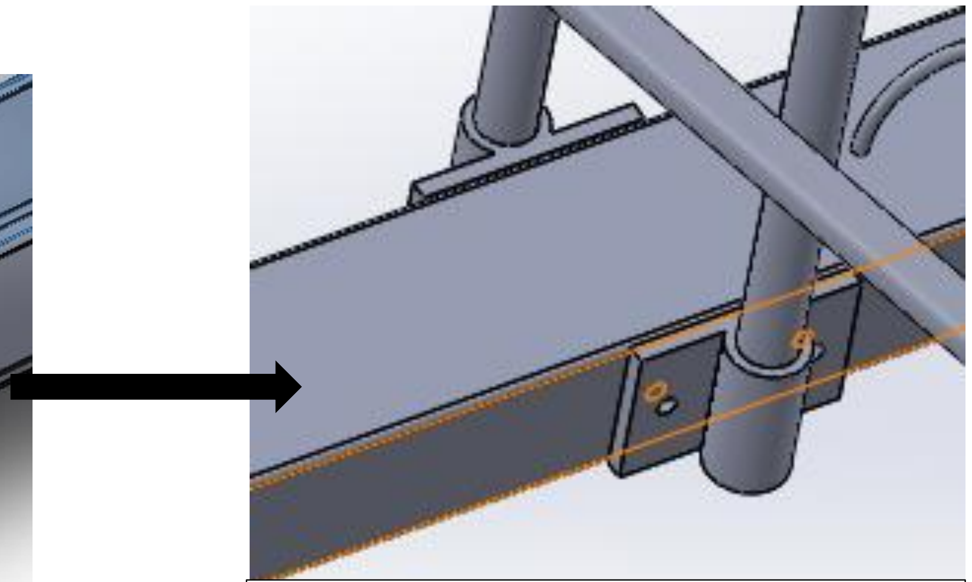
This new design will solve many problems that my previous design had.

For a start it should stop the bikes colliding with each other.

It will also make manufacturing much easier as the wheel cage mounting brackets will be paralell witheach other meaning I can have bolts that go all the way through the top bar.



With this design you can see the bolt holes line up meaning I can use one long bolt all the way through making it much easier to assemble

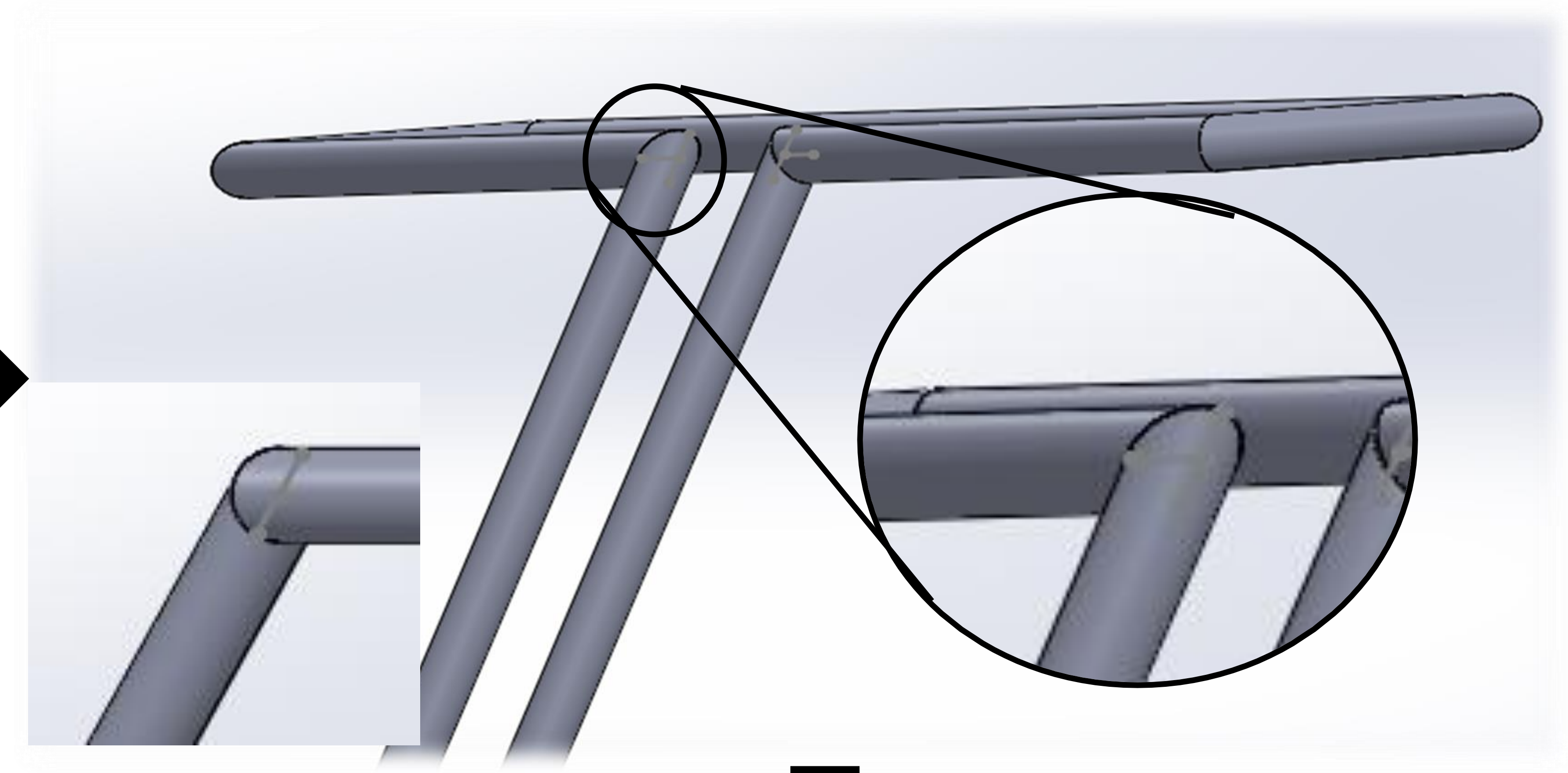


This is the old design; you can see that the bolt holes don't line up meaning I would have had to try and attach the nut whilst it was in the top bar.

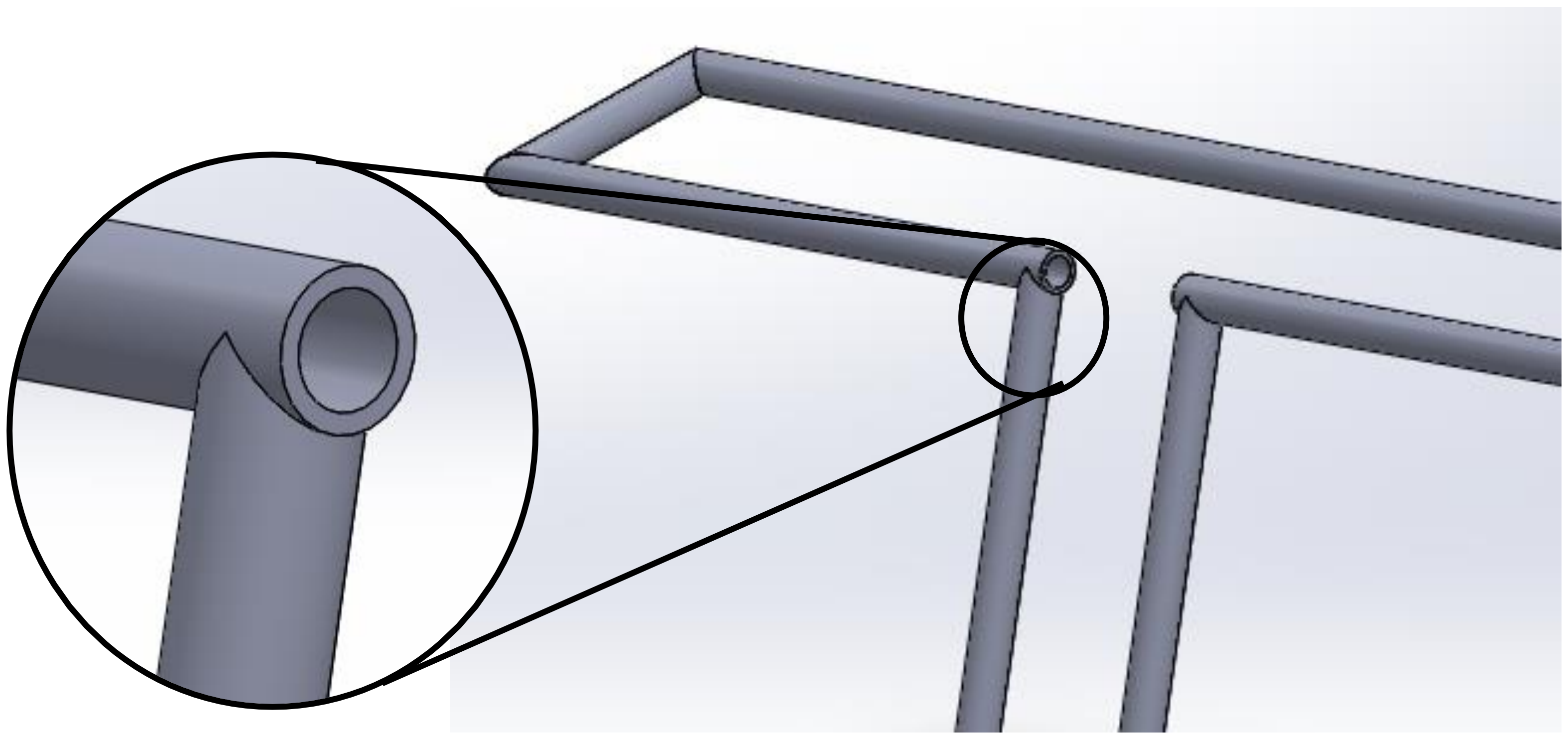
Problems with new design

One of the biggest problems with this new design will be attaching the angles tubes together at the correct 60° angle. As you can see in these images from Solid Works these tubes are not only mitred but are not mitred in the same vertex as the rest of them.

This will create a problem when I'm trying to cut the tubes as I will have to cut one mitre at a different angle to the rest.

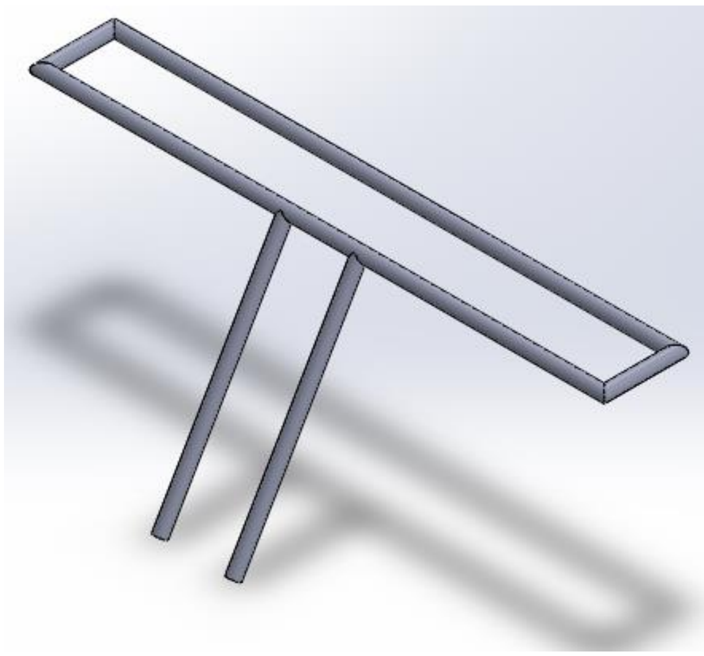


Instead of cutting mitres into the tube I thought about notching the pipe. Whilst this would solve the problem of having to cut the 45° angle so precisely, I also realised I do not have the suitable tools to accurately notch a pipe.



Despite having planned to use mitre cuts for all this cage during my testing I discovered it was incredibly difficult and time consuming to get all the parts lines up and decided I should instead use the approach of cutting a notch out using a hacksaw then filing the profile of the other half of the pipe.

Because I was using this notching approach, I realised that I didn't need to have the gap in the pieces, and I could increase strength and ease of manufacturing by simply having 1 piece that spans the whole length.

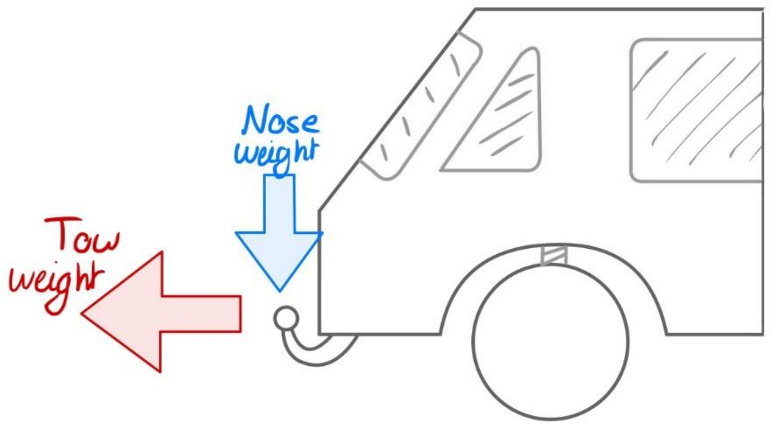


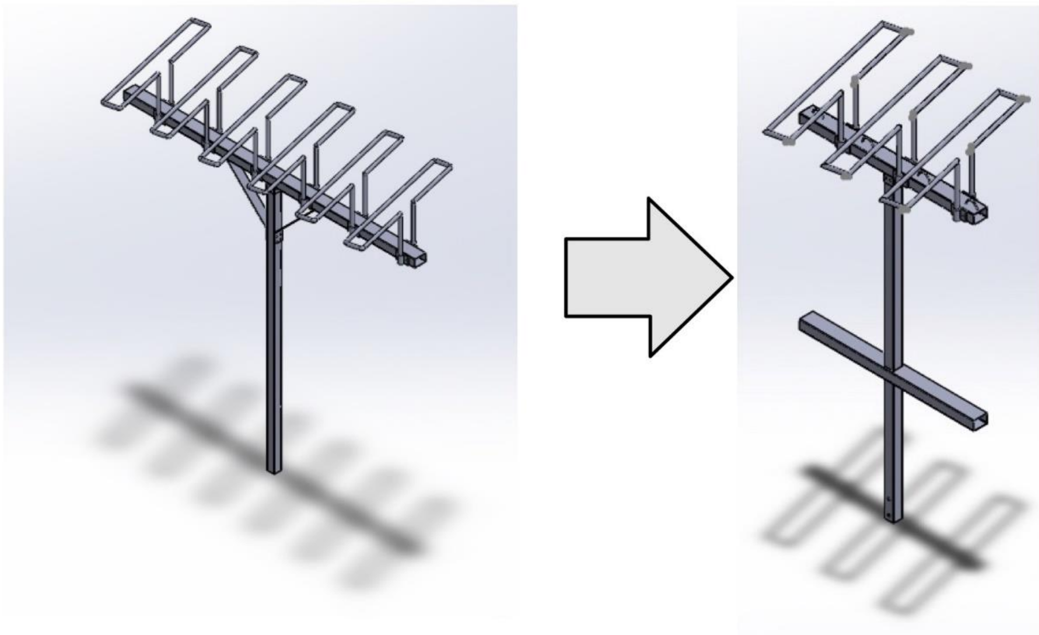
MKI -> MKII (tow ball weight issue)

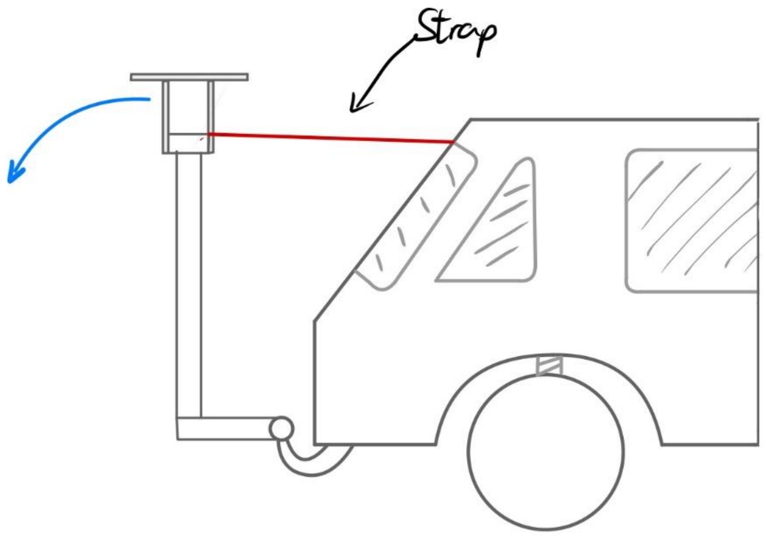
Upto this point most of my CAD work, sketches and ideas had been orientated around carrying 5 bikes, however once I had decided to use a tow ball mounted system for my bike rack I decided it would be a good idea to research the limitations, laws and specifications of a tow bar/ball.

There are 2 crucial specifications of a car and tow bar that will influence my design + specification, the obvious specification of the car is the tow weight, this is the maximum weight that can be attached to the tow bar and pulled by the car. The other specification is the nose weight of the car, this is the weight (or force) that can be applied straight down to the tow ball of the car, this is very important as exceeding the nose weight could cause the front wheels to lift off the floor.

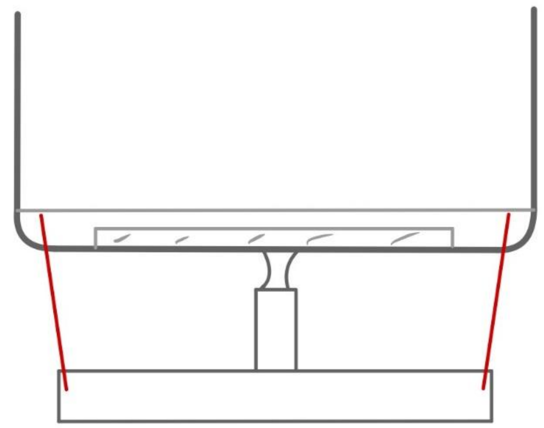
Because the nose weight of hatchback and smaller cars is around 60-70kg because of this I don't think my bike rack will be able to carry 5 bikes and I will change my design and spec to 3 bikes



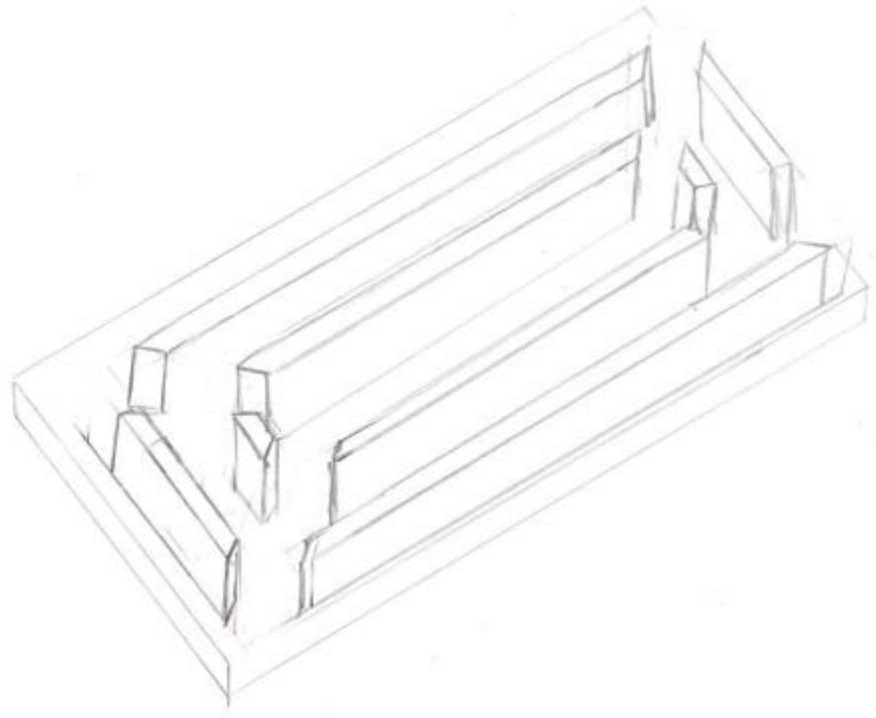
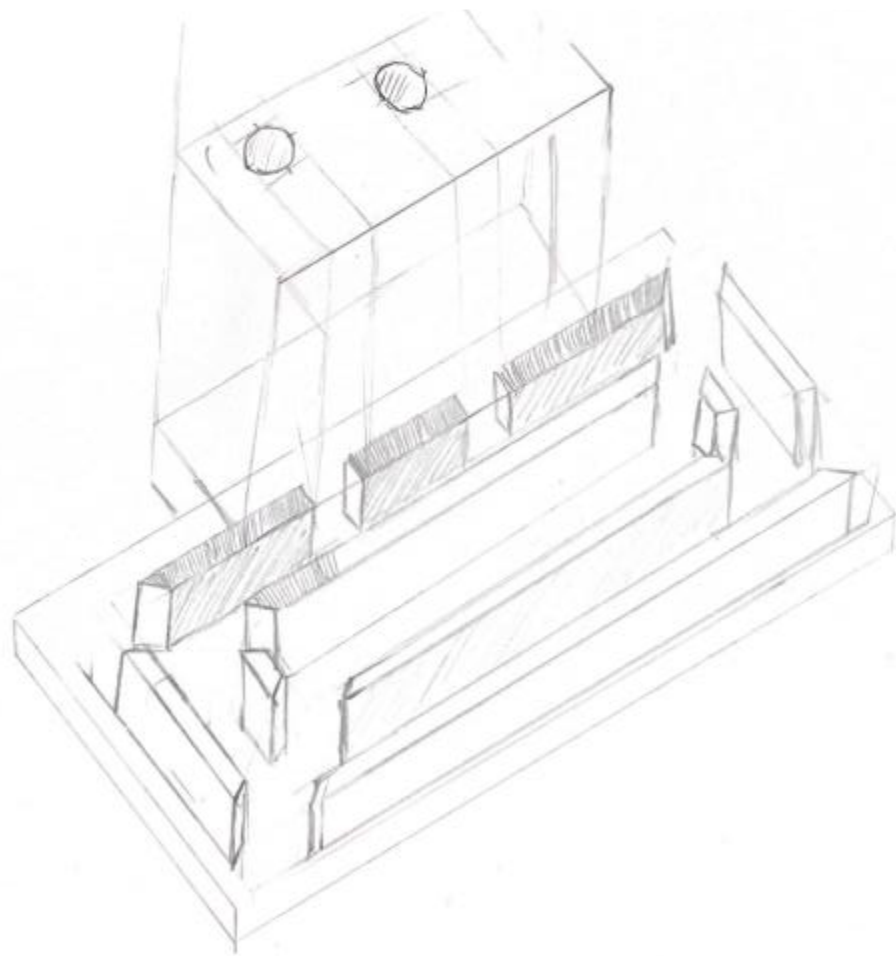
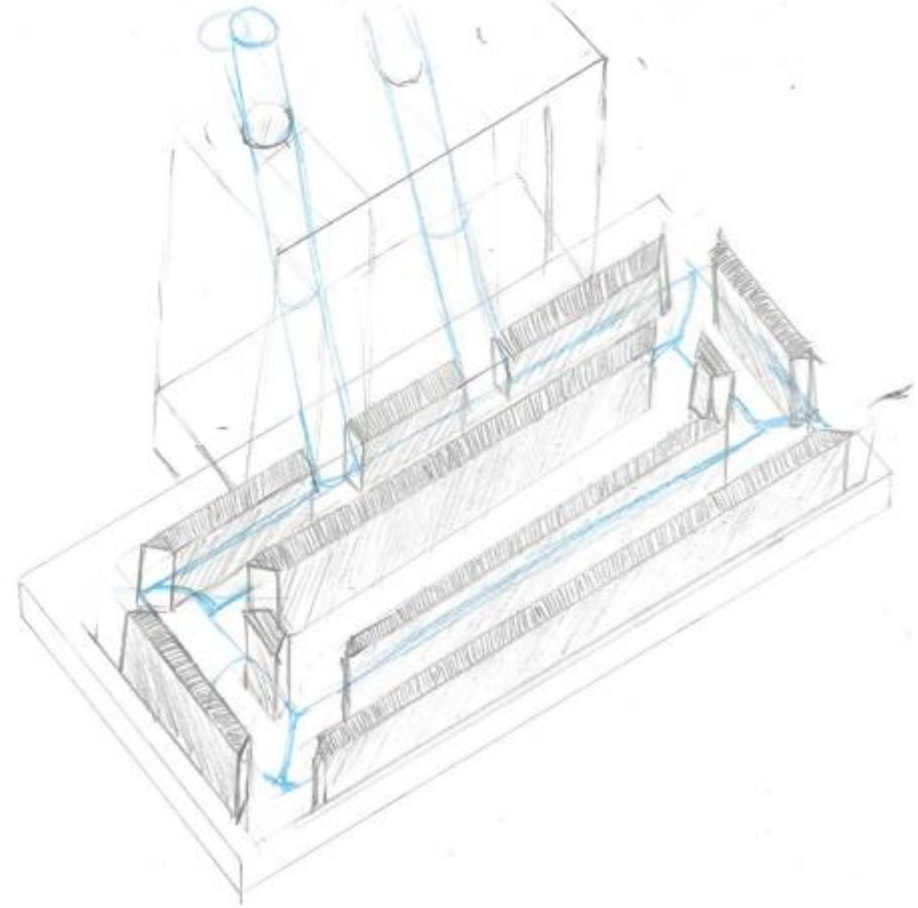




To try and reduce the rotational force on the tow bar I realised it would help to add some sort of strap from the top of the bike rack to the back of the car.
- This would also reduce any side-to-side sway
- These straps could easily attach by being clamped by the boot



Wheel cage jig initial design

My plan is to make a jig out of pine strip wood on an MDF base.

This will be a cheap way of making a jig, it will be relatively simple as it just needs to hold the steel tubes in a rectangle.

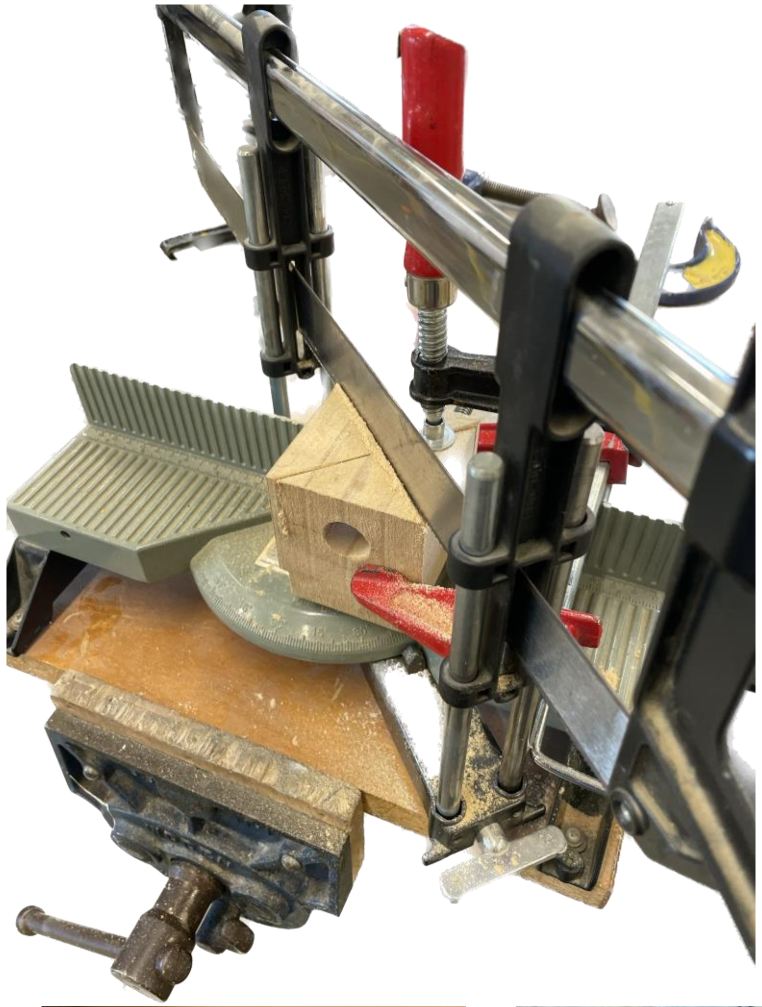
My plan is to cut a section out from all the corners to allow me to tack weld the tubes together.

For the new 60° angled piece it will make welding it together a bit more difficult, my plan is to build up a wooden block by stacking up MDF, I can then drill a hole through it and use that to hold the tube in place.

Prototyping and feasibility test

Before ordering material, I decided I should make a prototype wheel cage out of steel pipe to ensure this updated design will work. Instead of buying materials I managed to find broken chairs and could recycle the material from the steel legs, although this steel tube was not exactly the same as my planned 15mm pipe it would give me a good enough idea. It would also give me a chance to test different methods to adding the 45° cuts to the pipe.

Originally, I planned to roughly cut the 45° angle using a hacksaw and then use a file to get the angles accurate however I then realised this would be a very time consuming process and still probably not very accurate, I also realised I would have to do this about 40 times. I then tried making a Jig out of MDF:

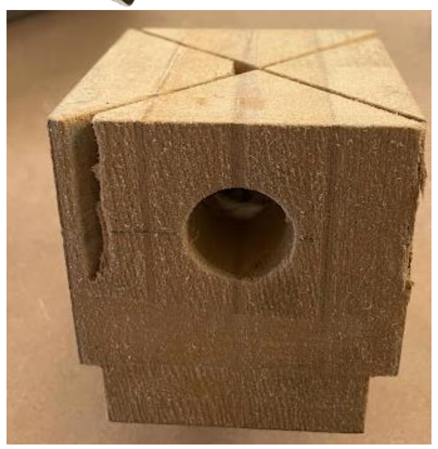


I used the mitre saw set to 45° to add cutouts that the hacksaw could go in and be used as a saw guide.

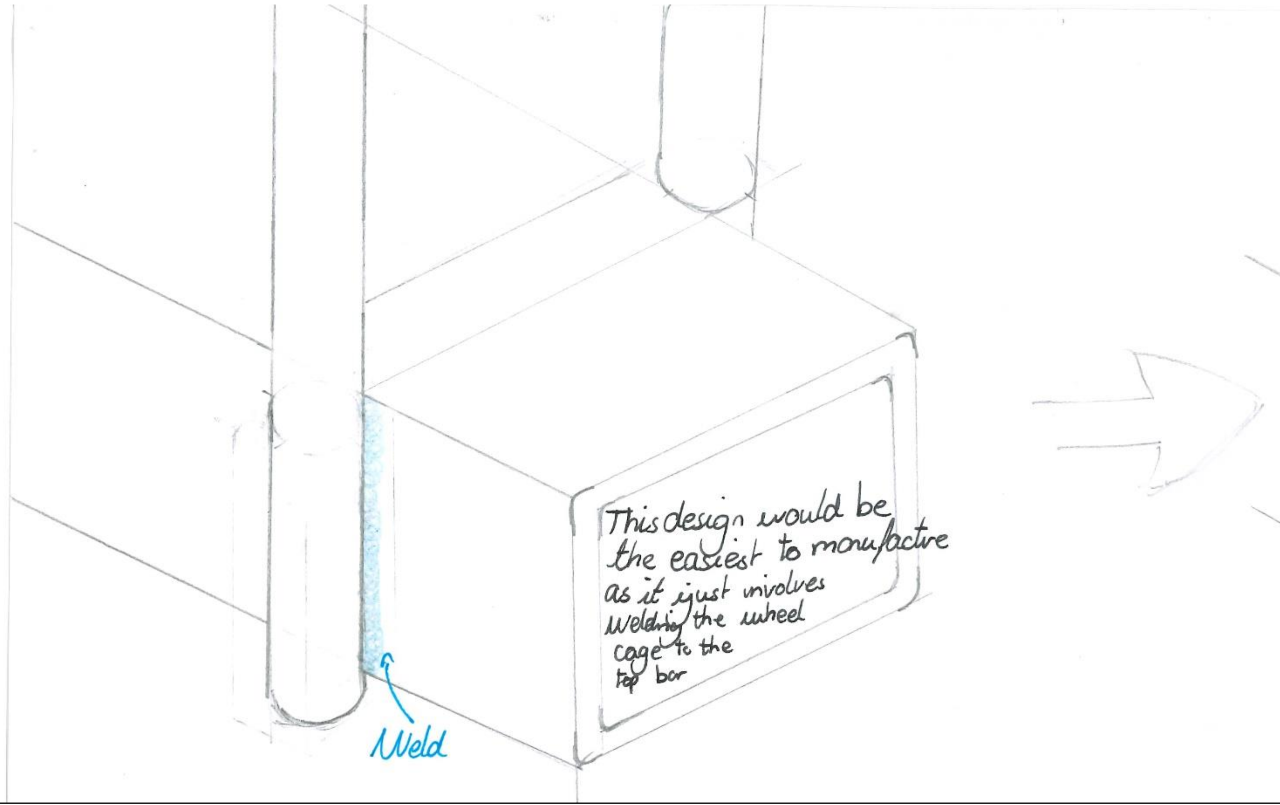
Annoyingly after using the jig a couple of time the angles started getting less accurate and the jig started wearing away.

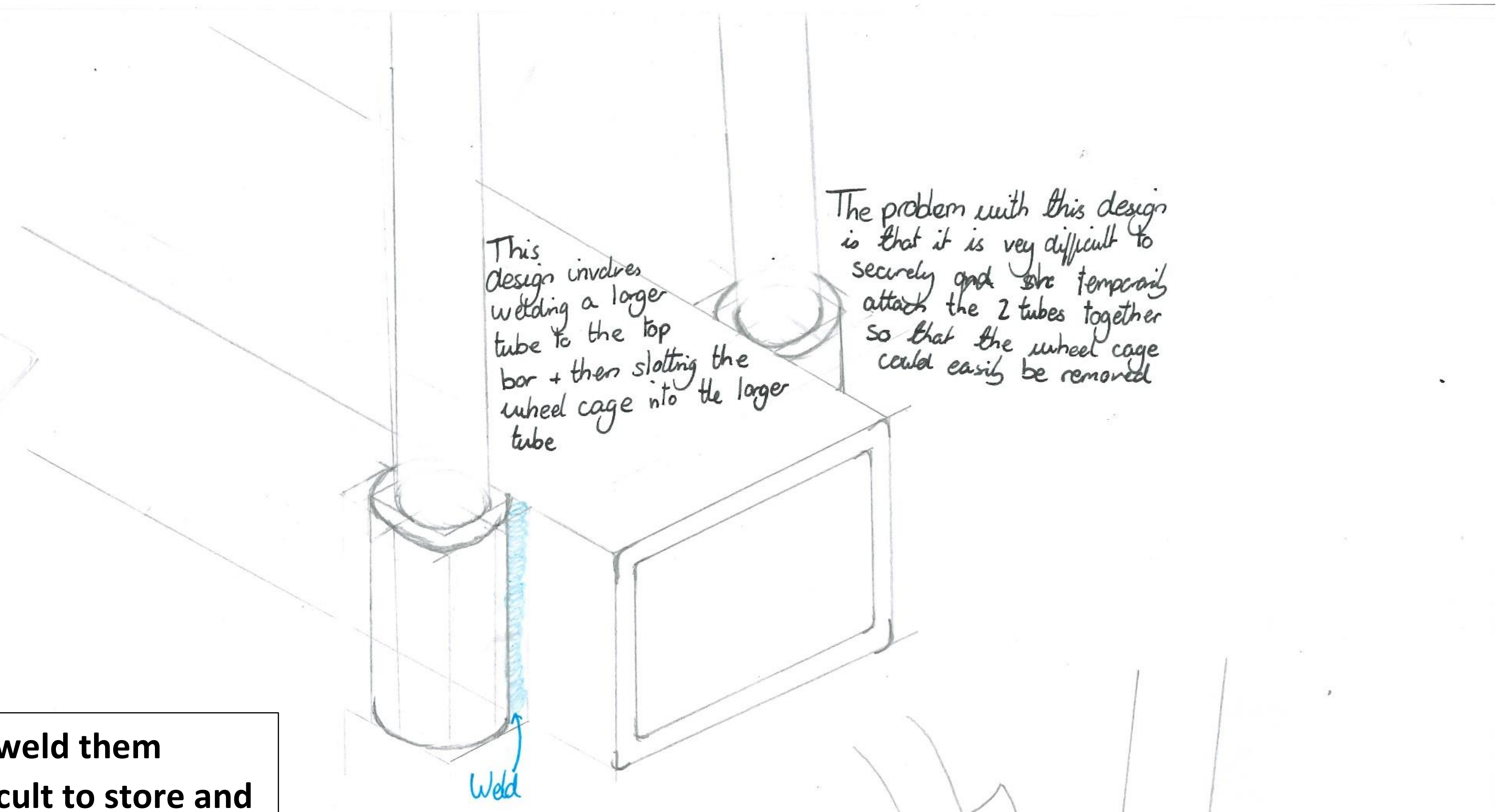
My new plan was to roughly cut the pipe using my jig or by using a template and then use the milling machine to get the accurate 45° cut.

Initially the jig worked very well, and I got a clean cut through the pipe and a pretty accurate angle

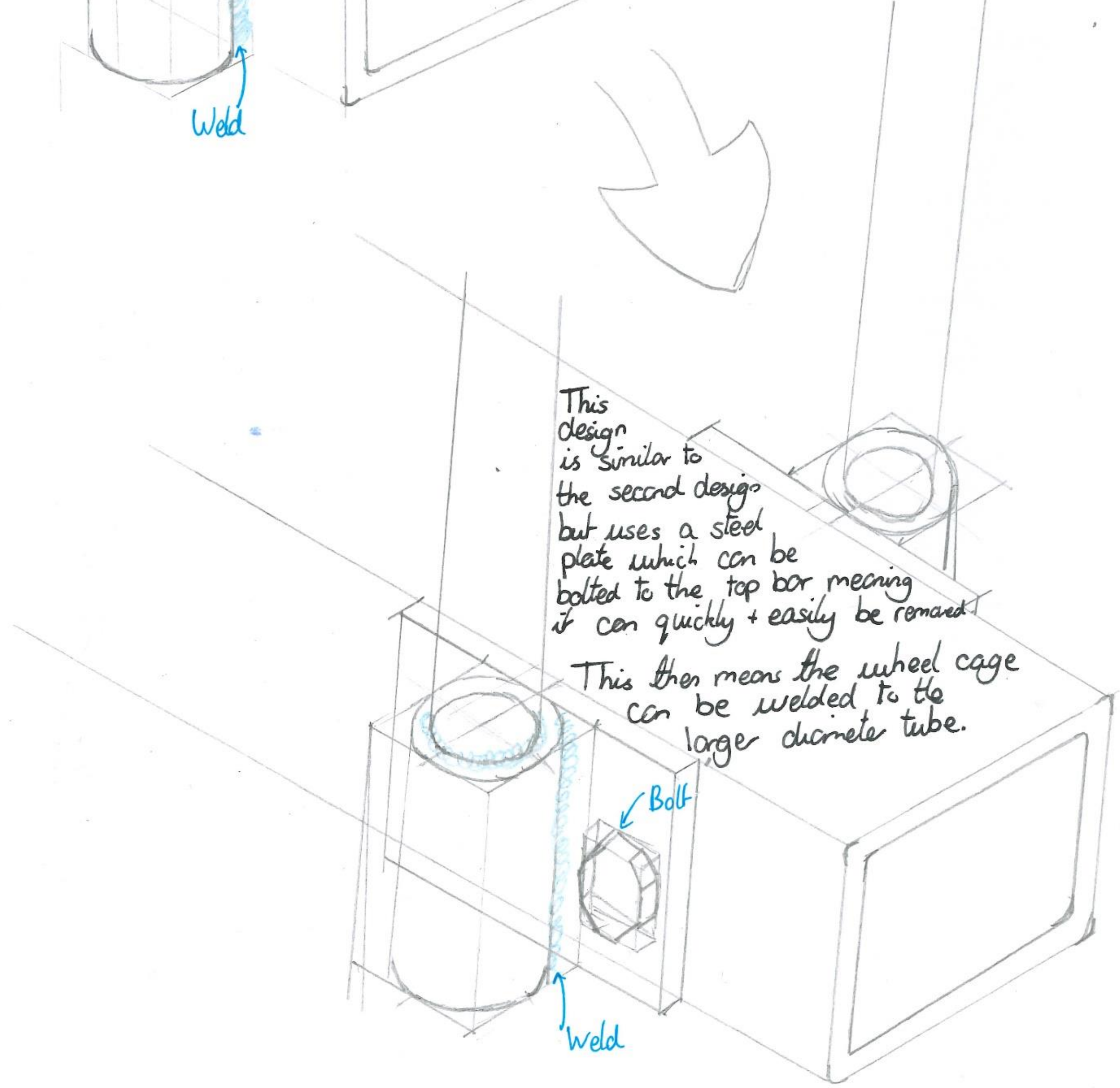


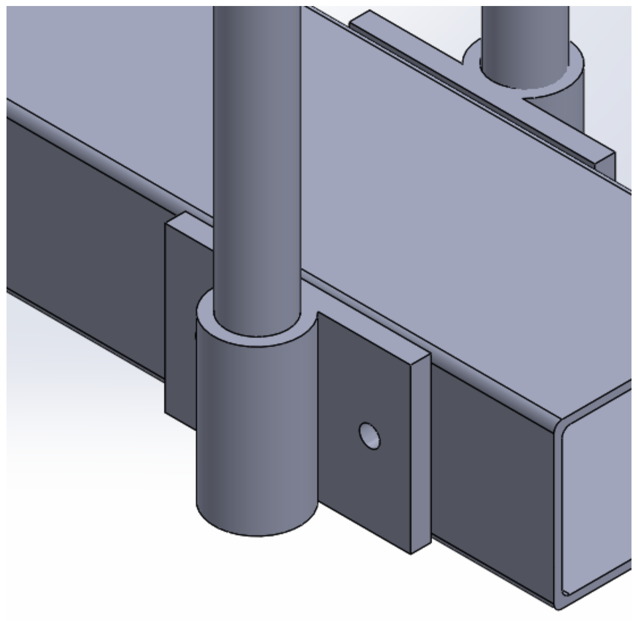
Wheel Cage Holder Development

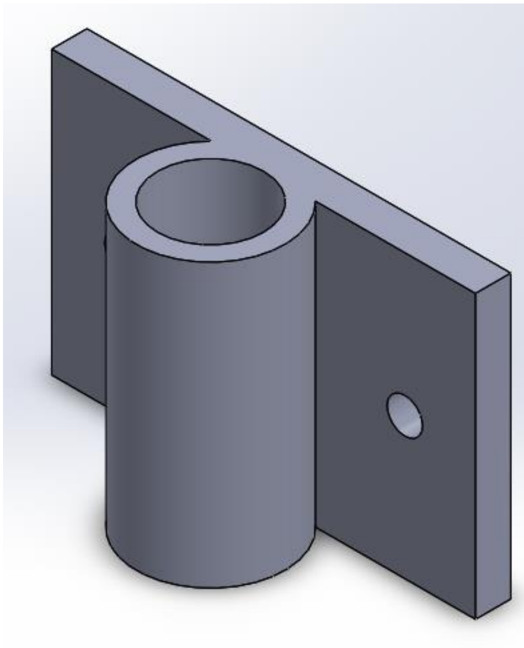




My initial plan for attaching the wheel cage to the top bar was to just weld them together. However, this would have made the product a lot more difficult to store and also to ship if it was to become a commercial product as the wheel cage would permanently be stuck to the top bar. Instead of this I decided to add a way to add or remove the wheel cage. This means I could also design different wheel cages to the rack is compatible with some specialist bikes such as fat bikes or children’s bikes.







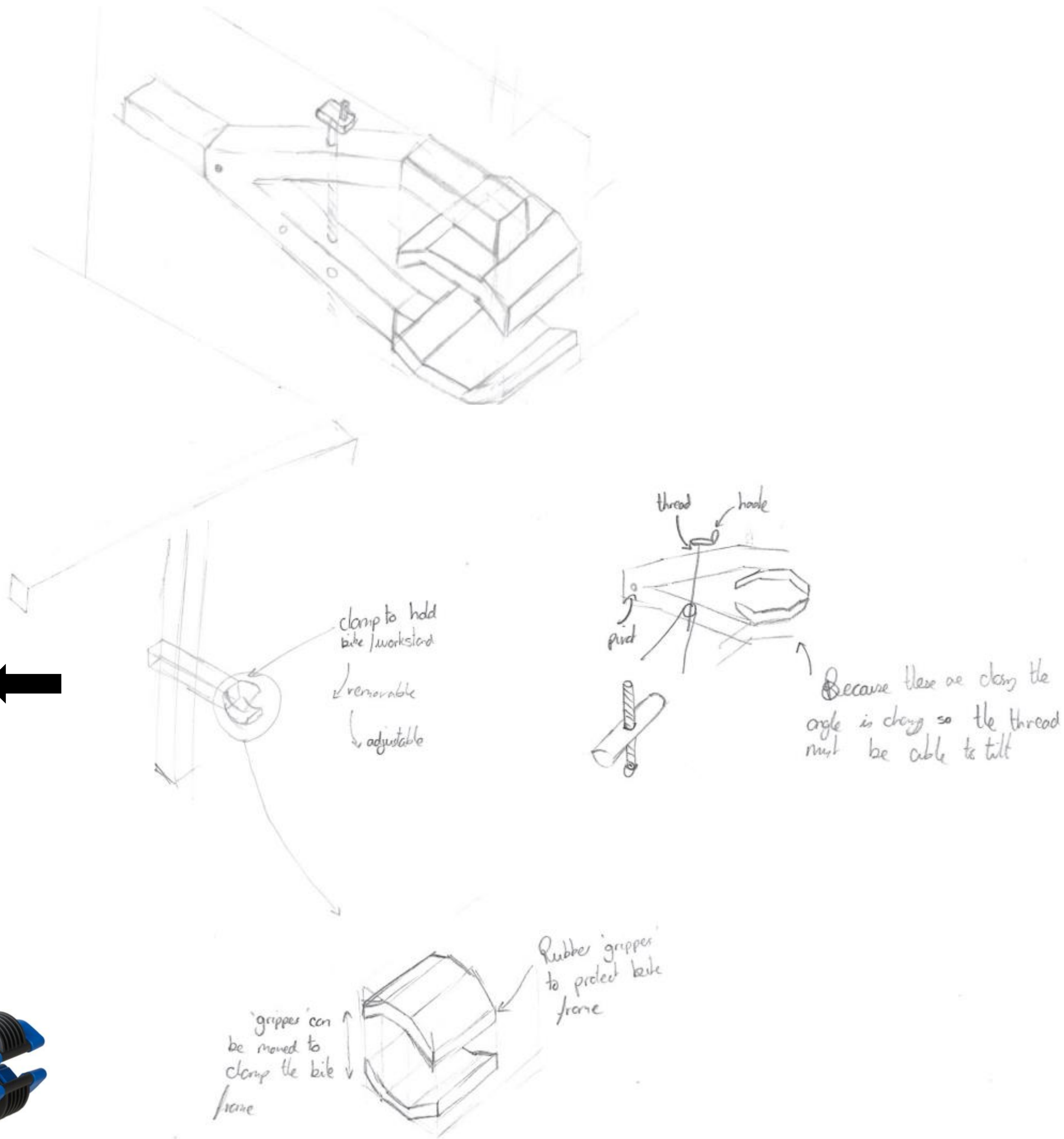
Bike Repair clamp feature

One of the features I want build into my bike rack is a bike repair stand, this would allow the user to repair and mend their bikes if they are on a multi-day trip, for example many mountain bikers go to Wales for a weekend of riding, the conditions of the mountains in Wales take a toll on bikes and usually mean a bike needs repairing or at least checking over at the end of the day.

Whilst bike repair stands are nothing new, I could not find any bike racks that have any way of holding the bike allowing the bike to be worked on. There are a few criteria I want my repair stand to have:

- It needs to be compatible with all different bikes.
- Must hold the bike without damaging it.
- Needs to be unobtrusive and not get in the way when the rack is being used.
- Needs to be quick and easy to use.

Initially I planned to design and manufacture my own custom bike repair holder. I made some sketches and noted features I wanted to include.

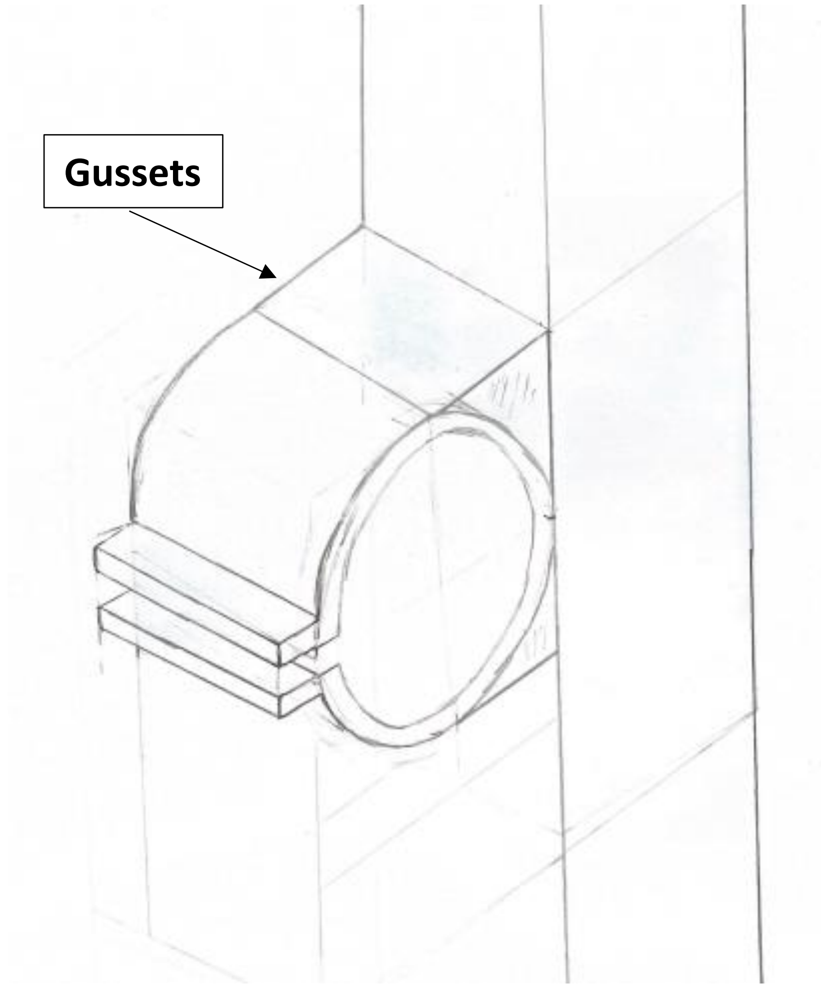


I realised designing my own custom repair holder would be a lot of work and As I said before a bike repair stand is nothing new, there are plenty of great examples that already exist. I didn't have to reinvent the wheel; I decided a good approach would be to see if I could integrate a pre-existing bike stand into my design.

Existing model integration

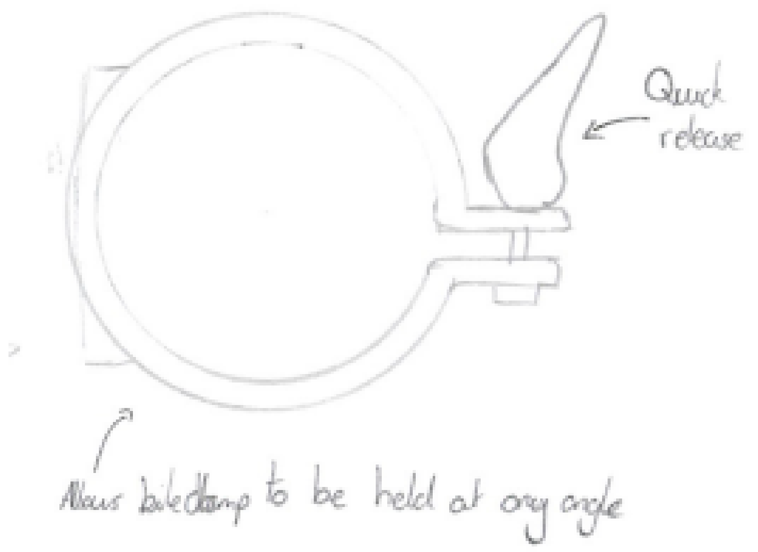
One of my plans is to use the top portion of an existing clamp mechanism like this. My plan would be to weld a large diameter steel pipe to the side of my upright and add a quick release handle to secure the clamping mechanism. The quick release clamp would also allow the bike to be rotated to allow easier access.

This design would also mean the repair clamp would be removable so it's not in the way when the bike rack is being used to transport bikes.



My plan is to get a large diameter tube and cut a slit in it, I then plan to weld it to the upright tube and add gussets to support it as there will be quite a lot of force going through it.

I also plan to add a quick release to allow the tube to securely hold the clamping mechanism.



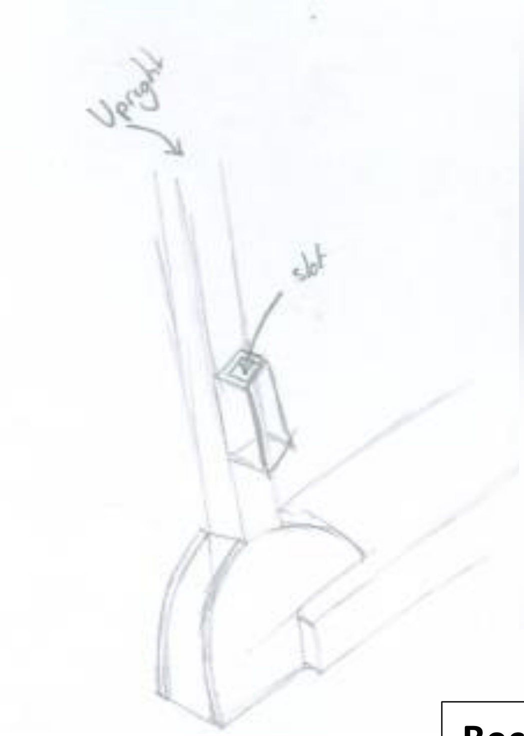
I will also need to create a place to store the clamping mechanism whilst the rack is being used to transport bikes.

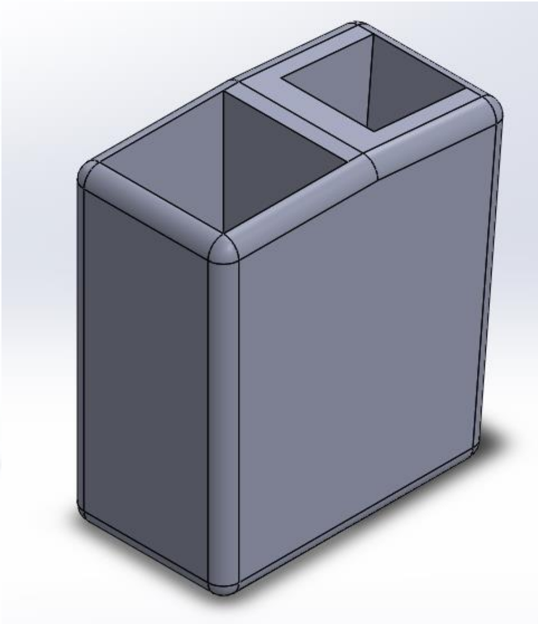
My plan for this is to weld a pipe to the upright which will hold the clamping mechanism upright & out the way.

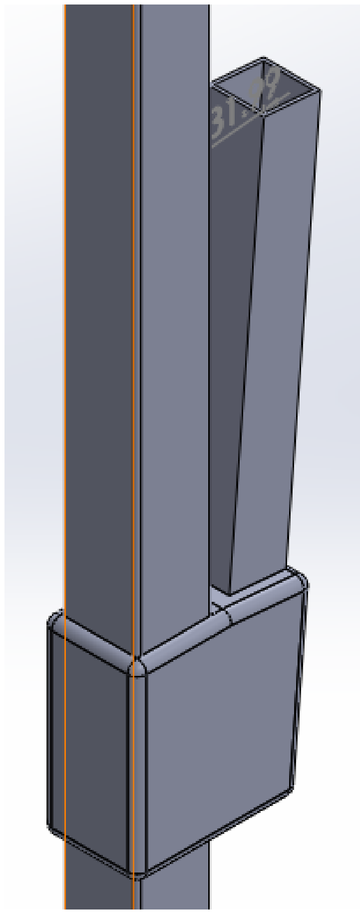
I found this bike repair clamp on amazon for £14.99. I chose to use this product as it was inexpensive but would be perfect for what I needed. It came with a plastic mount to allow it to be attached to a wall however I did not need this part so could easily remove it. I was left with a 30x30 box section which I could use to attach the clamp to my rack.

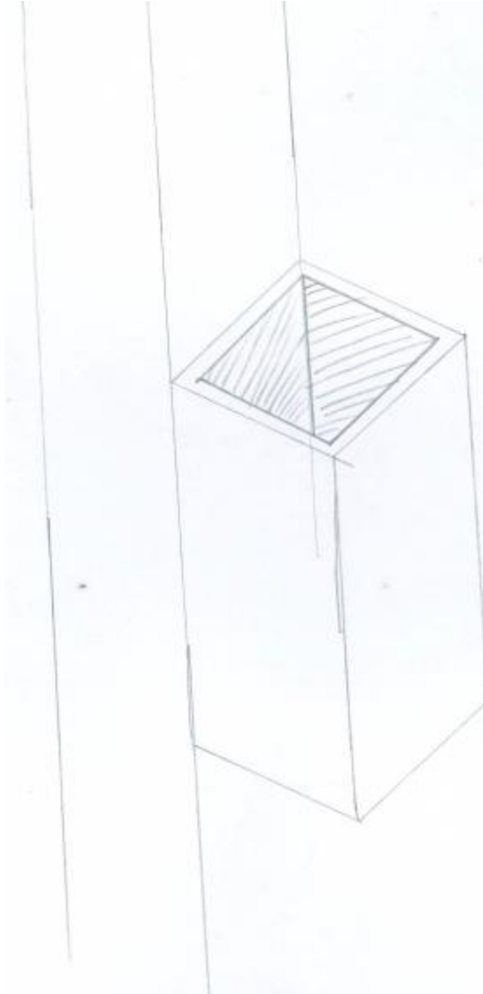
Initially I planned to store the clamp vertically at the bottom of the rack. However, because of the shape of the clamp it wouldn't fit with how I had originally planned.

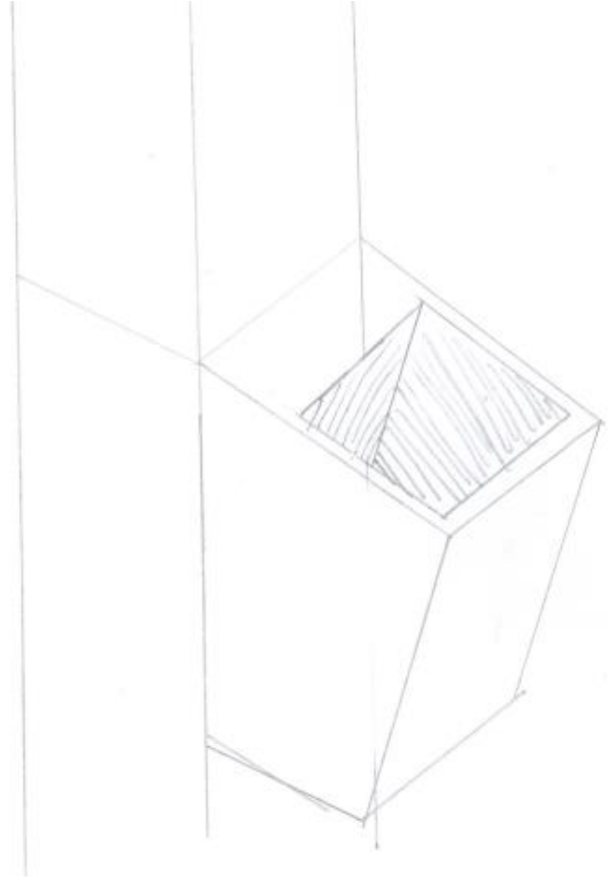
To hold the clamp, I decided to design a bracket that would attach to the upright and also hold the clamp at an angle to avoid them colliding with each other.

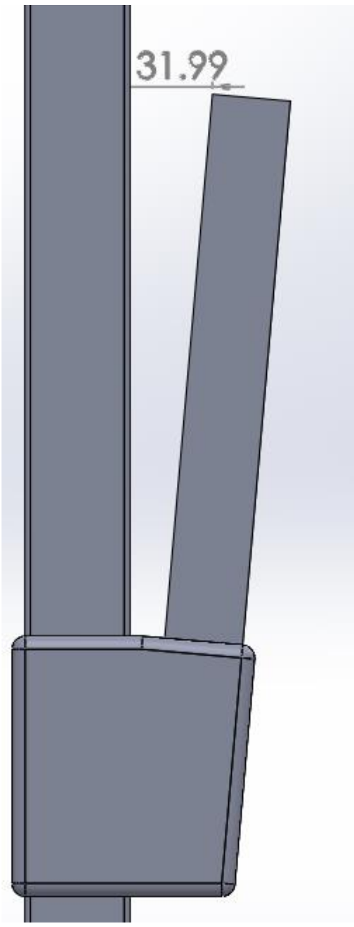












Because this part of the clamp attachment is just for storage and won't be structural it will be fine to be made out of a plastic. Ideally this would be a strong, durable & UV resistant plastic such as ABS however because this is a prototype, I am going to use PLA as it is cheaper and easier to 3D print.

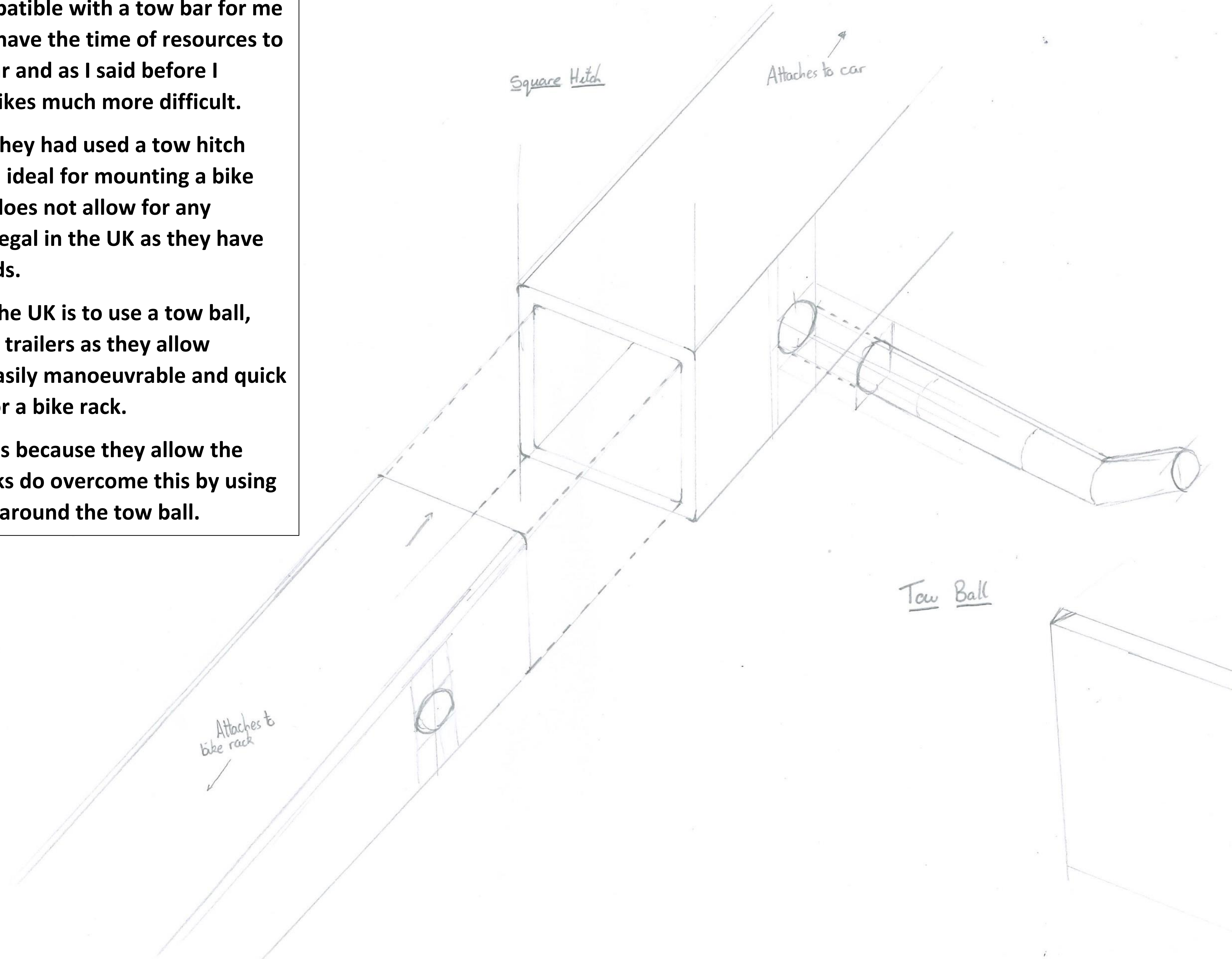
Tow Ball Mount development

After my research of existing bike racks and my initial design brief I decided the best way to attach my bike rack to a car would be t use a tow bar. I chose this option for several reasons. For a start I believe it is much easier to load bikes onto the back of a car opposed to having to lift bikes onto the roof, with the popularisation of E-bikes this is even more true as E-Bikes are incredibly heavy. My second reason is that Tow Bars use a standard 50mm ball which is universal (on any car which is compatible with a tow bar for me this was the most significant factor as I did not have the time of resources to design a different mounting system for every car and as I said before I believe it makes the loading and unloading of bikes much more difficult.

I had seen with some rear mounted bike racks they had used a tow hitch system. This tow hitch system would have been ideal for mounting a bike rack as the tow hitch is easy to connect to and does not allow for any movement. Unfortunately tow hitches are not legal in the UK as they have not been approved by the DVSA safety standards.

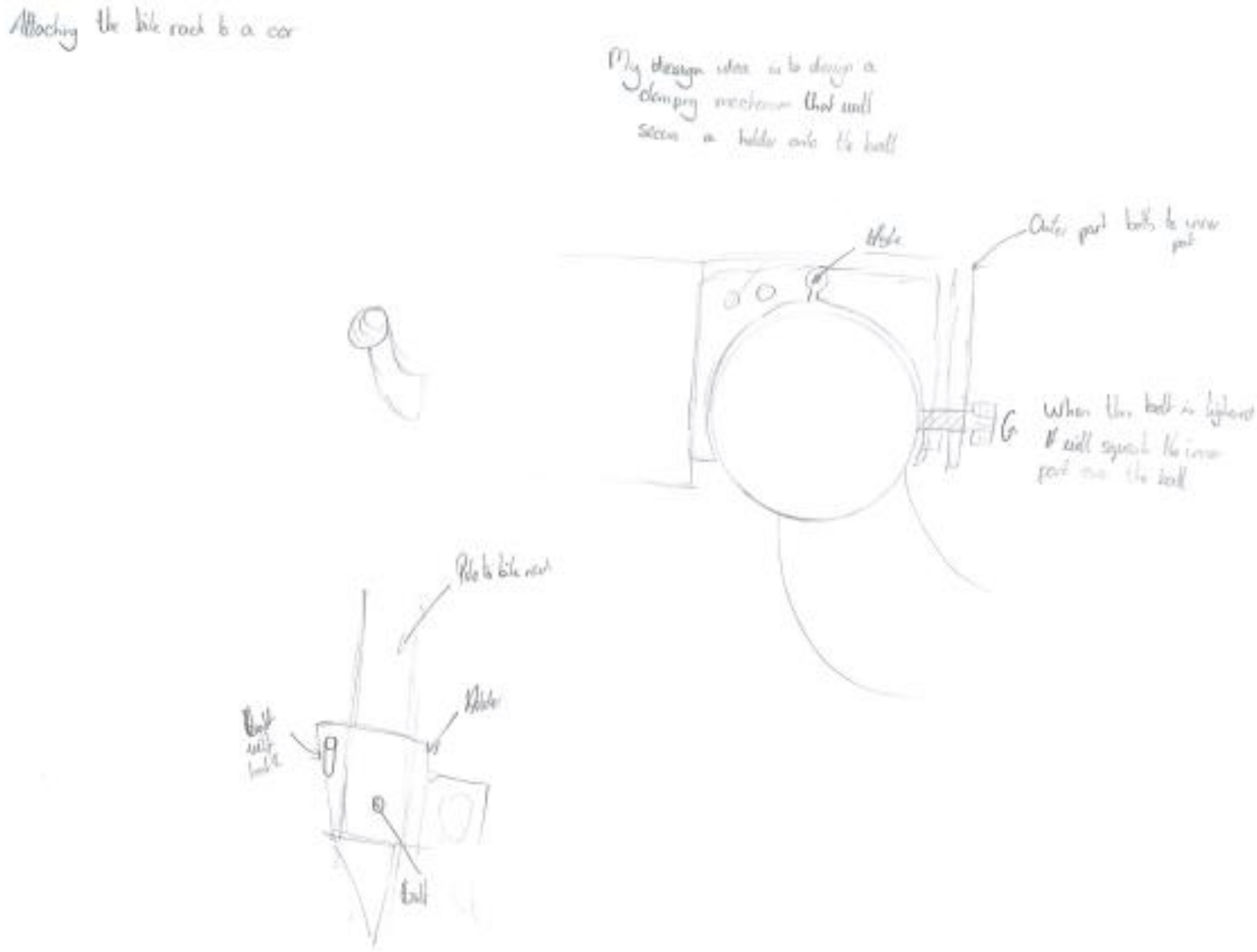
The only legal method of towing something in the UK is to use a tow ball, whilst tow balls are incredibly useful for towing trailers as they allow movement in all directions making the trailer easily manoeuvrable and quick to connect and disconnect, they are not ideal for a bike rack.

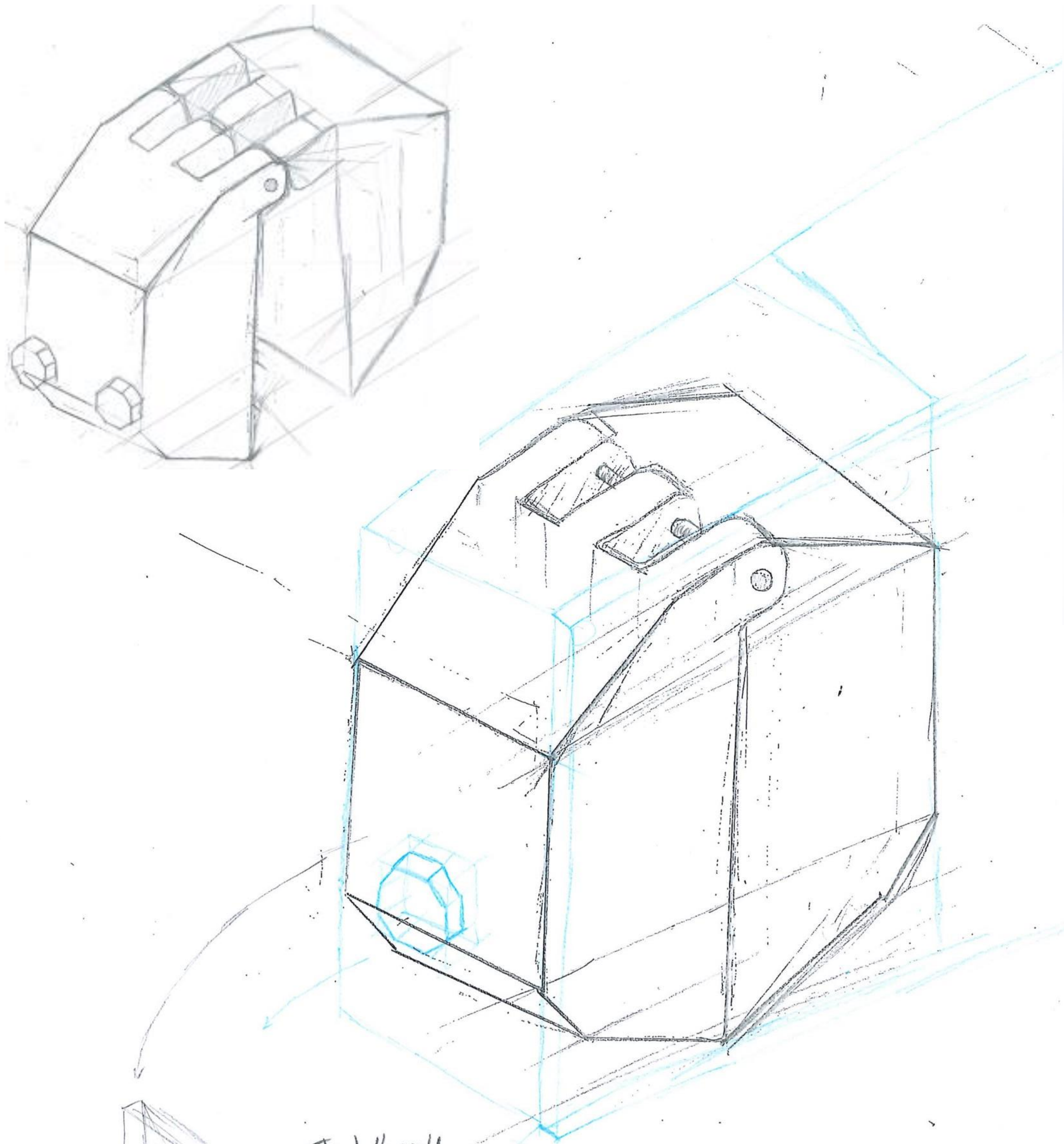
The reason they are not suitable for a bike rack s because they allow the mounts to pivot around them. Existing bike racks do overcome this by using special (incredibly strong) mounts which clamp around the tow ball.

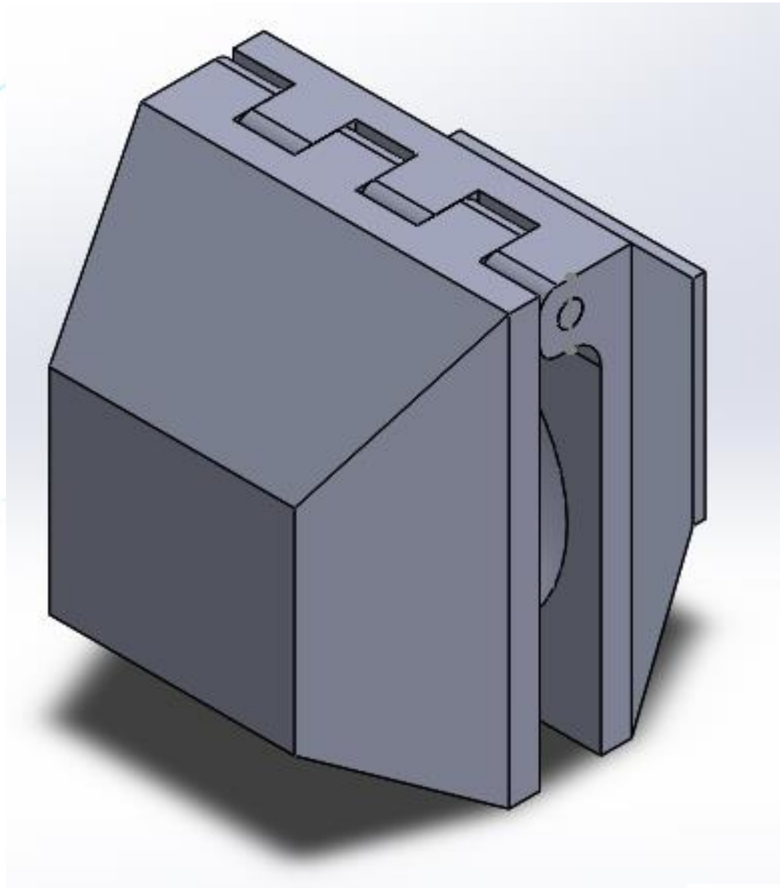


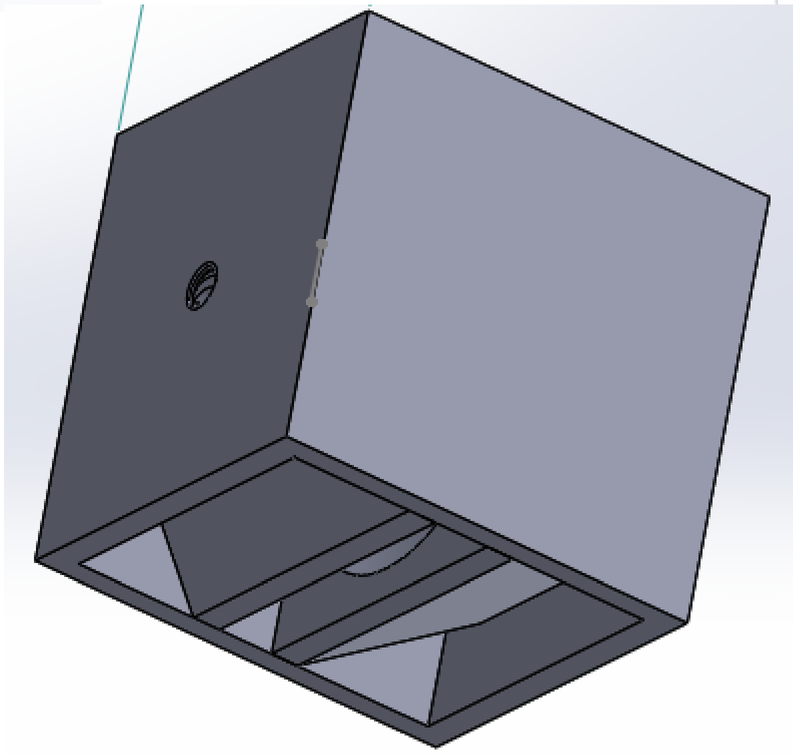
Freddie Knight

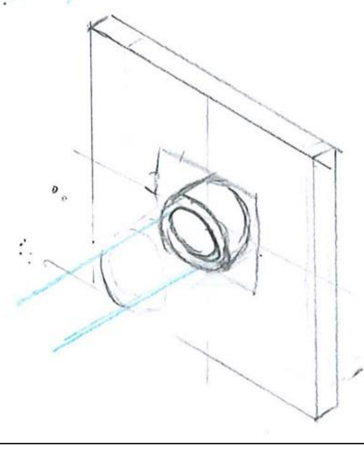
I then started off doing some initial sketches and designs of how I can make a mechanism to clamp onto the tow ball and also hold a steel bar upright whilst also allowing it to pivot and allow access to the boot of the car.

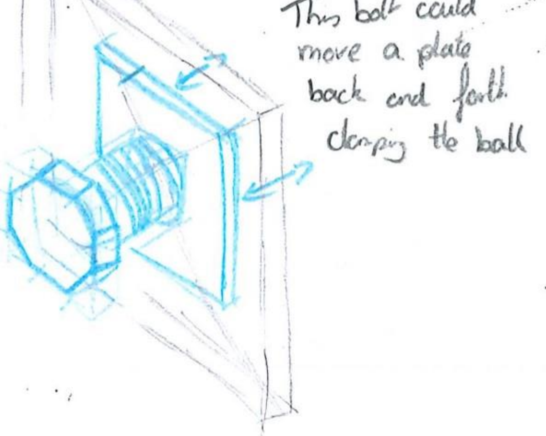






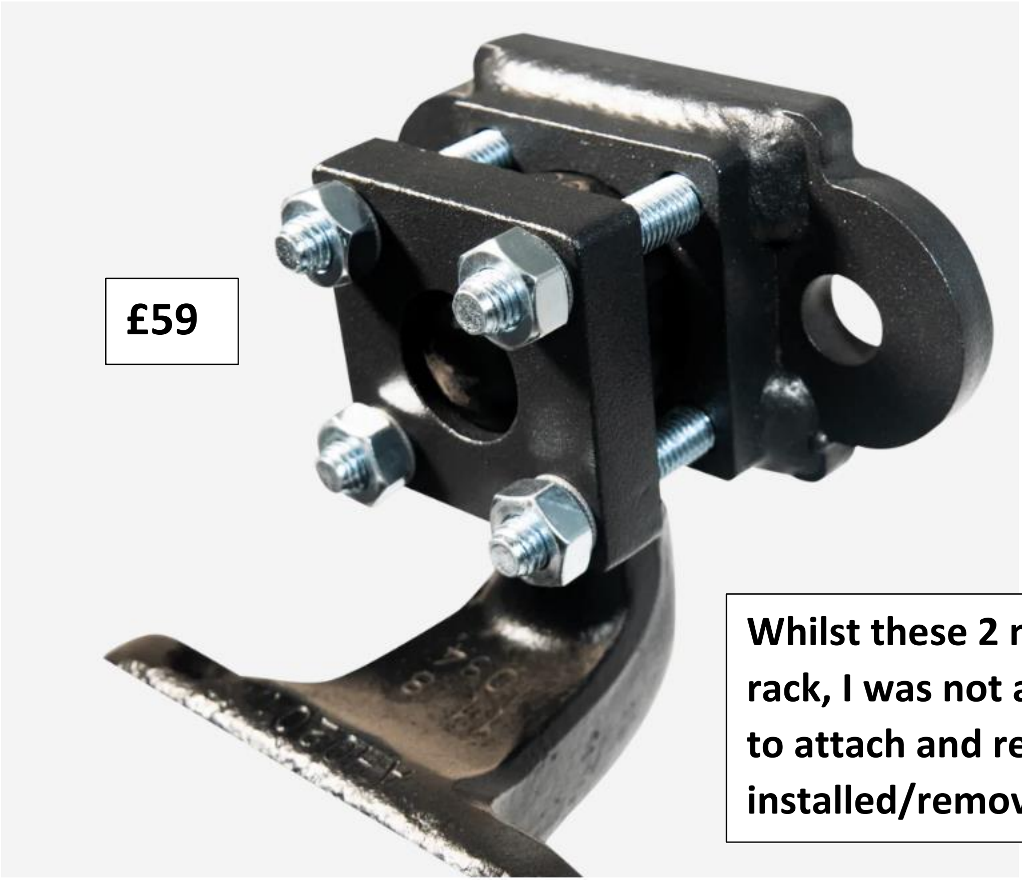






After some rough sketches and CAD, I came up with this system which used a short M10 Bolt to squash 2 custom made pieces of steel around the tow ball using friction to hold it securely onto the tow bar. I could ten easily make a way of holding the steel upright and weld it onto this outer box. After looking at this design I realised how complex it was and realised the ideal way of making it would be to use a CNC machine, unfortunately school do not have one capable of machining steel. Whilst I could have outsourced this part of the manufacturing process, I realised it would be expensive and there would be no guarantee it would work.

I started looking into Pre-Made tow ball clamping mechanisms, I decided as this project was mainly going to be a proof of concept and a prototype it would make more sense to buy a part, I knew would work than to send hours prototyping a small subassembly which probably wouldn't work as well as a bought in one. If this project was to become a commercial product, I would then look into in-house manufacturing of a tow ball clamp however for a one-off prototype it was unnecessary.



£59

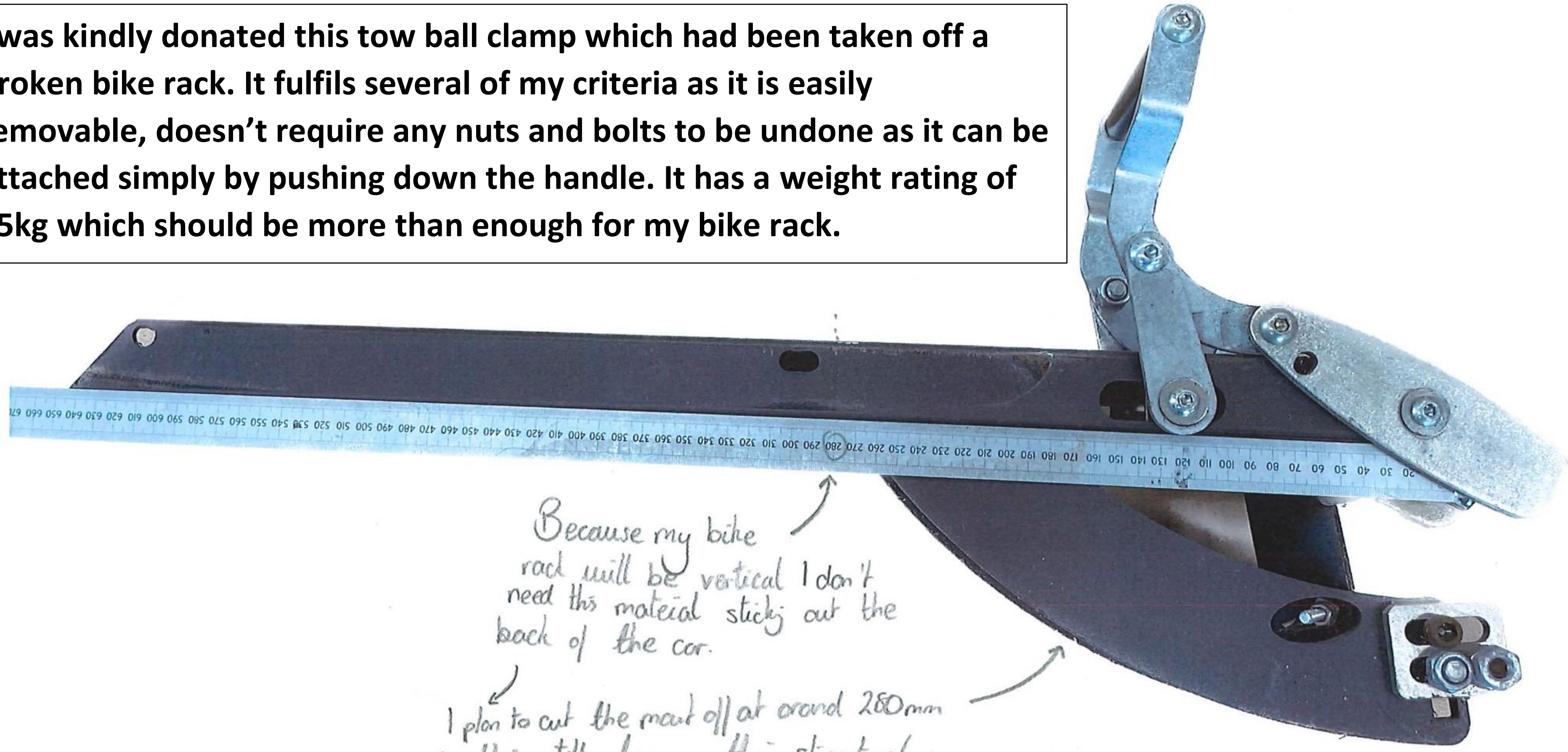
£97

£330

Whilst these 2 mechanisms would have worked for my bike rack, I was not a fan of them due to how long it would take to attach and remove them as several bolts had to be installed/removed.

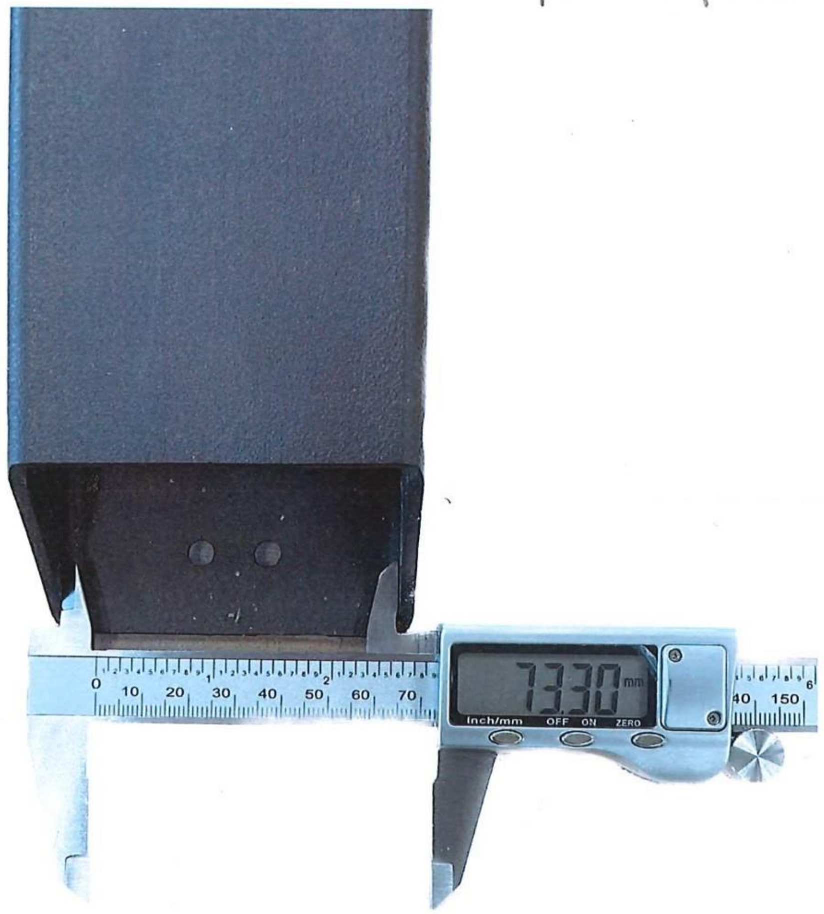
I then looked into a quick release style clamp, unfortunately I just couldn't justify this price.

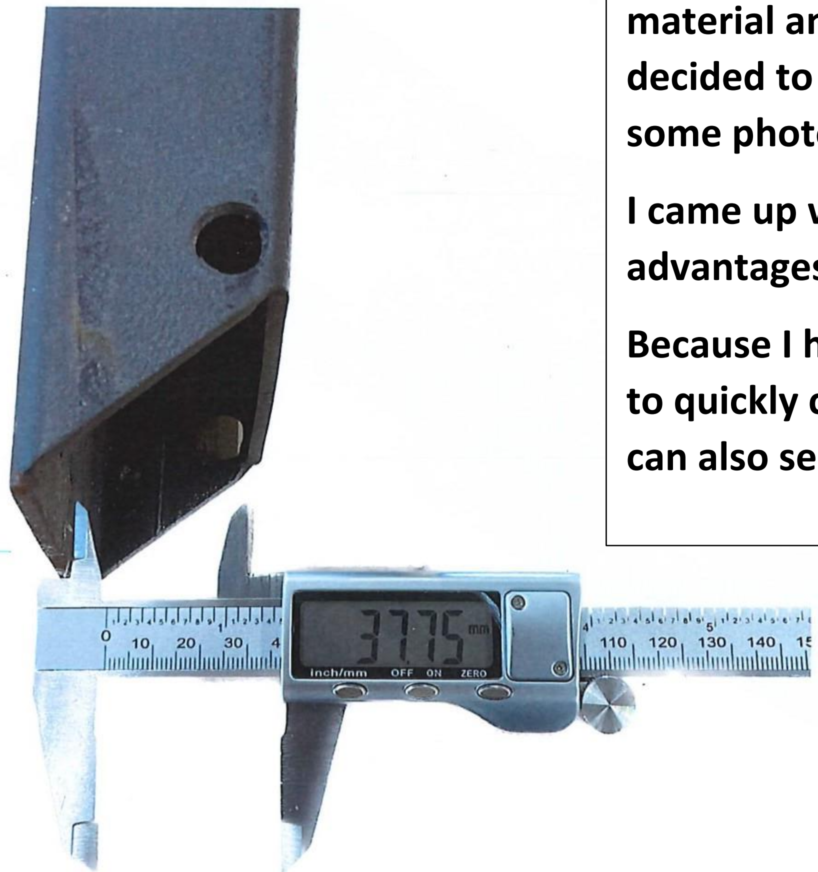
I was kindly donated this tow ball clamp which had been taken off a broken bike rack. It fulfils several of my criteria as it is easily removable, doesn't require any nuts and bolts to be undone as it can be attached simply by pushing down the handle. It has a weight rating of 75kg which should be more than enough for my bike rack.



Because my bike rack will be vertical I don't need this material stickg out the back of the car.

I plan to cut the mout off at arond 280mm as this still leaves this structural support but make the mont as compact as possible.

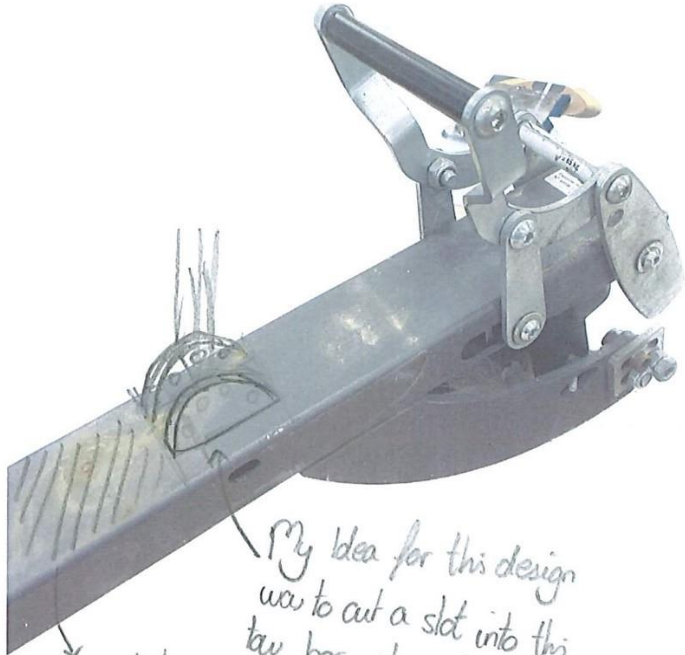




This bike rack was not perfect however because of its steel construction it meant I could easily modify it by removing excess material and welding on additional parts to fulfil my criteria. I decided to adopt an iterative approach to this design and print out some photos of the clamp and draw over the photos.

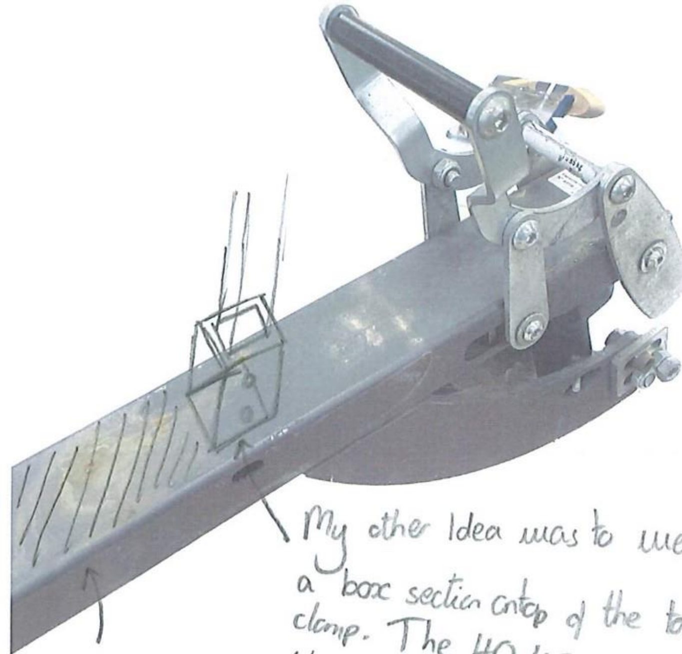
I came up with several different options each of which had advantages and disadvantages.

Because I have done so much CAD I the past I find it an easy way to quickly come up with accurate designs, using the CAD models I can also see how different parts will interact.



This material can be cut off

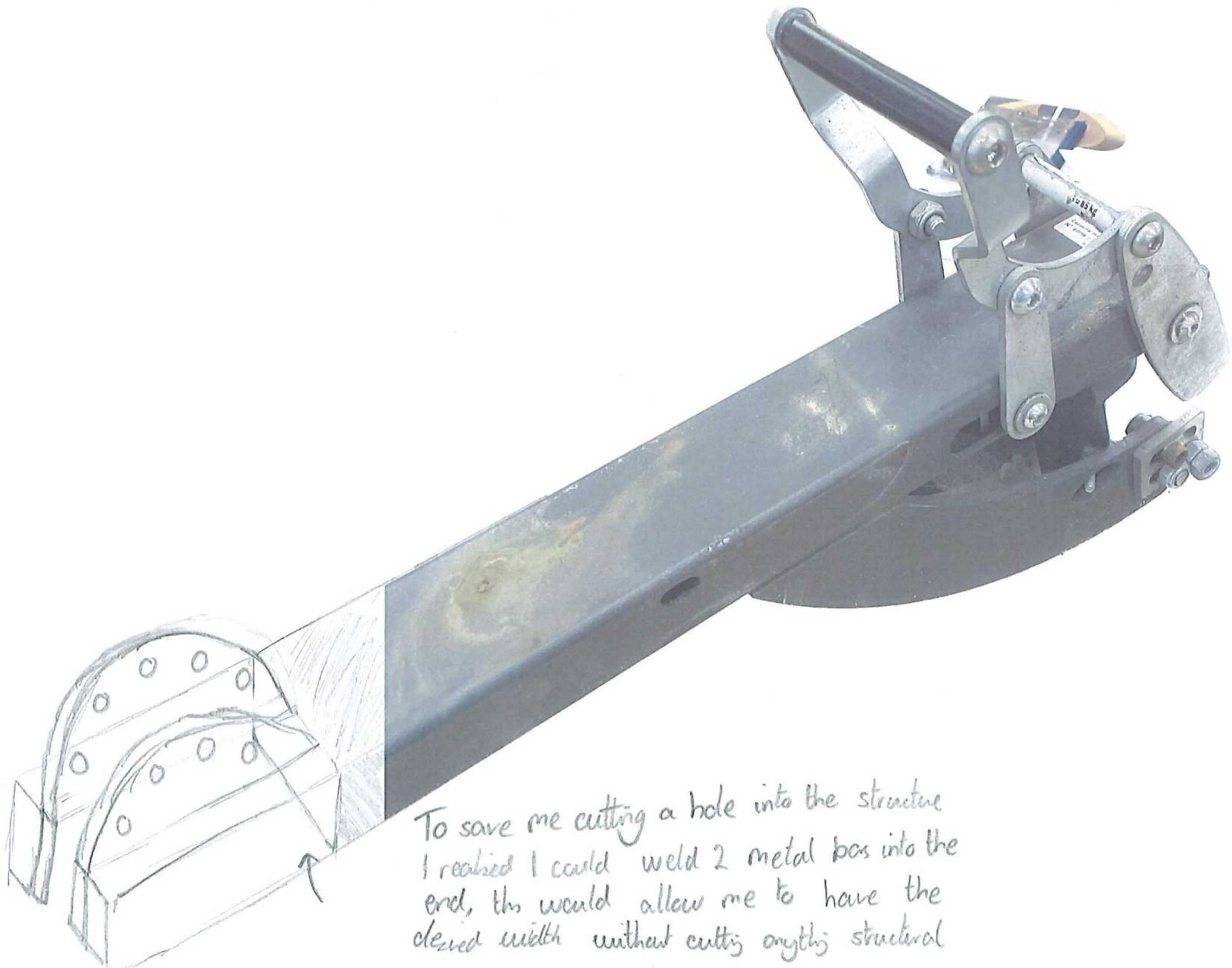
My Idea for this design was to cut a slot into this tow bar clamp to add a space for the 40x40 upright + a rotating mechanism



This material can be removed

My other Idea was to weld a box section ontop of the tow ball clamp. The 40x40 upright could then slot in and be bolted in.

The problem with this design is that the bike rack can't pivot so the boot of the car wouldn't be able to open



To save me cutting a hole into the structure I realised I could weld 2 metal bars into the end, this would allow me to have the desired width without cutting anything structural

Fr

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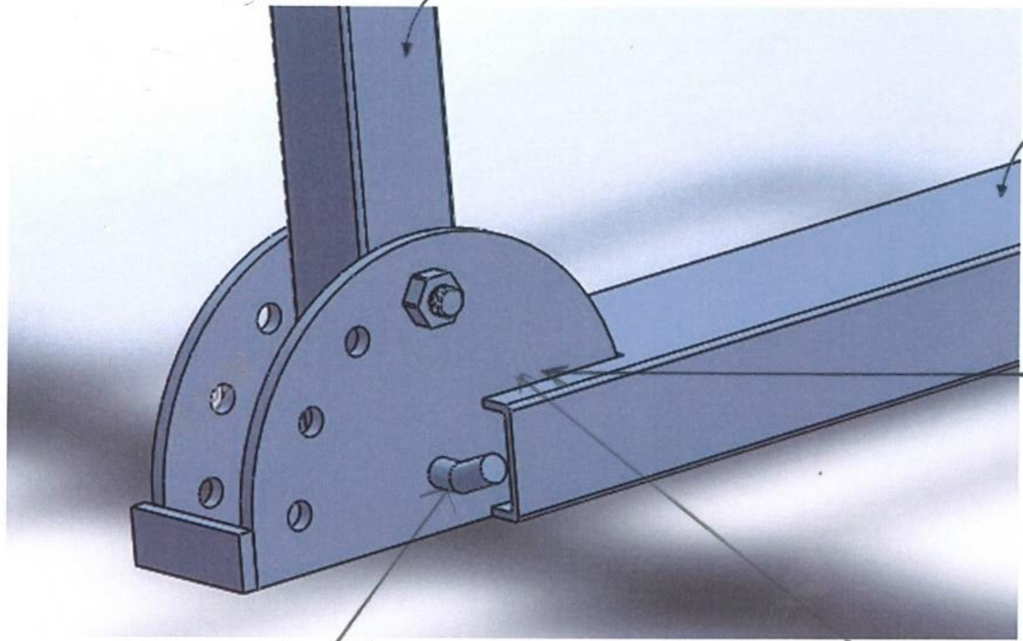
Up to bike rack



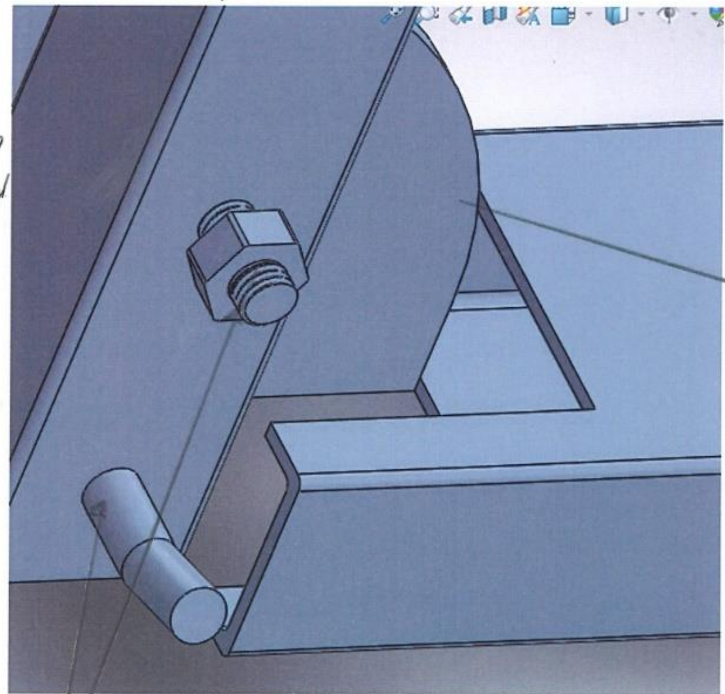
I first started by modelling this tube section which comes off the tow ball clamp.

I then cut this 52mm slot into the tube section. This would give me enough room for my 40x40mm upright and a 6mm plate on each side

This bent metal rod will have a hole on the otherside for a padlock

This will prevent the upright from being detached by someone trying to steal bikes

My plan was to weld these 2 semi-circular sections to the box section of the tow ball clamp



Before I can weld to the clamp I will need to remove the paint

Initially I planned to just weld the semi-circle sections into the cut out but I began to question if this would be strong enough. I realised there would be alot of wasted space inside the tube and I could probably use the space to add strength.

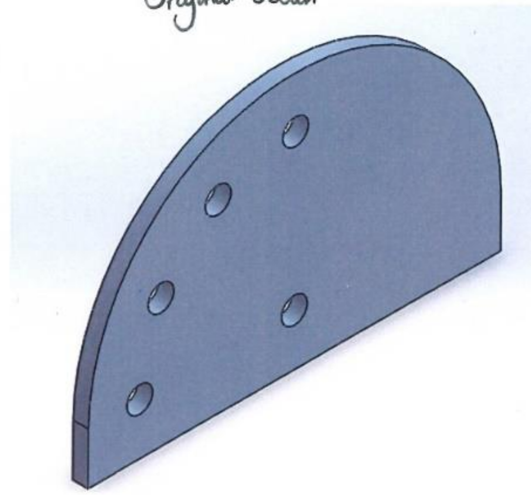
I decided I could extend the semi-circle sections so it would slot into the box section

The difficulty with doing this is finding a way to secure the extended section inside the box section

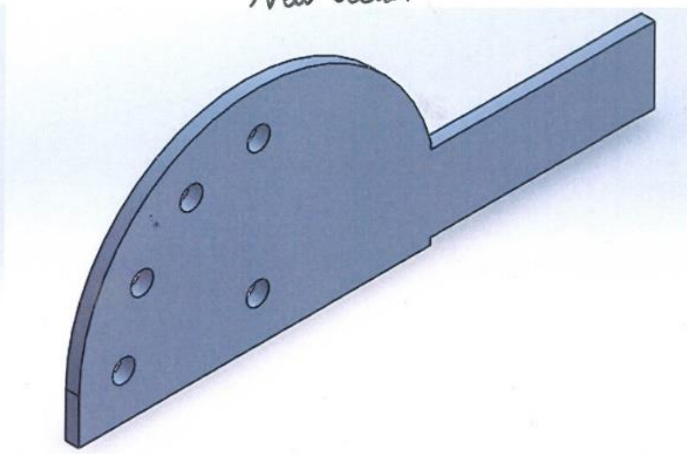
My plan is to add a pin that goes through the box and the supports and it could be welded to the outside of the box section

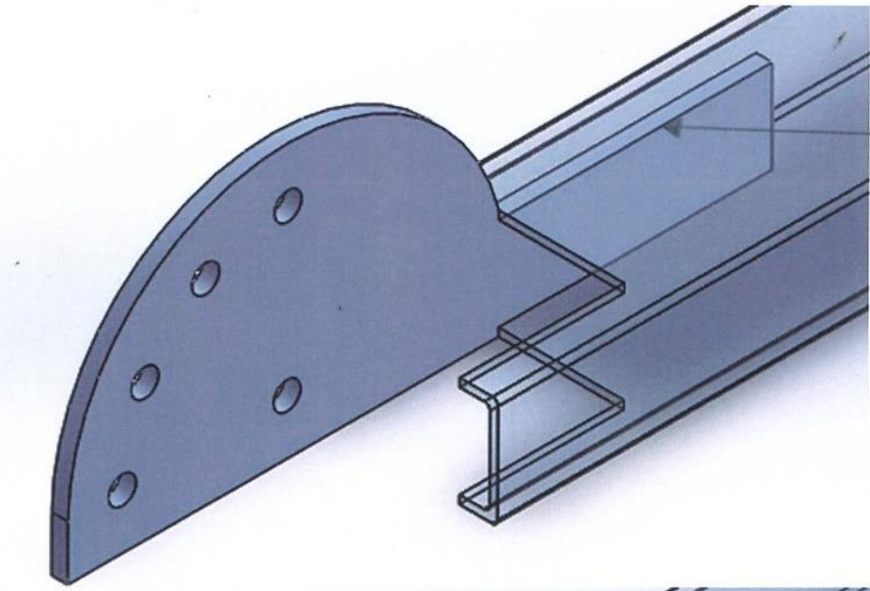
I realised It would make alot more sense to swap the positions of the bolt and metal bar. Because I want the rack to be easy to pivot and allow access to the boot of the car it makes sense to not have to undo a bolt and instead just be able to slide out a bar.

Original section

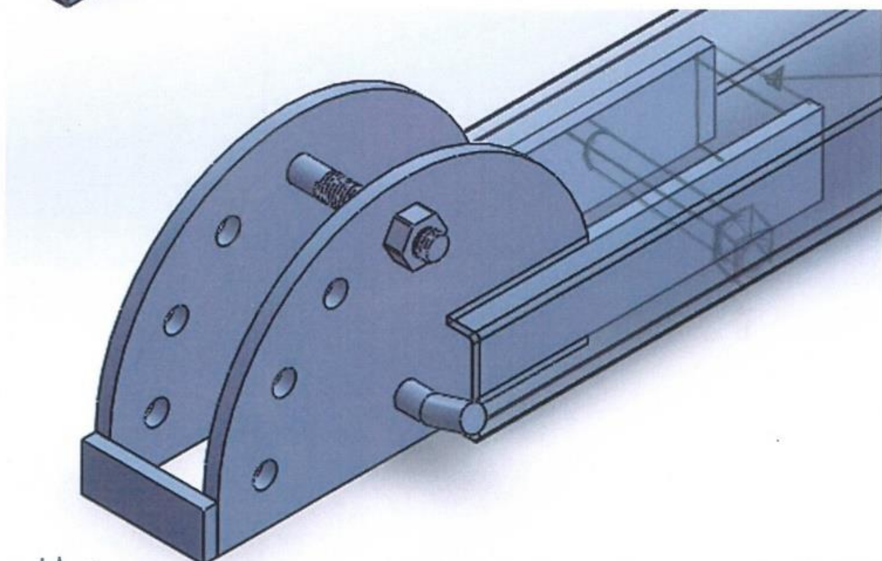


New section





As you can see having this extended support structure will massively strengthen my design as it stops the semi circle being able to tilt



I also plan to add this spacer which will hold the 2 sections 40mm apart and add support

Manufacturing Techniques, Tools, Materials, Safety & Finishes

Researching materials

During my research of existing designs I discovered a lot of pre-existing designs were predominantly made out of extruded aluminium or steel.

Whilst aluminium is significantly more expensive than steel you can also see it is much lighter. This is beneficially as the more the bike rack weighs the less efficient it is using it on a car. It also significantly reduces the shipping cost as a lot of distributors price their services according to weight.

Problems with using aluminium is it is not as strong as steel and can crack If it is repetitively stressed. Because of my available tools I also would not have been able to weld any of the parts together and would have had to rely on buts, bolts and other methods of attaching parts. For the wheel cage in particularly this would be near impossible to get the same outcome as I can get with welding steel

	Density	Approx Price per kg
Steel	7.85 g/cm3	£0.21
Aluminium	2.7 g/cm³	£0.60

For the main body of my bike rack, it would simply not be possible to use wood or plastic as these materials do not have the strength to resist the weight of bikes and the stresses whilst driving.

These stresses can be compared using the values for the ultimate tensile strength which is how much force per unit area is required to break the material and also the yield strength which is the force per unit area required to stretch the material plastically.

Material	Yield Strength MPa	Ultimate Tensile Strength MPa	Density g/cm³
Structural Steel	250	400	7.8
Mild Steel	248	841	7.58
Titanium	940	1040	4.5
High Density polyethylene	33	37	0.93
Aluminium	414	483	2.8
Polyester Resin	55	41	1.3
Copper	70	220	8.92
Brass	200	550	8.57
Carbon fibre	N/A	1600	1.75
Pine Wood	N/A	40	0.5

For some of the jigs and finishing pieces of my design I planned for make them out of plastic as it is lighter and easier to work with. I plan to 3D print these parts. 3D printing can use a large variety of thermosetting plastic, 2 of the most plastics are PLA and ABS.

PLA and ABS have different properties and there are both advantages and disadvantages to them. ABS in general is much stronger and more durable than PLA, it is also much more resistant to UV light.

The advantages to PLA are it is much easier to print however it is not as strong as ABS and is affected by UV light.

Because this model is just a prototype, I will use PLA plastic due to its ease of manufacturing and it is also significantly cheaper than ABS. If this was to become a product on a commercial scale the pieces would be made out of ABS and probably injection moulded opposed to 3D printed

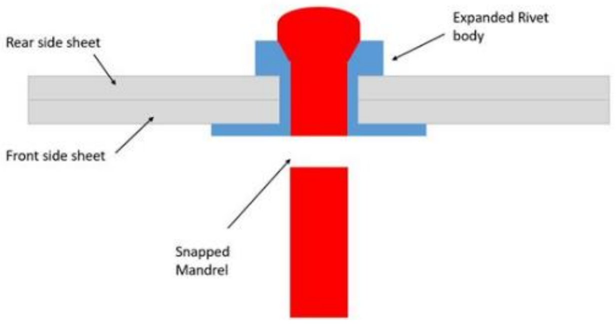
It is hard to gauge the prices of different materials as they vary depending on the form (plate, billet or bar) However a rough gauge is the price per kilogram.

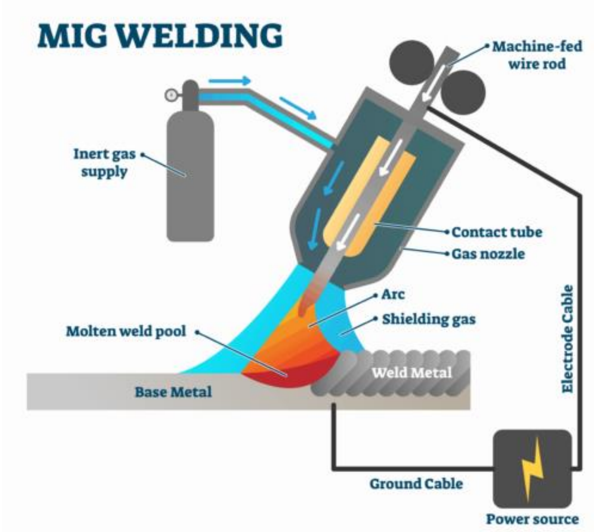
Researching Manufacturing Techniques

After selecting steel as my main material to use for this project I started researching different methods of attaching pieces together both temporarily and permanently.

To me I believe 'temporary' methods of manufacturing mean the parts that have been attached can easily be separated and reassembled without using up any fixtures or material.

A great example of this is using nuts and bolts. Nuts and bolts are available in a large variety of lengths & thicknesses allowing them to be used in a large variety of applications.

Method	'Temporary'/ Permanent	Explanation	Picture	Advantages	Disadvantages	Solutions
Nuts & Bolts	Temporary	Nuts and bolts are a system that uses threads and friction (with elastic deformation) to compress parts and hold them together		Come in a wide variety of shapes and sizes so can be used to join parts that require different strength ratings. Easy to assemble and disassemble. Can be used several times (unless locking nuts are used)	Nuts can rattle themselves loose. Can be hard to just buy a couple of bolts and usually they come in large packs meaning additional cost for bolt that aren't used	Using locking nuts. (Locking nuts use a nylon insert which heat up and soften when the nut is done up and then cools down and hardens locking the bolt in position)
Rivets	Temporary as can be removed by drilling them out but they are used up in doing this.	A rivet works by using a special rivet gun which is placed on the rivet, pulling the mandrel into the rivet body, causing it to expand and grip the parts to be joined. Once gripped, the mandrel snaps, permanently holding the rivet in place		Cheap and fast to install. Great for joining sheet or plate stock	Not a great sheer strength and aren't very strong in certain directions. Do not come in large lengths	

Welding	**Permanent**	**Welding works by using a high current of electricity to melt a wire electrode and fuse 2 pieces of metal together. It uses a shielding gas to protect the weld.**		**Incredibly strong Can be painted over. Can quickly join different forms i.e., rod and plate**	**Metals that are joined must be the same metal. Very difficult to remove if the joints need adjusting.**	**Ensure parts are perfectly aligned before welding. Only do tack welds (small welds) initially before completely welding parts together**
Brazing	**Permanent**	**Brazing is similar to welding in the sense that it is permanent and involves melting the metal to fuse parts together however brazing works by using a filler metal with a lower melting point than steel such as brass which is then melted and fills any gaps holding the steel together**		**Fairly Strong and leave clean joint. Can be painted over. Minimal finishing required**	**Requires more steps than welding (flux etc) and also is more time consuming. Not as strong as welding so not ideal for any structural components**	
Adhesive	**'Temporary'**	**Using an adhesive to join metals is not incredibly common as it is not very strong so does not make a very good permanent method of manufacturing. Can be removed easily by heating metal which will burn off the adhesive**		**Quick to apply. Can be used for small parts. Easy to remove. No clean-up/finishing required**	**Not strong Produces bad fumes when burnt. Can be hazardous for skin. Can be messy**	

Manufacturing Techniques I will use.

I plan on using a variety of manufacturing techniques for my project, the main 2 being welding and also using nuts and bolts. I have chosen to weld some of the components as this will give me an incredibly strong joint between complex pieces such as the wheel cage holder and also for the wheel cage where bolts or rivets would not work. I plan to use nuts and bolts for any of the components I want to be temporary to allow for disassembly for transport and also for compact storage.

I will need quite long nuts and bolts to hold the wheel cage holder onto the top bar, they will need to be at least 80mm long (72mm for the material and also at least 4mm for the nut) Because of the availability of bolts I decided to get M8 bolts in a 100mm length, I also got these bolts in stainless steel, despite these bolts being more expensive they will last much longer and wont corrode over time weakening the joint. Despite the fact that this left excess threads sticking out the back of the bike rack this did not affect the performance and the bolts could not be seen. If this product went to market, I would use 80mm long bolts as this would give a cleaner, more aesthetically pleasing look.

I also plan to use M8 nylon locking bolts, this would ensure the bolts would not come undone due to any vibrations whilst the car is driving along.

For the more complex joints or the structural joints that don’t need to come apart I will MIG weld them. This creates an incredibly strong bond that won’t break and can be used to join steel of all shapes and sizes. It is important when welding different thicknesses of steel that they welder is set up correctly, for example when welding thick pieces of plate it is important to use a high voltage to ensure the weld penetrates into the steel ensuring a strong bond, however if a high voltage is used with thinner steel there is a risk that the weld will simply melt through the material leaving a hole and no joint.

Quality Control & Assurance

For my quality control, I will visually inspect every part before it is assembled into subassemblies. I will also compare its dimensions & critical measurements to my CAD designs using digital callipers. Where applicable I will use jigs to ensure parts are assembled to be the same size and to confirm all dimensions and measurements are correct.

Before painting I will conduct a visual inspection of all welds to ensure there are no cracks or oxidation. I will then do a load test by standing on the bike rack upside down, this will ensure all the wheel cage welds are strong and can support significant weight of the 3 bike.

Tools & Safety considerations

Because my design incorporates lots of different forms of steel, from round bar to square stock lots of specialist tools are required to ensure I can safely and precisely machine the material.

The first tool I used was a manual hacksaw, this tool was used to cut my pipe to its rough length as in its 3m length it was awkward and would not fit into other tool vices. After making these rough cuts I could move over to the lathe.

A hacksaw is a fairly simple tool that consists of a handle and a tensioned hardened steel blade with teeth.

As you move the blade back and forwards the tooth remove tiny pieces of the steel.

Good for quickly and roughly cutting steel <3mm thick.

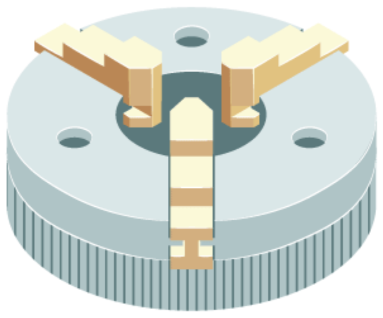
Time consuming for any material >3mm thick and not incredibly accurate.

A lathes primary use is for machining round pieces of material which it holds in a 3-jaw chuck. A lathe can be used for other forms of material however I will only need it for round material.

A lathe works by spinning a piece of material and a cutting tool (made out of high-speed steel or tungsten carbide) is introduced.

Produces a large amount of extremely sharp swarf.

Material is rotated extremely quickly so it is important to make sure no loose items of clothing can get caught.



Three-jaw chuck

Can accurately remove material and ensure faces are perpendicular.

To make all the angled cuts for my project I am going to use a milling machine. This is an extremely accurate tool which works by spinning incredibly sharp high speed steel pieces (I'm going to use an end mill for my work)

It is very important to ensure the vice on the milling machine is set at the correct angle relative to the tooling.

Much like the lathe the mill produced a lot of sharp swarf.

It is important to wear goggles and make sure the machine is turned off when adjusting the tooling or having your hands near the blade.

Safety consideration that applies to any methods whilst working with steel (including cutting, drilling or shaping):

Wear goggles as swarf (metal small razor-sharp pieces of steel produced by cutting the material) can go in eyes. Tooling such as drill bit or saw blades can shatter and it is important eyes are protected from the metal shards.

Wear a lab coat to protect clothes from oil of getting swarf ingrained in fibres.

Take care after cutting or drilling holes as this can leave burs (thin sharp shards that stick to the metal) as these can very easily cut skin, after cutting or drilling handle with care and remove burs with a file or countersink.

In my opinion the most dangerous tool I'm going to need to use is the angle grinder. It can be used for both cutting material and also for filing and removing material.

For cutting steel an angle grinder uses an abrasive disk which is spun at an incredibly high speed. This produces a lot of sparks, metal filings and also makes the work piece incredibly hot.

A grinder can also be used with a flap disk which is lots of pieces of sandpaper which spins around very quickly. It can be used for smoothing out welds and removing paint/scale.

It is important to wear lots of PPE using this tool, including a face mask, a leather apron, ear protection and heatproof gloves.

The abrasive disks can shatter if they're under incorrect force, that is why it's important to wear a face shield in case it shatters.

This tool can easily and quicky remove a lot of material and I will use it to cut through any of the thicker material and also to clean up any welds.

Another tool I am going to use is a 3D printer, in general this tool is very safe and there are not a lot of safety considerations. I am going to use a 3D printer to make jigs and other small pieces such as end caps.

A 3D printer works by melting a thermo plastic and creating lots of layers to create a 3D object.

A 3D printer is great for making accurate parts however it does take a long time to produce these parts however it can be left running with no input.

Some safety considerations are to make sure you do not touch the nozzle of the printer as it is incredibly hot (about 200°C)

It is also important to wear goggles when removing support material as the plastic can shatter.

Another tool I will be using is a MIG welder. A MIG welder is a very versatile tool that can be used to 'permanently' and quickly join various stock forms of steel.

There are several risks associated with welding, but the 3 biggest concerns are burns, eye damage and also fume inhalation. Because of these 3 factors it is very important all body parts are covered up with a lab coat and a leather apron covering as much as possible. Heat proof gloves are also essential as metal get very hot during the welding process. During welding many tiny pieces of molten metal fly everywhere so it is important these don't land on your hands or bare skin.

It is also very important to have good ventilation in the area you are welding or by using an extraction fan, this is especially important If any metal you are welding has paint on it as it will burn and release toxic fumes.

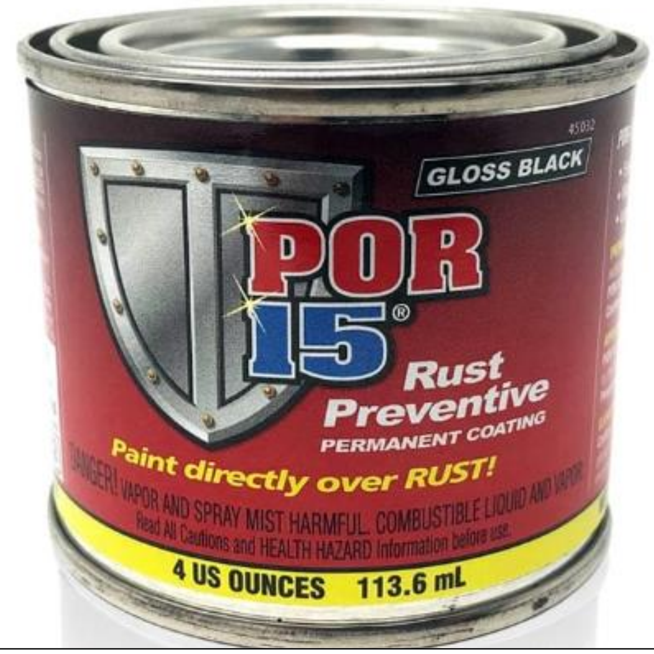
Because metal is being melted during the process it is incredibly bright and can damage your eyes if looked at, for this reason it is incredibly important to wear a welding helmet which has tinted glass to protect your eyes.

Researching finishing methods

During my research of existing products, I discovered many of them did not use any finishes or paint on their final products. I quickly realised this is because the majority of them are made out of aluminium which is very corrosion resistant as it creates its only aluminium oxide coating which protects the metal from corroding.

Because I was using steel, I would have to apply some sort of finish to protect the steel from water as this would cause it to corrode and rust which would not only ruin the look of the product it would also damage the steel and reduce its strength potentially causing compete failure of the bike rack.

The easiest and fastest way to protect my product would be to use some purpose made paint designed to protect steel from the elements. This could be applied in the form of spray paint or by using a roller and brush. Whilst this would initially protect the steel from the rain and the elements, I learnt from using it on my GCSE project that these paint do not withstand use or wear, Because some of these pieces will have muddy tyres rubbing against them it was important they had a durable



I decided to try and get some quotes for the powder coating before deciding whether to go for this or raptor liner. If this product was to become a commercial product it would probably be much cheaper to get them powder coated as it would be a bulk order instead of a one off.

Whilst researching different finishes I came across raptor liner. This is an aerosol based protective coating, it is designed for use in the bed of pickup trucks so is highly durable and also can be easily applied. Raptor liner is a lot more expensive than other aerosol paints however it is far more durable ad I believe would be well worth the additional cost as it would last a lot longer and protect the steel from corroding, extending the life of the bike rack.

Another solution would be to powder coat the bike rack, once again this is a highly durable finish however it is not something I could do myself as it requires specialist equipment. If my product was to become a commercial product this finish would probably be the best and I could outsource the powder coating like many other companies and manufacturers do.

Powder coating works by covering the metal in a fine thermosetting plastic powder using electrostatic force to hold it there before placing the metal in a large oven which bakes the plastic onto the steel.

Hammerite is another great finishing option as it does not require any primer or special treatment of the meta and can just be applied using a brush or roller. It is much cheaper than powder coating however does not offer the same level of durability and protection.

Environmental sustainability:

I have decided my products environmental sustainability can be divided into 3 sections: Materials, Manufacturing & Use.

Materials:

The majority of my project will be manufactured out of steel. Whilst initially this does not sound very sustainable as steel usually has a high carbon footprint, in the UK 85% of steel is recycled meaning chances are the material I am using has been recycled reducing its carbon footprint massively.

Steel is also incredibly durable meaning my product should last a long time without needing to be replaced.

I plan to either spray paint of powder coats my product, whilst these methods of finishing are not very sustainable as they release gases into the atmosphere they will protect the steel and mean it should last much longer than the un-finished metal

Manufacturing:

Most my project will be made out of stock-sized material meaning I will only need to order what I need and will have very little wasted material.

I believe my processes of manufacturing also support this minimal waste process. For example, my MDF Jigs will be able to be used several times if I ever wanted to manufacture more wheel cages or need to make replacements.

Most of my project will be welded together, during my research I learnt that welding is not very good for the environment as it requires a lot of energy to produce the heat to melt the metal and also releases argon and carbon dioxide which both harm the environment.

Use:

During its use my project should help reduce the amount of emissions produced by my car when using other bike racks as it sits behind the car reducing drag and therefore reducing fuel consumptions and emissions which would damage the environment.

Because I will use powder coating or another method of finish this will protect the steel meaning it will last and won't need to be replaced reducing its environmental impact.

Anthropometric Research

Height: The height of the rack should be positioned at a level that allows users of different heights to comfortably and easily store and retrieve their bikes. For instance, a height of around 1.1m to 1.3m is typically considered appropriate for an adult bike, while a child's bike may require a lower height.

Reach: The rack should be positioned so that users can easily reach their bikes without having to bend or stretch, especially for tall users. This means that the rack should not be positioned too low or too high and should be accessible to users of different heights.

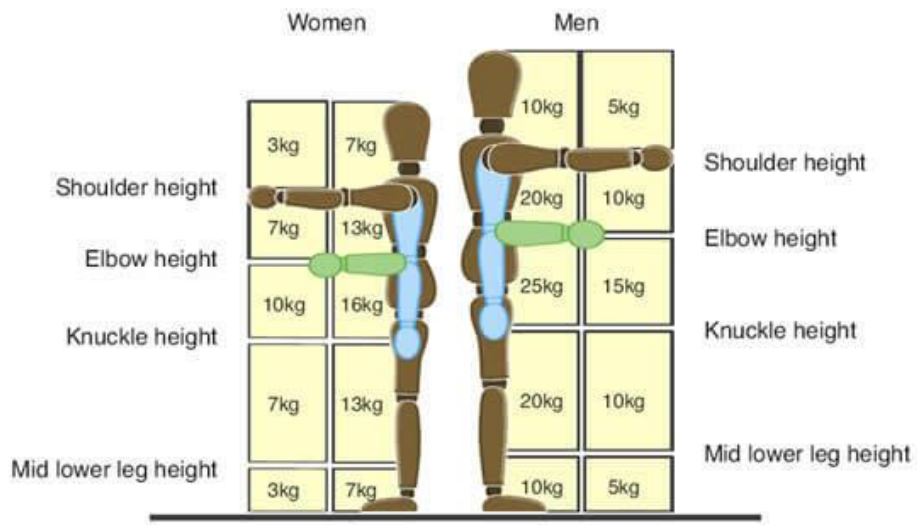
Clearance: The rack should provide enough clearance for users to easily mount and dismount their bikes, as well as for different bike frame sizes and styles. For example, a bike with a step-through frame may require more clearance than a traditional diamond frame.

Load capacity: The rack should be able to support the weight of different types of bikes, including heavy electric bikes. The load capacity of the rack should be clearly indicated, and the rack should be designed to safely hold the weight of the bikes without causing damage to the bikes or the rack.

This person is having to use a step to help secure the bike on the roof, this adds an extra(unnecessary) step in the process.

With larger cars and SUV's becoming a more popular choice for people to drive around it becomes increasingly difficult to load the bike onto the roof of the cars as the bike must be balanced and strapped in above a person's head making it awkward and risking dropping the bike damaging it and the car or hurting yourself.

The role of the bike repair rack is to hold the bike at a level where all the parts are easily accessible and to prevent a user having to bend over or alter their body position which could lead to back pain or problems.



There are laws and legislations that outline the maximum weights lifted by people in the workplace. For men it Is 25kg unless lifted above head height. This diagram gives a good indication. Because bikes re around 15kg it is important that they are not raised above head height for my bike rack.

Final Design Brief

Purpose:

- **The purpose of this project is to design a durable, secure, and easy-to-use mountain bike rack for use on cars. The rack should be able to accommodate a variety of bike frame sizes and styles and should be easy to install and remove.**

Target Audience:

- **The target audience for this rack is mountain bikers who regularly transport their bikes to trailheads, bike parks and other outdoor locations. The rack should be designed with the needs of this audience in mind, with an emphasis on durability and ease of use.**

Design Requirements:

- **The rack must be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes. Accommodating; 27.5” & 29” wheels with widths from 2.2” to 2.6”**
- **The rack must be easy to install and remove, with minimal tools required.**
- **The rack must be able to securely hold the bikes in place during transport, with minimal movement or sway.**
- **The rack must be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel.**
- **The rack must be lightweight and compact, taking minimal space on the car.**
- **The rack must be easy to use, with clear instructions and intuitive design.**
- **The rack should not impede access to the car boot or any other parts.**
- **The rack should be made of mild steel.**
- **The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.**
- **The rack must not damage or scratch any parts of the bikes and will hold the bikes using the wheels with the contact between the tyres and metal work of the bike rack must integrate a bike repair clamp to allow for repairs.**

Design Constraints:

- **The rack should be designed to be compatible with a 50mm tow ball.**
- **The rack should not exceed a weight of 30kg.**
- **The rack should not exceed the dimensions of the rear of an average car: 1.65mx1.49m**

Timeline:

- **The manufacturing should be completed by January 2023 with a final design ready by October 2022**

Budget:

- **The budget for this project is £500, this budget only covers materials as if this was to become a commercial product the manufacturing & labour time/cost would be greatly reduced.**

Final Design Specification

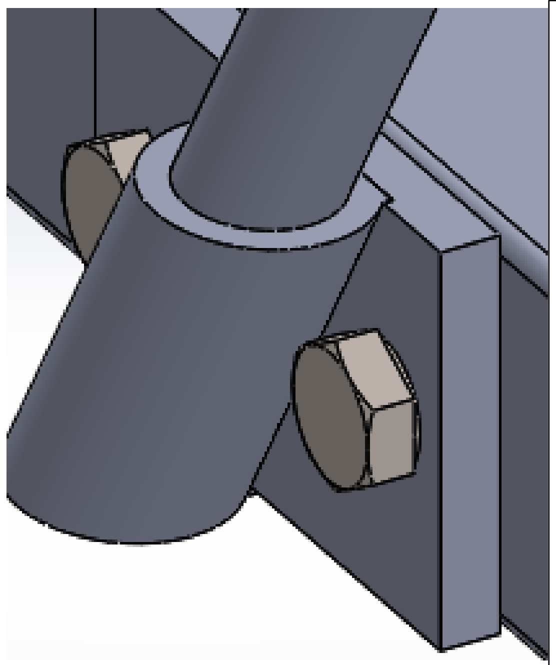
Materials:
The rack should be primarily constructed out of mild steel with stainless steel bolts and plastic finishing details.
Dimensions:
The rack should not exceed the dimensions of the rear of an average car: 1.65mx1.49m
Capacity:
The rack should be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes. It should be able to hold a minimum of 3 bikes securely. This had to be changed from 5 bikes due to the nose weight of the average car not being suitable to support the weight of 5 bikes. **(See page 14)**
Mounting:
The rack should be easy to install and remove, with minimal tools required. The rack should be able to be mounted to a 50mm tow ball (the UK & EU standard)
Security:
The rack should be able to securely hold the bikes in place during transport, with minimal movement or sway. It should integrate an existing locking mechanism.
Durability:
The rack should be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel. It should be designed to resist rust and corrosion.
Weight:
The rack should be lightweight and compact, taking minimal space on the car. It should not exceed a weight of 30kg.
Aesthetics:
The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.
User-Friendly:
The rack should be easy to use, with clear instructions and intuitive design.
Safety:
The rack should be designed to ensure that the bicycles are secured in a stable manner, to prevent them from falling off while in motion. It will use Velcro & tie down straps to ensure they're secured.

Design adaptations due to material availability:

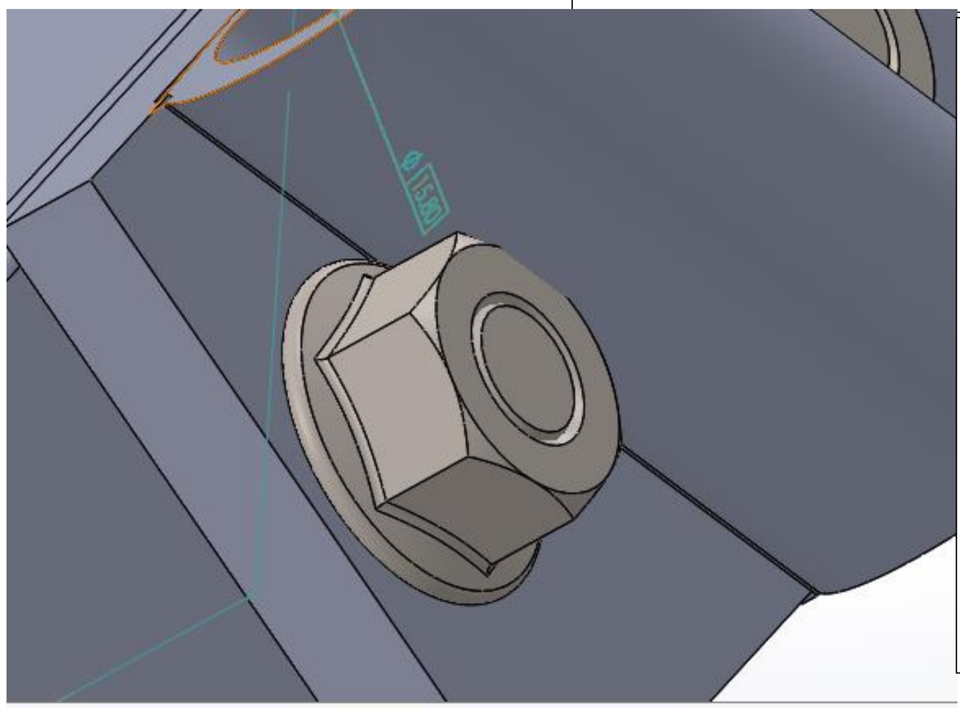
Whilst designing my project I knew roughly what materials I had available to me and therefore decided it would be easier to get a near final design before making sure this aligned with my materials.

Something I also like doing is visualising different sizes of materials I had modelled in CAD in real life to see how they would interact:

A good example of this is part of the wheel cage holder.

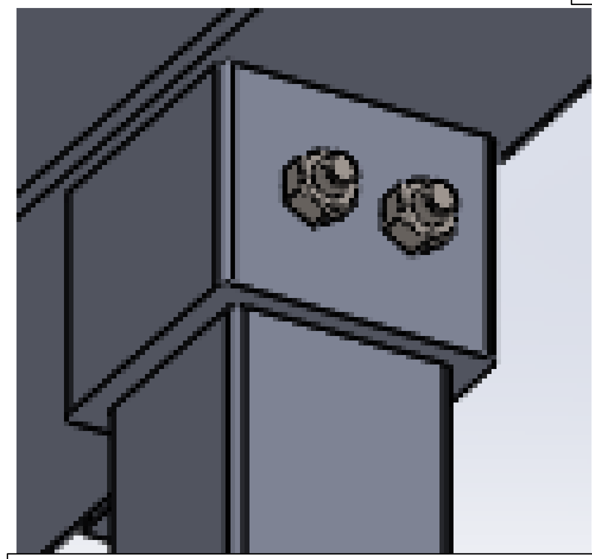


Initially I had planned to use a 20mmø metal rod to house the 15mm wheel cage pipe however when I compared the 2 sizes of tube and pipe in real life the 2.5mm surroundings did not provide enough support material and I did not think it would be strong enough. Initially I thought I could use 25mmø bar, but this looked too large and would add unnecessary weight. Whilst looking at ordering material I realised there was 22mmø stock.



Because I had increased the diameter of this material, I no longer had enough room for the nuts to fit on. Luckily, I realised this before I started manufacturing as it means the whole top bar and wheel cage holder will need to be redesigned as the spacing between bolt holes needs to be increased.

Another part I wasn't quite sure on was the wheel cage material. Throughout my designs I had modelled the wheel cage as 15mm pipe. When I had modelled my prototype, I used recycled chair legs which was 18mm in diameter. To decide between 15 and 18mm diameter I discovered that I could get a 15.8mmø material in a 1.6mm thickness which was the same as the 18mm diameter meaning both sizes should be very similar in strength, so I decided to opt for the 15.8x1.6mm material.



This piece of box section plays a crucial role in the assembly of the bike rack as it will allow the upright to bolt onto the top section.

Initially I thought I would have to custom make this section by welding 4 plated together so I could get the correct internal dimensions of 40x40mm.

Luckily, I managed to find some 50x50mm box section with a 5mm wall thickness. Despite this piece being a bit overkill and quite heavy it will be more than strong enough and will also save me from having to custom fabricate the part.

Checking Final Design against specification

Materials:
The rack should be primarily constructed out of mild steel with stainless steel bolts and plastic finishing details.

Safety:
The rack should be designed to ensure that the bicycles are secured in a stable manner, to prevent them from falling off while in motion. It will use Velcro & tie down straps to ensure they're secured.

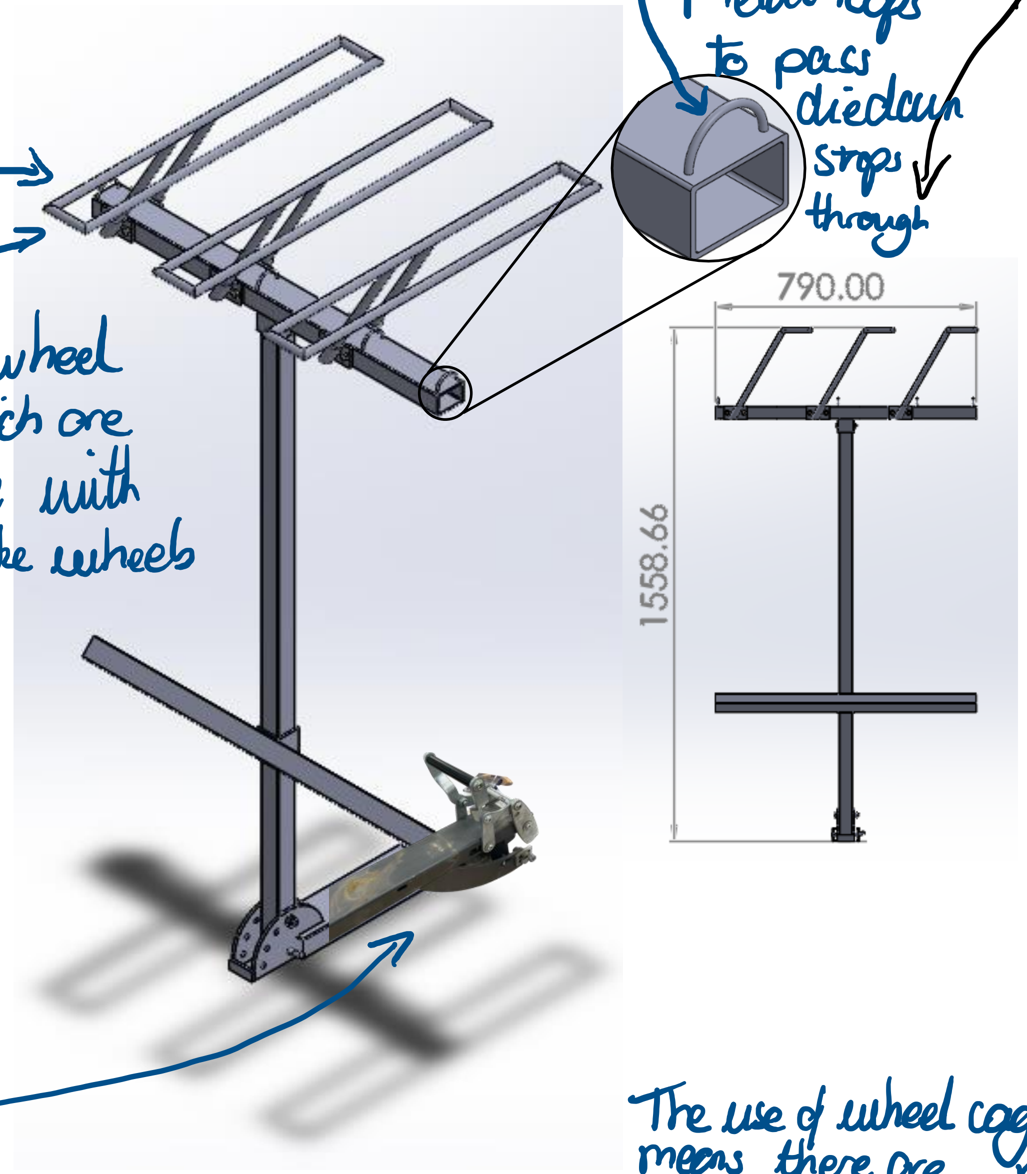
Dimensions:
The rack should not exceed the dimensions of the rear of an average car: 1.65mx1.49m

Weight:
The rack should be lightweight and compact, taking minimal space on the car. It should not exceed a weight of 30kg.

Steel construction

Metal loops to pass tie down straps through

Uses 3 wheel cages which are compatible with mountain bike wheels



Capacity:
The rack should be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes. It should be able to hold a minimum of 3 bikes securely.

Aesthetics:
The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.

Mounting:
The rack should be easy to install and remove, with minimal tools required. The rack should be designed to be mounted on the tow ball of a car.

Durability:
The rack should be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel. It should be designed to resist rust and

The use of wheel cages means there are no complex mechanisms or straps

The rack will be powder coated which is a rust resistant finish

Security:
The rack should be able to securely hold the bikes in place during transport, with minimal movement or sway. It should integrate an existing locking

User-Friendly:
The rack should be easy to use, with clear instructions and intuitive design.

Allows a cable style lock to lock all the bikes to the frame.

Also uses locking pin to attach rack to car

Manufacturing:

Manufacturing Plans

Lessons-Divided into 30-minute segments	2.11.22	2.11.22	2.11.22	2.11.22	3.11.22	3.11.22	3.11.22	3.11.22	7.11.22	7.11.22	10.11.22	10.11.22	11.11.22	11.11.22	11.11.22	11.11.22	14.11.22	14.11.22	16.11.22	16.11.22	16.11.22	16.11.22	17.11.22	17.11.22	17.11.22	17.11.22	21.11.22	21.11.22	24.11.22	24.11.22	25.11.22	25.11.22	25.11.22	25.11.22	28.11.22	28.11.22	30.11.22	30.11.22	30.11.22	30.11.22
Materials arrive																																								
Wheel Cage																																								
Wheel cage jig construction	■	■	■	■																																				
Wheel cage material cut to size					■	■	■																																	
Wheel cage material mitred on mill								■	■	■	■	■	■																											
Grooves filed into uprights													■	■	■																									
Wheel cage welded															■	■	■	■																						
Wheel cage holder																																								
Back plates cut to size																			■																					
8mm holes marked and drilled																				■																				
Tube holders drilled out on lathe																					■	■																		
Tube holders flattened on mill																							■	■																
Tube holder welding jig																									■	■														
Tube holders welded to back plates																									■	■														
Top bar																																								
Holes drilled for wheel cage mounts																											■	■												
Upright attachment welded on (drill holes first)																												■												
Upright																																								
Holes drilled																													■											
Towbar attachment																																								
Cutting out slot in tow ball clamp																														■										
Cutting out ARC pieces																															■	■								
Drilling holes in arc pieces																																	■							
Welding towbar assembly together																																		■	■					
Bending and drilling hole in bottom bar																																				■				
Final Touches																																								
Dry assembly'																																								
Any modifications																																								
Paint/dipcoat																																								

I have divided up my manufacturing into 6 stages and have made a gant chart using available lessons split into 30minute categories over the next month.

I am hoping that I can stay to these deadlines and have a finished prototype by the end of the month however come tasks may be more time consuming than what I've allowed for. To assist with my manufacturing, I plan to make a variety of drawings using the technical drawings feature on solid works. This will allow me to quickly and accurately cut and shape pieces to their corresponding dimensions quickly and accurately.

I decided to use a Gant chart to organise my manufacturing as it allows the steps to be easily seen much like a flow char however a gant chart also has dates and timeframes for when tasks must be completed.

Manufacturing Specification

Materials:

- **Main structure: Steel tubing, 40x40mm & 60x60mm**
- **Wheel Cages: 15.8mm diameter steel pipe**
- **Other parts: A combination of steel plate and other stock forms**
- **Smaller parts & Details will be made out of 3D printed PLA.**

Dimensions:

- **Overall width: 800mm**
- **Overall, Height: 1600mm**
- **Distance between the wheel cages: 250mm**
- **Height of the top bar: 1310mm**

Tolerances:

- **All components and subassemblies must be within ± 0.5mm**

Surface finish:

- **Steel Frame & tubing: Powder Coated Steel**
- **Welds must be ground smooth.**
- **Bolts must be done up tight and correct washers used.**

Quality control:

The bike rack must be inspected for proper dimensions and surface finish before packaging.

A load test must be performed to ensure it meets the load capacity requirement.

Random sampling of the finished products must be tested and inspected to ensure they meet the manufacturing specification.

Packaging and Shipping

Bike rack must be packaged in a corrugated box with polystyrene foam inserts to prevent damage during shipping.

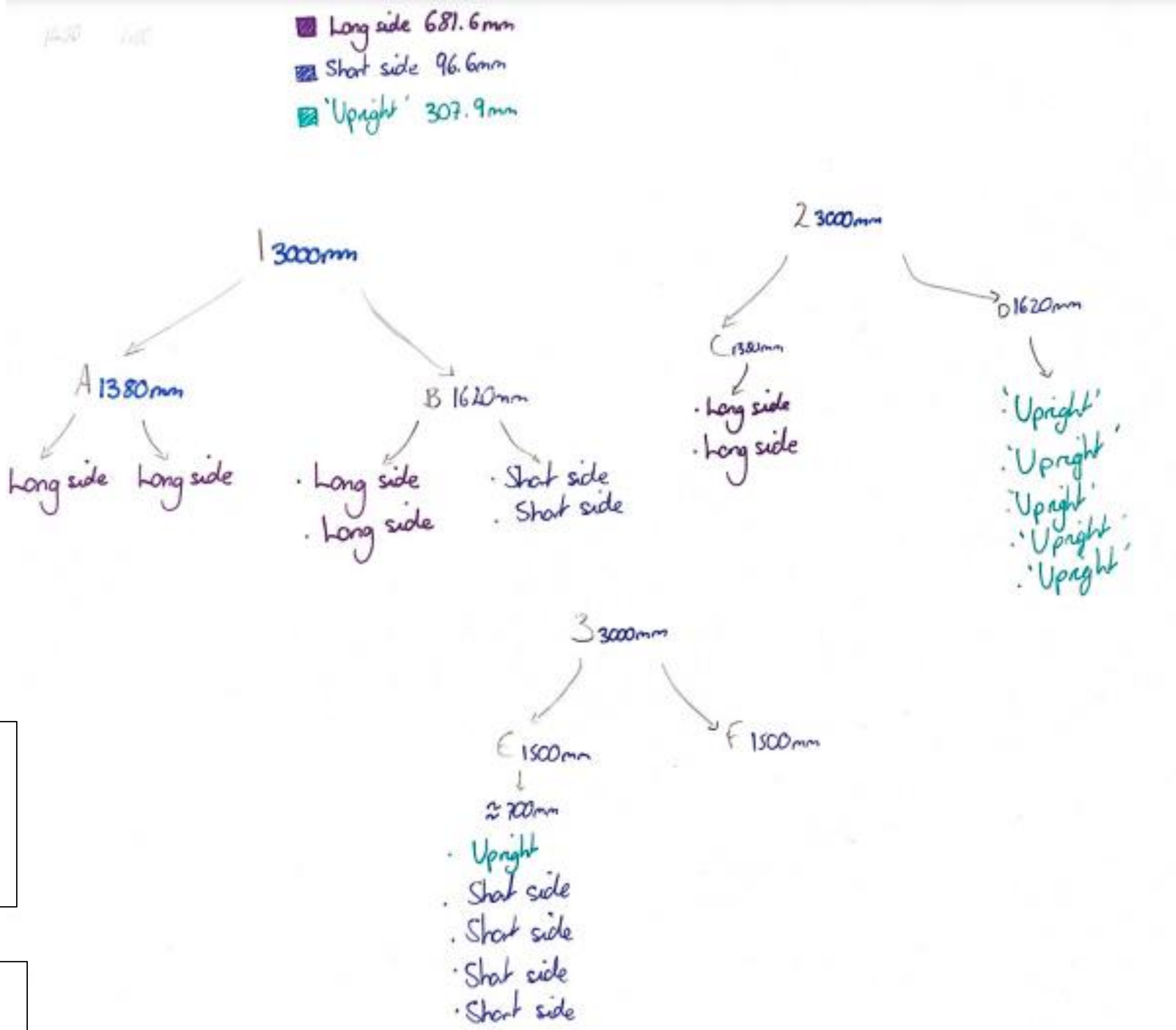
Ordered materials.

I managed to find a website online where I could get all my material for a very good price, they also offered a free custom cutting option and you only paid for the material you bought. This was very useful as some of the larger material I wanted such as the 60x40mm square stock was only sold in 3m lengths. The tolerance of the free cutting was ±3mm, because of this I decided to order my parts slightly longer than I needed and I will cut them down where appropriate.

100mm x 6mm Black Mild Steel Flat *Length* 600mm *Weight* 2.83 kg *Length* Custom	2072-0	£10.21	1	£10.21
40mm x 6mm Black Mild Steel Flat *Length* 400mm *Weight* 0.75 kg *Length* Custom	2063-0	£2.40	1	£2.40
50mm x 50mm x 5mm Mild Steel Box Section *Length* 100mm *Weight* 0.71 kg *Length* Custom	2309-0	£3.00	1	£3.00
50mm x 50mm x 5mm Mild Steel Box Section *Length* 100mm *Weight* 0.71 kg *Length* Custom	2309-0	£3.00	1	£3.00
15.8mm x 1.6mm (5/8" x 16 swg) Mild Steel Tube *Weight* 1.68 kg *Length* 3 Metres	2323-1	£7.48	3	£22.44
22mm Black Mild Steel Round *Length* 500mm *Weight* 1.49 kg *Length* Custom	2364-0	£6.02	1	£6.02
60mm x 40mm x 3mm Mild Steel Box Section *Length* 800mm *Weight* 3.58 kg *Length* Custom	2310-0	£20.53	1	£20.53
40mm x 40mm x 3mm Mild Steel Box Section *Length* 1300mm *Weight* 4.58 kg *Length* Custom	2301-0	£16.89	1	£16.89
40mm x 40mm x 3mm Mild Steel Angle Iron Hot Rolled *Length* 800mm *Weight* 1.41 kg *Length* Custom	2273-0	£5.85	1	£5.85

For the 15.8mm pipe I'm using for the wheel cage I decided to order a fair amount of extra material as the parts are very complicated and if I need to redo any I have the option.

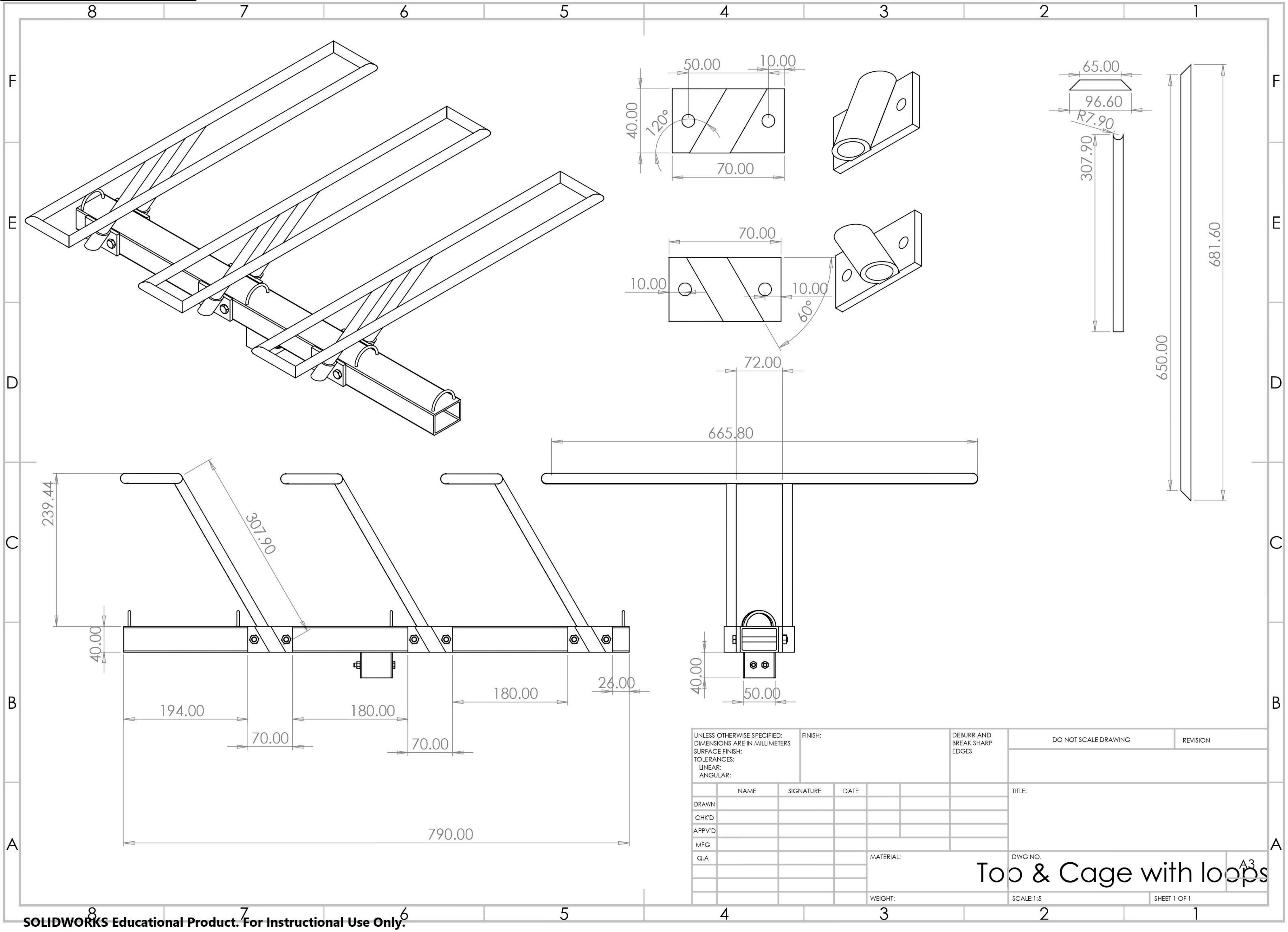
The only problem with ordering this much was that they came in 3m lengths, and this would be very awkward to transport to and around the workshop, because of this I worked out what the optimal way to roughly cut the pipes down to make it easier for me to transport them.

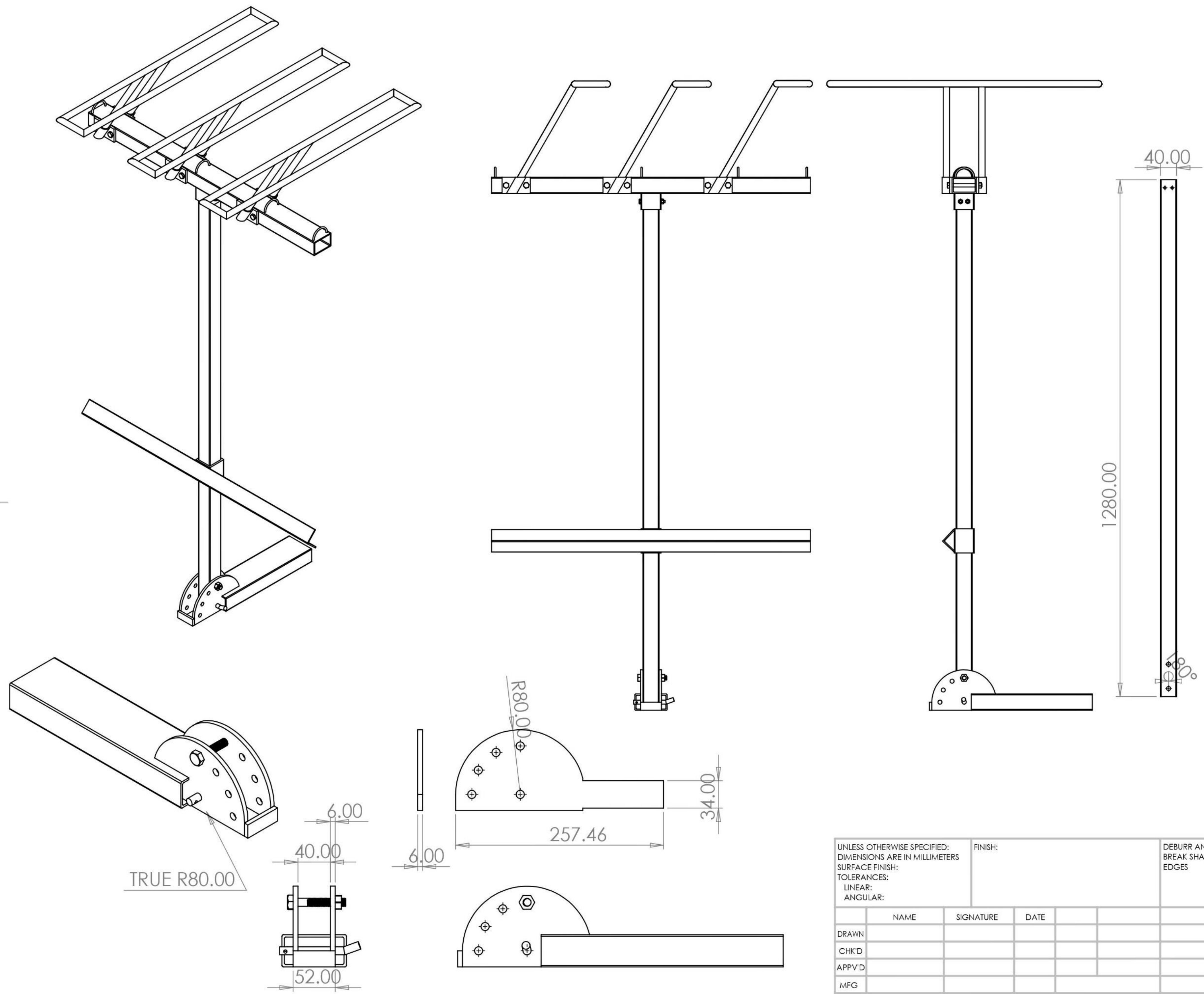


I also decided to get my jigs designed and manufactured before starting manufacturing as it was easier to get them out the way and have them prepared for when I needed to start manufacturing, I didn't need to make the jigs I could just continue.

Because I had a very accurate CAD design, I decided to use the Solid Works Drawing feature to give myself detailed diagrams of the parts with dimensions and how they are assembled.

SolidWorks Drawings



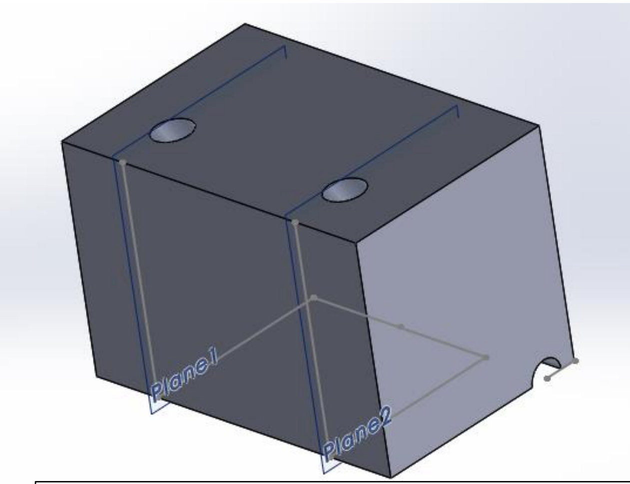


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:		DEBURR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING	REVISION
	NAME	SIGNATURE	DATE		TITLE:	
DRAWN						
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:	DWG NO. MK5 assembly 2	A3
				WEIGHT:	SCALE:1:10	SHEET 1 OF 1

Jigs

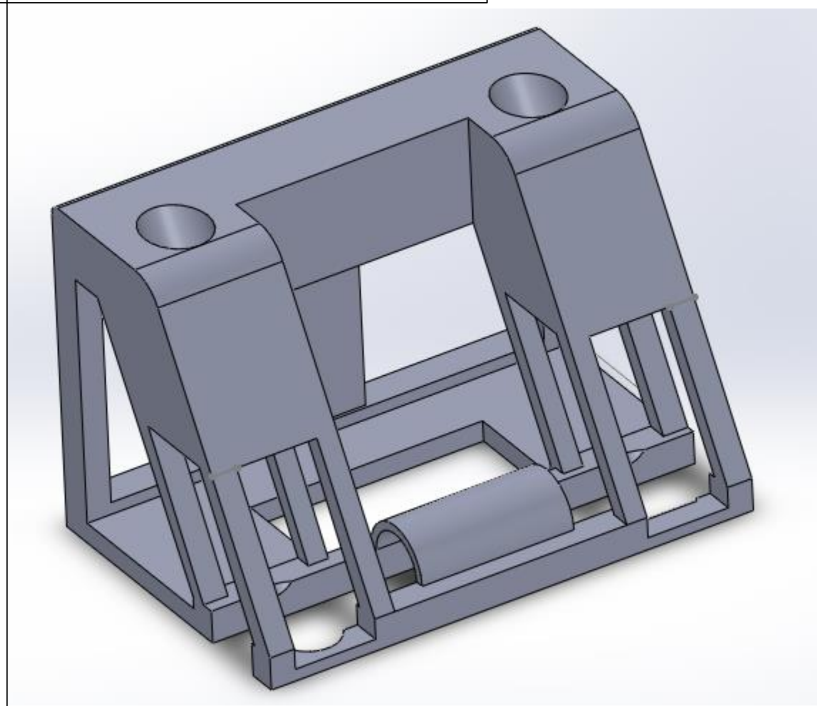
Despite the fact my bike rack was a one-off prototype some of the parts/assemblies were repetitive tasks such as the wheel cage and the wheel cage attachments.

During my CAD development I had made a small jig to align the ‘uprights’ of the wheel cage at the 60° angle and also so they had the correct spacing of 72mm as this was crucial to it attaching to the top bar.



I decided having something like this during my manufacturing would be necessary. I planned to make this out of MDF block glued together with a hole drilled

Unfortunately making this part would not be very helpful in real life as it would not allow me to weld the pipes together. I decided to modify my design to be more useful and allow room for welding. However, this part then was way too complicated to make out of wood with traditional handheld tools. I decided because I already had a CAD model I could 3D print it



This jig ended up taking me 3 attempts to make so ended up costing me about £4.50 in plastic. The reason for this it I could not get the clearance right to allow to tube to snugly fit into the slots without wobbling or getting stuck in.

For the base of the jig I used the offcuts of the 9mm MDF I had after making the first MDF prototype.

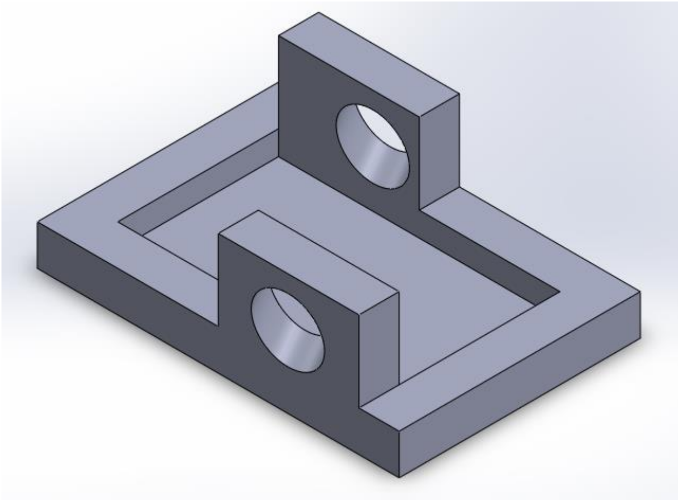
I left gaps in the corners of the jig, this will allow me to tack weld the tubes together whilst they are in the jig

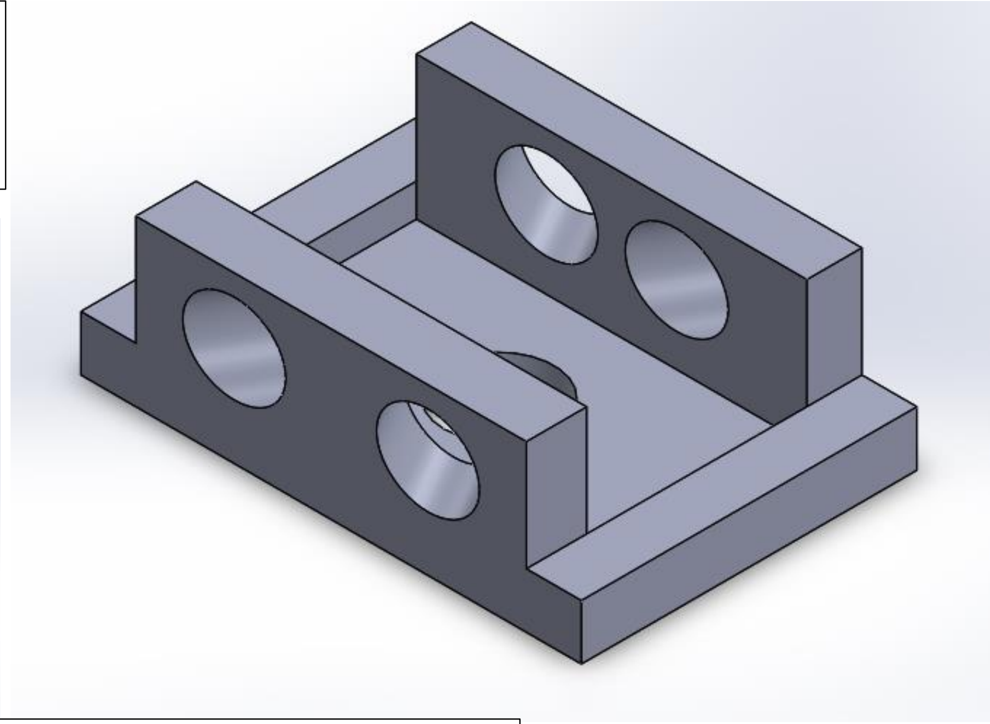
For the ‘walls’ of the jig I found this pine strip wood that was straight so decided it would do the job at no extra cost

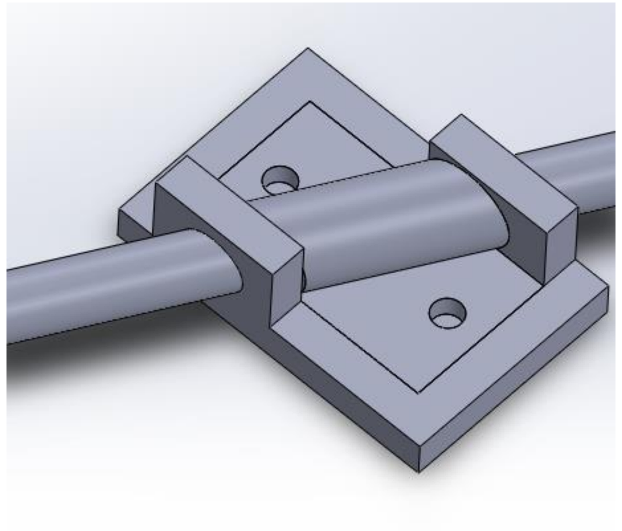
For the wheel cage I decided I could make a jig out of MDF and pine strip wood to make sure everything was square and all the wheel cages were the same size. Because I needed the cage to be very accurate I decided I could use the laser cutter to engrave an outline of the profile of the wheel cage and also space for the 20x20mm pine wood I used.

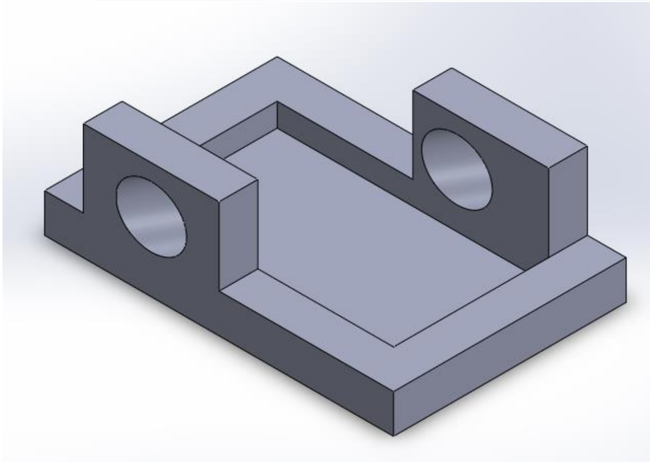
As you can see from this picture the jig was very accurate and fits within my tolerance of ± 0.5mm

3D printing is an ideal method of manufacturing this part as it will be very accurate and despite the fact it will take hours to print it can run when I am working on other parts or overnight meaning I do not waste

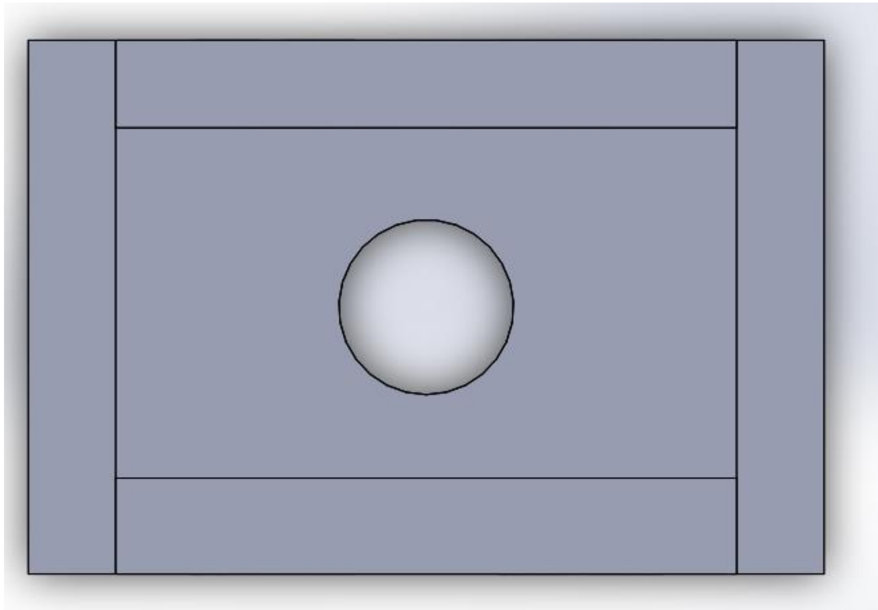


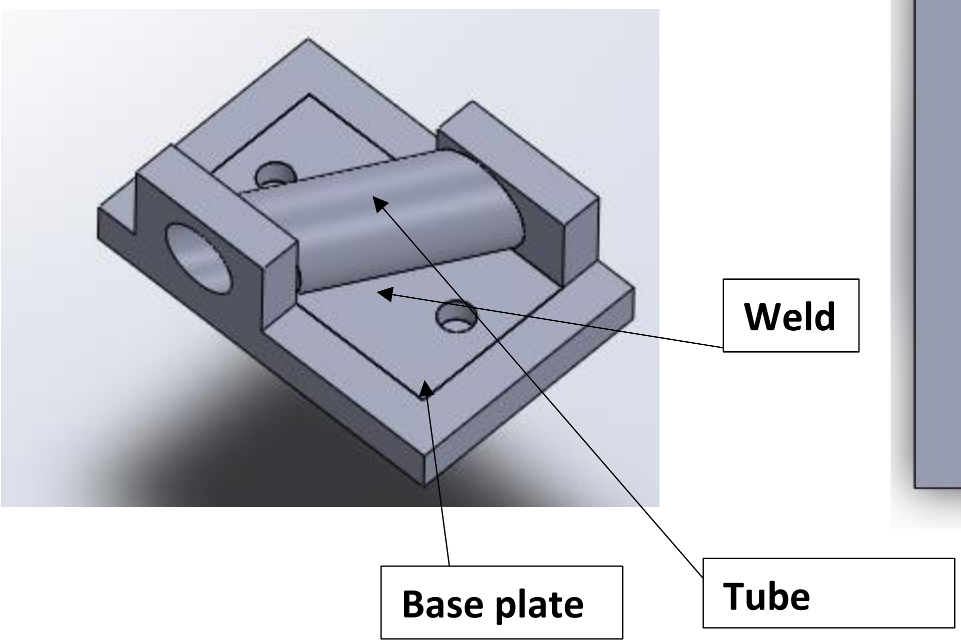




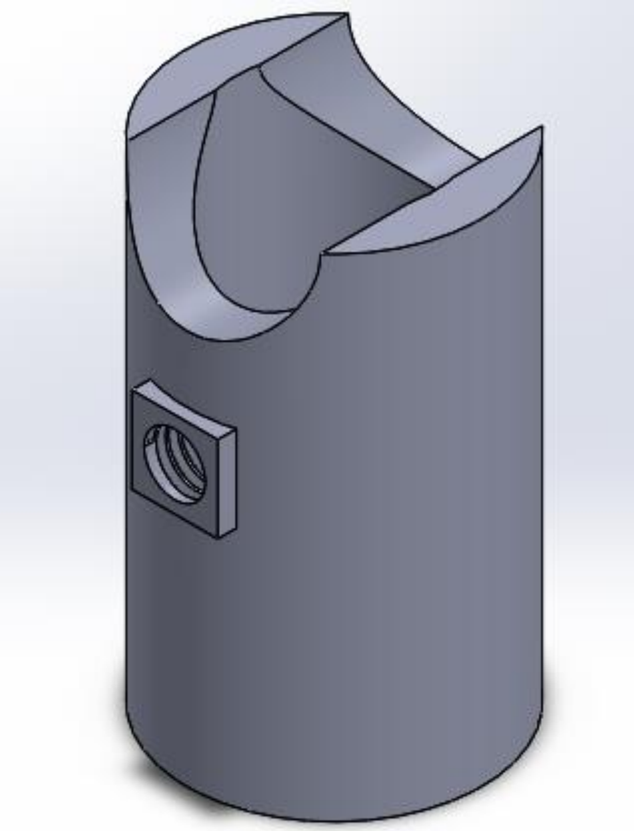


I also added a 20mm hole to the bottom of the jig, this will allow me to easily push the back plate out of the jig. I also added a 0.5mm clearance to allow for some in inaccuracy for the material.



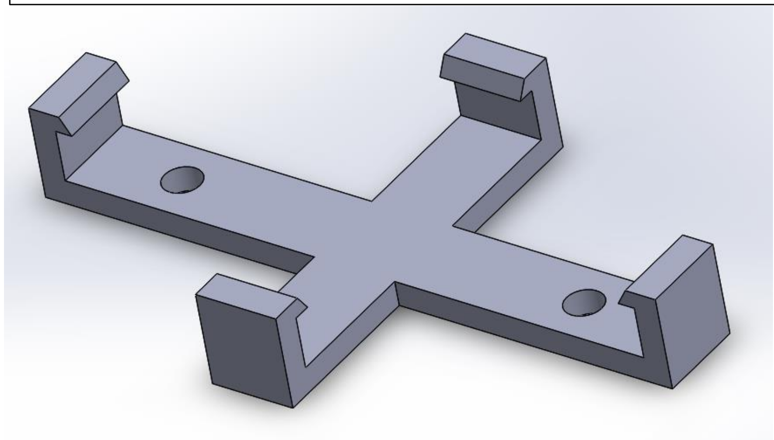


To help and ensure I get the correct radius on this joint I decided I could 3D print a jig to slot over the pipe and act as a file guide.

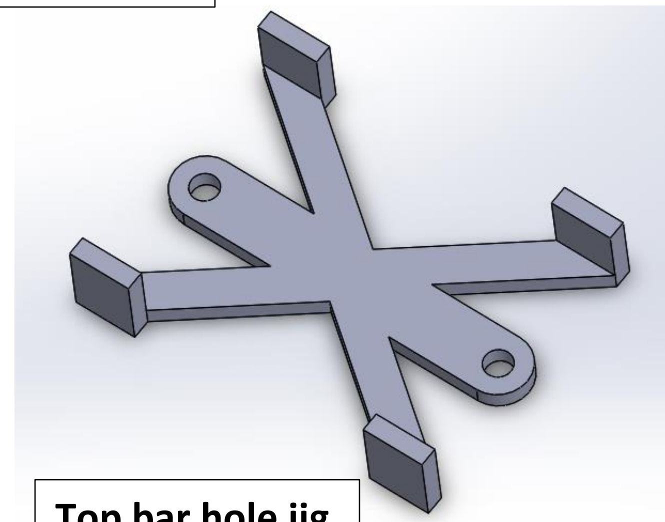


I left a hole in the side so I could tap in some M6 threads and use a bolt to hold the jig onto the

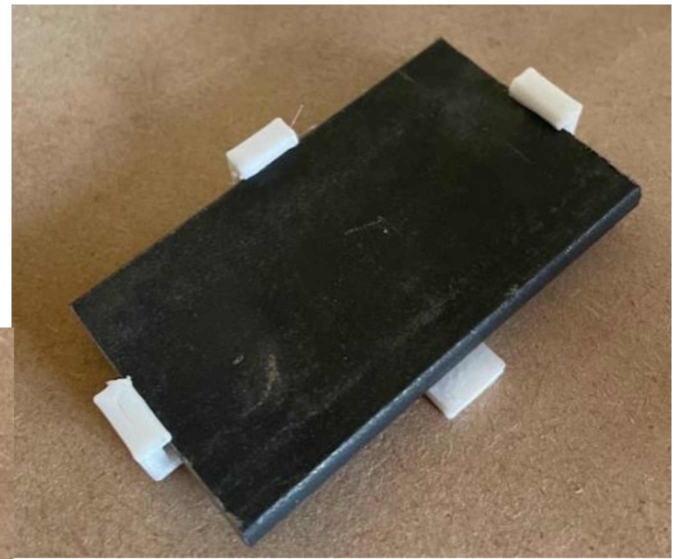
Because the holes in the wheel cage holder plate and the holes on the top bar needed to precisely line up to allow the bolts to fit through. I decided I could make a jig to allow me to perfectly align the centre punch mark and the pilot hole on both pieces.

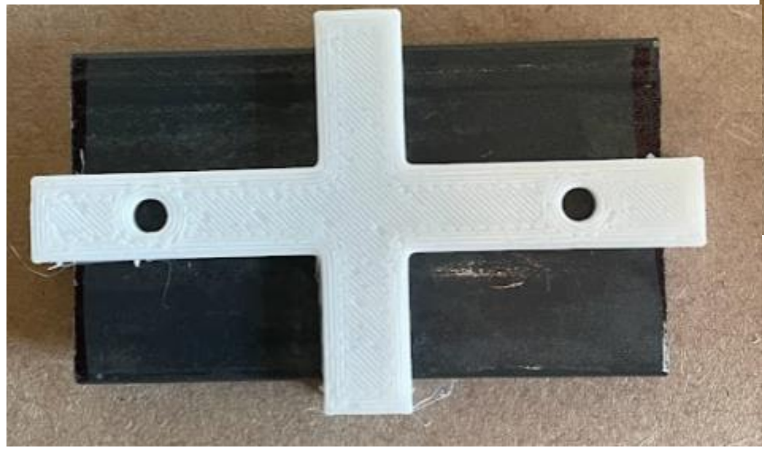


Wheel cage hole



Top bar hole jig





Because these jigs are only made out of PLA plastic, they might not withstand being used several times however being so small they only cost a few pence of material to make so I can always make more.

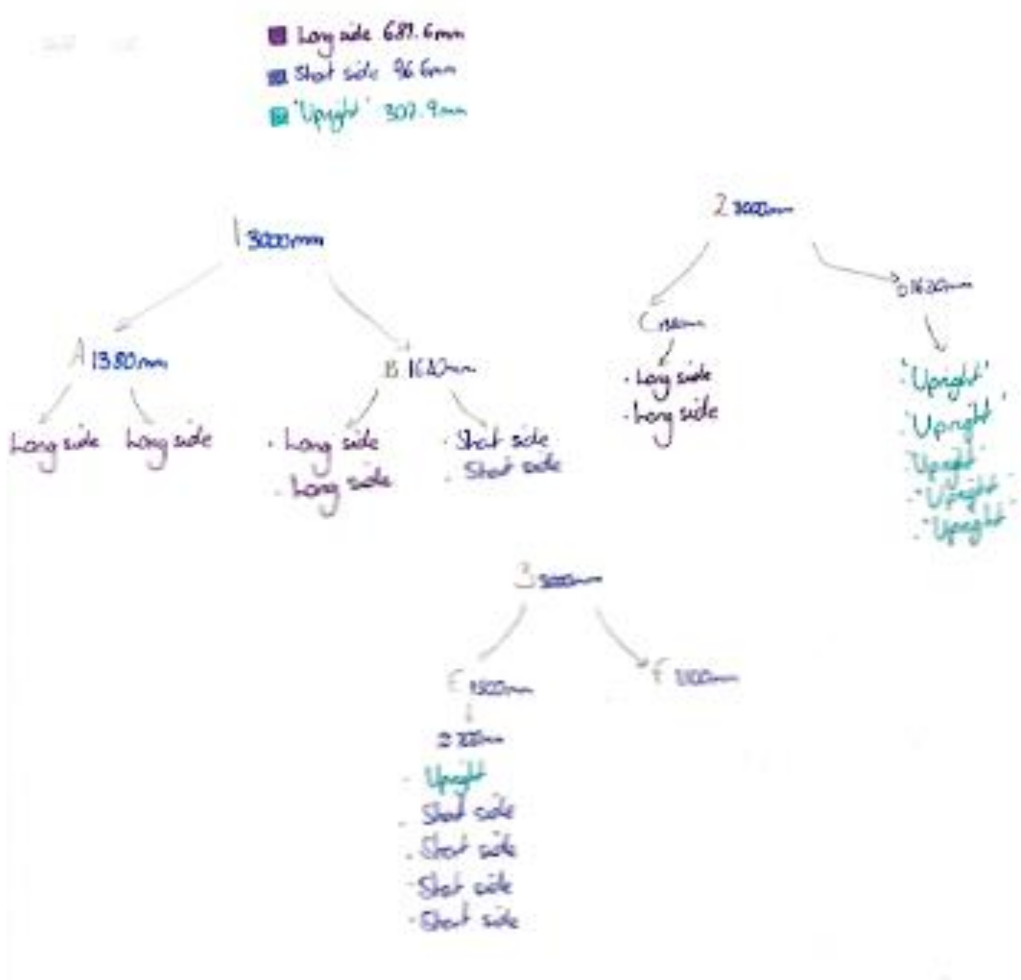
Because I now had access to a 3d printer I really made use of it making small jigs and templates to help with all aspects of manufacturing. These less significant jigs can be found in the

Having this 3D printer opened up several opportunities. To speed up the process of making the tube holders for the wheel cage holder I decided to 3D print a template to help me cut the tubes at the right angle.

Manufacturing Diary

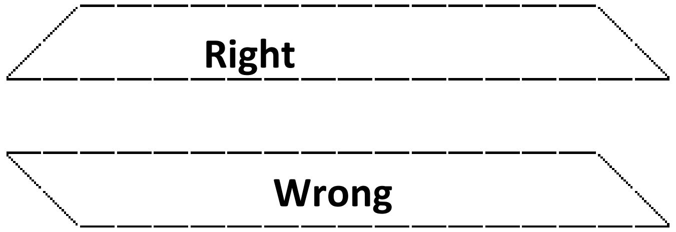
Because I had ordered most of my materials cut to size the only materials, I needed to cut to the correct lengths was the pipe for the wheel cage.

Using my solid works drawings and my Gant chart I could start manufacturing.



Step 1: Wheel Cage

After getting the pieces roughly cut to size, I then added a rough mitre cut to each end using a hacksaw and a combination square. It was important at this stage to make sure the mitres both faced in the same direction.



After getting all 24 mitres roughly cut, I moved over to the milling machine. Because the milling machine has a swivel vice, I could rotate it, so the jaws were at 45° to the end mill. Before starting to cut in my mitres I checked the vice against the mill bed and realised that the gauge on the vice was not accurate, so I had to set it using the combination square.

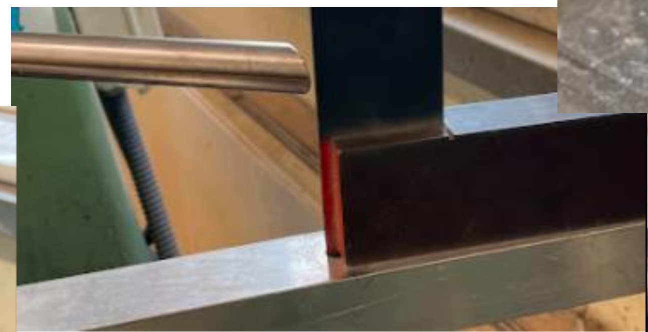
I then moved onto manufacturing the 'uprights. I had roughly cut all the pieces but realised it was best to cut them all to their final length now. To do this I faced off one side on the lathe. I then used a flat surface and the vernier height gauge to mark them all at their final height. I used a sharpie to make it easier to see the scribe lines.

I could then face off the other edge using the lathe until they were all the exact same length.

From here the next step was to file in the grooves which would allow the parts to sit flush together and allow more surface area to weld which will increase strength.

I could then use a variety of round, half-round and triangle files to achieve my desired shape. I also 3D printed a template to help me file the correct shape, this also saved me a lot of time as marking the lines out on the face of a pipe is very difficult.

I started with the shorter edges of the wheel cages as these were much easier to hold in the vice whilst ensuring the mitres at both ends were parallel to each other. This was easily accomplished using an engineer's square against the already milled mitre.



This task was much more difficult when adding the mitres to both ends of the longer pieces. To do this I clamped a straight aluminium extrusion to the mill bed and then used a large engineers square to align the mitres. Whilst this was not the most accurate process, I corrected for any slight errors during the welding of the wheel cage.

It was also important to ensure the pipe was level.

This process was a lot more time consuming than I had originally allowed for. Not only did it take a very long time as I could only remove 0.2mm of material on each pass. But I did not have access to the milling machine due to other classes being in the workshop. Because of this I had to spread it out over soe lunchtimes and also meant I fell a bit behind.

After getting all my pieces cut to size, the mitres all cut, and the notch filed in I could move on to getting all the pieces set using my jigs before welding.

Because this jig was only made out of PLA plastic which has a melting point of approximately 180°, I had to be very careful when welding, making sure I only did a few tack welds and didn't heat up the metal too much as this would result in warping or melting of the jig.

After getting the tubes into the 'upright jig' I could check that the spacing between them was the 72mm I needed to allow the cage to slot into the wheel cage holders.

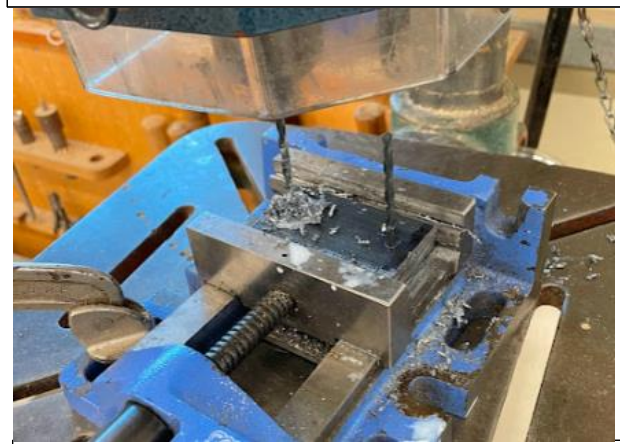
I added small tack welds to each face of the uprights so they would be held in the correct position but would not melt the jig. I could add full welds to the rest of the wheel cage whilst it was being held in the jig to avoid it warping.

To ensure the 'uprights' stayed correctly spaced, after doing the tack welds I slid the jig to the other end so the jig would not heat up and melt but would ensure there was the correct spacing during fully welding them as they could have warped otherwise.

Step 2: Wheel Cage Holder

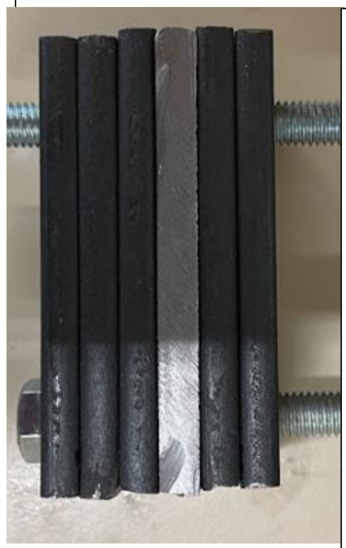
To start manufacturing the wheel cage holder I started off by cutting the back plates to size. Deviating from the plan slightly I then started working on the holding tubes.

Using my jig, I could get the holes in the back plate marked and drilled out, I made sure to get this done before welding the holder together to allow more access for the drill.



To ensure the spacing between the holes on the backplate was the same for all the plates I decided to drill through all the pieces at once. Just like with the lathe I centre drilled and then used a 4,6&8mm drill bit.

To ensure all the back plates were lined up I used a 4mm drill bit through the hole to ensure they all stayed lined up.



Because I had used a hacksaw to cut the backplates there was a slight deviation in the plate size. I had left about 1mm of extra material when cutting to ensure I could square up the cuts later on. To ensure all the plates were uniform and the correct size to fit in the jig I decided to bolt them together and take them over to the mill and remove ≈0.6mm from each end meaning they were all the same size and also had square straight

Because of how thick the steel was I realised it would have taken me ours to get through it with a regular hacksaw, so I decided to use the power hacksaw instead. I then moved onto the lathe so I could hollow out the metal rod. I started with a 6mm drill bit and moved up in 3mm intervals until I got to a 16mm hole. This allowed enough clearance for the 15.8mm pipe to fit in. This process took me a lot longer than I had planned, this meant I was now running a

The next steps in this process were very similar to the manufacturing of the wheel cage. I initially rough cut the pipe to the 30° angle.

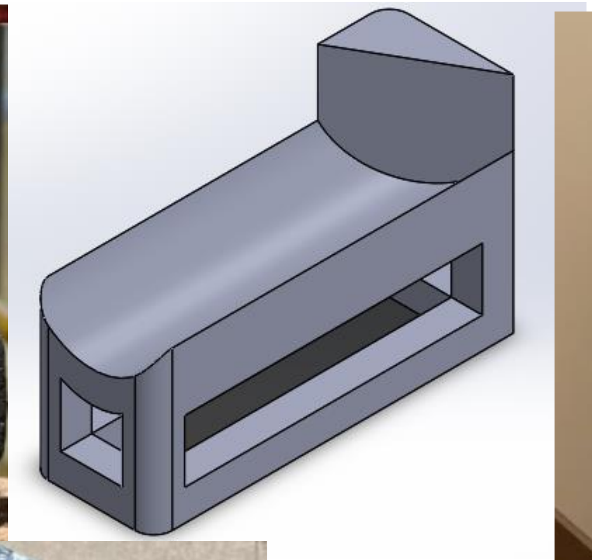
I could then move over to the milling machine. I set the vice to the correct angle using the jig I'd 3D printed and a machine square as this was much more accurate than the guide on the vice as it had a hugely significant 0 error (approx. 2.5°)

To help with marking out the angles for me to rough cut with my hacksaw I 3D printed a template that I would slot over the metal bar and trace with a scribe.

I made this jig 2mm longer than the final size I needed to allow for some inaccuracies with my cut and also to allow for the material the mill will remove.

ecause of how small these parts were getting it was becoming increasingly difficult to hold them in the vice of the milling machine, to help me hold the part more securely I used some of the spare rod holder turning in on the lathe to both slot into my part and also to stop the vice jaws from twisting ensuring I could hold the piece tightly.

When facing off the wheel cage holder tube it was very important that the metal tube was perpendicular to the end mill and that it was securely clamped whilst still having enough material sticking out the top. To help with this I 3D printed a little spacer to sit under the pipe, to hold the pipe perpendicular and also to have the angle parallel to the cutter.

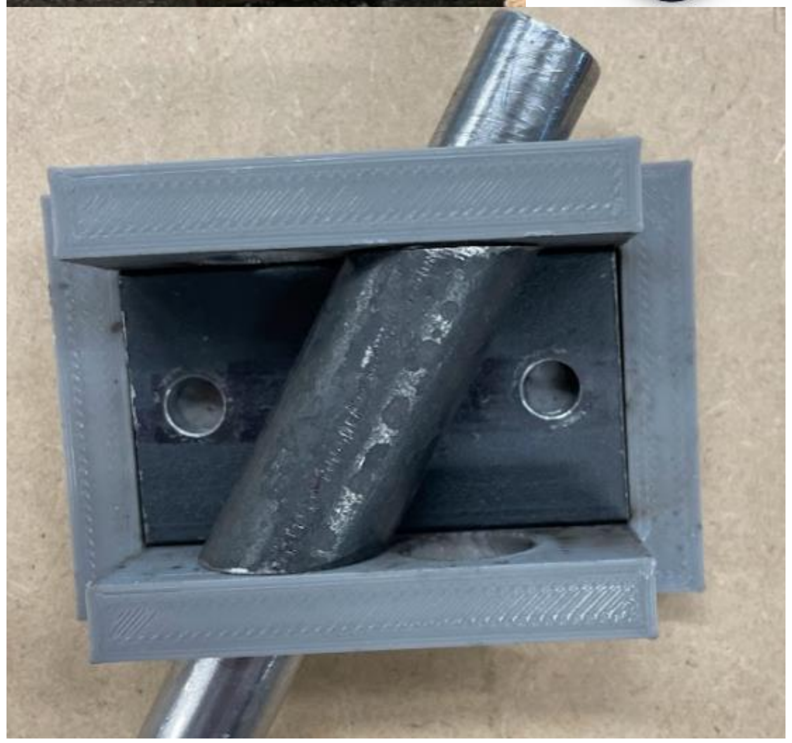


Sharpie line

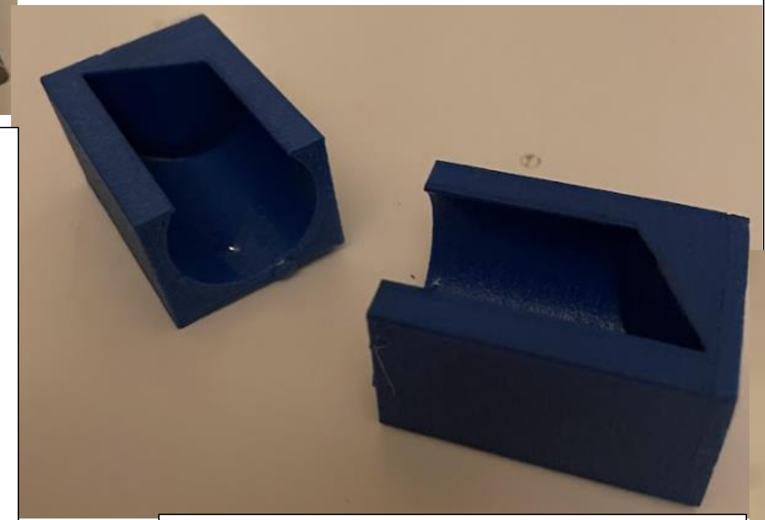
After about an hour of trying to flatten this face on the mill it became apparent to me that this was not going to work as the piece was getting too hot and the machine was really struggling.

My next attempt was to try using a file, once again this process was taking too long and was not effective. I decided an angle grinder would be a good approach to the material removal.

Because I needed the flat face to be perpendicular to the cut in angle, I decided another jig would be very helpful. I 3D printed a template that the tube could slot into, initially I planned to grind down the face whilst it was held in the template however the steel got very hot whilst grinding and I was worried this could melt or warp the PLA. I decided instead of using the jig as a cutting template I could instead use it to mark the correct line. This ensured that the flattened face was perpendicular to the



After getting the flat face machined onto the tube, I could then place the back plate and tube into my jig using an offcut from the wheel cage to align it. Similar to when I used the wheel cage jig, I initially added tack welds to avoid warping the plastic jig. I could then remove the metal from the jig and fully weld the 2 parts together.



Because the flat face needed to be on different sides relative to the angled face, I needed 2 jigs to align the different pieces on.

As well as using the sharpie lines I also knew when I got to the correct depth when this line appeared.

I used a 40grit flap disk on the angel grinder as the surface finish was not hugely important, I was just using it to remove material.

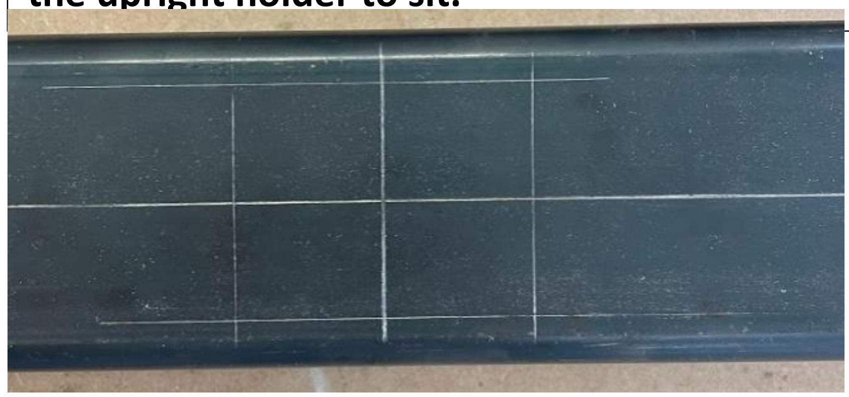
b

Step 3: Top Bar

Using the vernier height gauge on a flat surface I could mark all the holes I needed to drill. To ensure these holes were exactly where I'd marked I very careful centre punched & centre drilled the holes out. I could then move over to the pillar drill and drill a 4mm, then 8mm hole.

I ordered the top bar pre-cut to the correct length as this was the easiest way of ordering it and transporting it.

So, the upright holder sat in the correct position I used a combination of a long metre rule and the vernier height gauge to mark out the correct sized space on the underside of the top bar for the upright holder to sit.



Because of the thickness of the upright holder, I realised it could take a long time to cut by hand and because the cut did not need to be hugely accurate, I decided to once again use the power hacksaw.

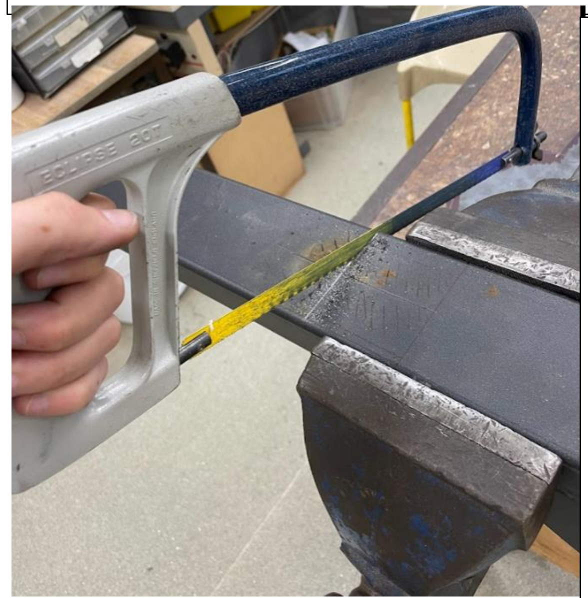
Just like with the top bar I could get the holes marked and drilled. Ensuring the holder was completely square to the top bar using engineers squares and magnets I added 2 tack welds. I could then slot the upright in and ensure it was all square before adding the full weld. Because of how key this weld was, I made sure to use a high voltage to get deep penetration into the 2 surfaces.

I made these hoops by bending 3mmø steel rod. I could then bend the rod bar a large piece of steel stock to get a uniform shape for all the hoops. These could then simply be welded to the top bar. I tested to see if these were securely welded by seeing If I could pick up the bike rack using just the hoops and I could this meant the welds were plenty strong enough.

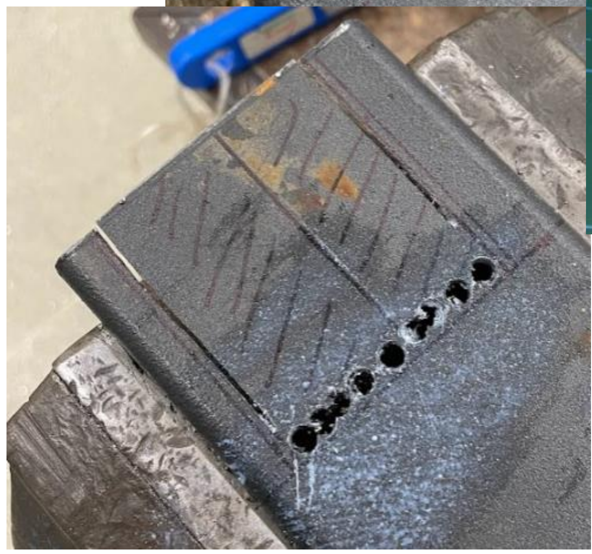
The final step of manufacturing the top bar was to add the loops to allow the bikes to be down with tow straps.

Step 4: Tow Ball Mount

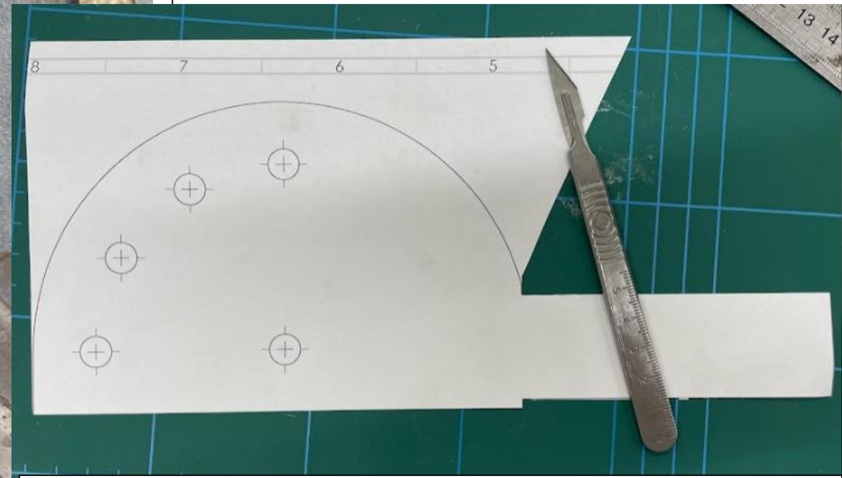
The next step in the manufacturing process was to adapt the tow ball clamp and attach the rest of the mechanism. I started by marking out and cutting the tow ball clamp, so it had the right length and also, so it had the profile I had designed. I initially started to cut this with a hacksaw however this process was very time consuming, so I switched over to an angle grinder with a cut of wheel.



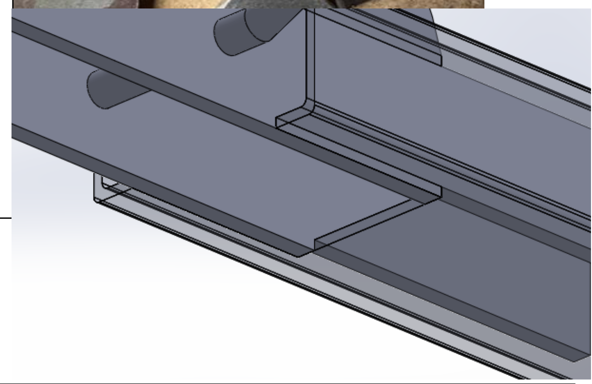
I started by cutting the tow ball mount to the correct length. I could then move on to cutting out the square section. Because I couldn't cut at a right angle, I decided my best option was to make the cuts I could and then drill holes to weaken the material so I could snap off the part. I could then file down the metal, so I got a smooth right angle I needed.



I then turned my attention to the arc mechanism. Because this was a complex shape, and the position of the holes was very important I decided to print out a template using my Solidworks model. I could cut out the template with a scalpel and then transfer the design onto the metal using a sharpie and scriber. Because of the thickness of this metal, I decided to use an angle grinder to cut and grind the profile.



I then transferred the holes over by holding the template down with a magnet and used the centre punch. I could superglue the 2 pieces together and drill the holes, this way they would be perfectly aligned. I also used a 40grit flap disc to make both the pieces identical. To remove the superglue, I simply heated the metal slightly to burn off the glue. Making sure to use a fume hood so I didn't inhale any of the fumes.



To ensure I got the correct spacing for the upright I bolted it to the 2 arc pieces. Using a mallet and a square I could ensure the upright was square and aligned with the

Before I started welding, I removed all the paint from the existing mount to ensure there was a strong weld and also to stop the paint burning and releasing

In my design I wanted the 2 arc pieces to snugly fit into the existing towbar mount. To do this I took a very iterative method as I wanted the parts to perfectly align. To achieve this, I slowly removed material from the arc pieces with a flap disc until they would tightly slot into the existing

I then needed to get the arc pieces welded onto the existing mount, Because of how thick the steel is and how structural these joints where I used a very high voltage and a generously sized weld.

Because of the size of the model at this point I couldn’t fit it on the welding table, so I held it in a vice, to ensure it was grounded correctly I removed the scale from the steel and connected the grounding clip directly to the assembly.

I added tack welds and then double checked that everything was still square. I could then fully weld the whole assembly together. This whole process took a lot longer than I had initially planned but the time spent was worth it as everything was square.

I could then fully weld these parts together.

Bottom Bar Design + Manufacturing

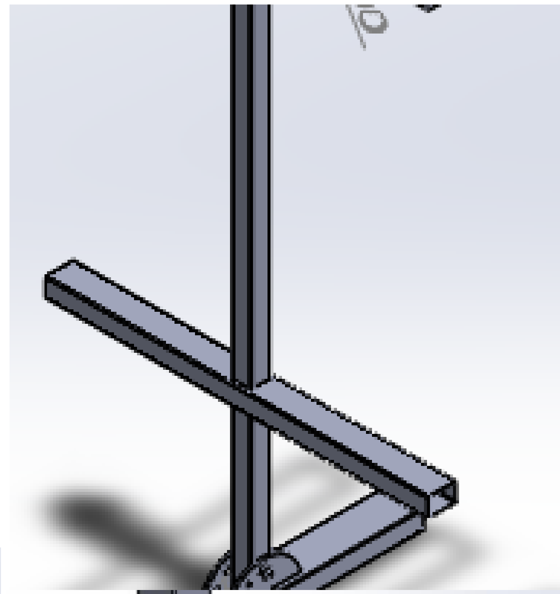
The primary focus of my design work so far was designing the wheel cages and how I could securely hold the front wheel as this was the main way of holding the bike.

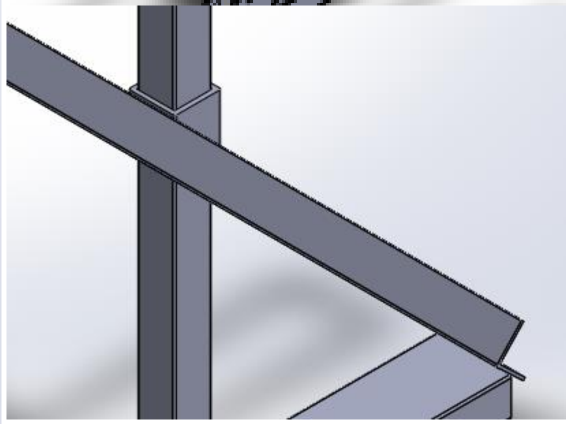
Because of the way my design was working the bike would just be left hanging by the front wheel, whilst this would probably hold the bike fine it would become a problem when moving the bike rack around as the bike would swing around when turning, accelerating or breaking.

To stop the bikes swinging forwards towards the car I decided adding a bar in-line with the position of the rear wheel of the bike would stop it moving in this direction.

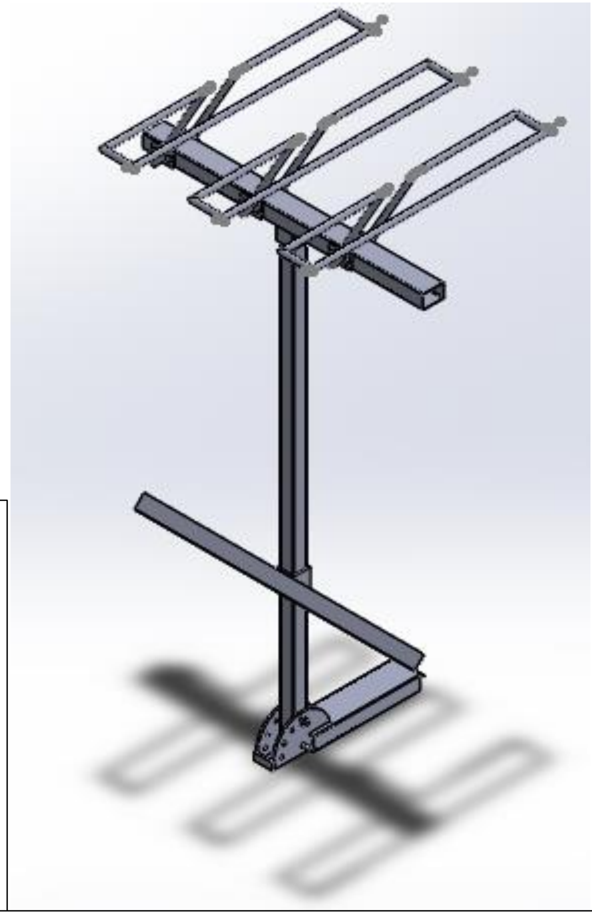
Initially I was planning on using the same material as I had used for the top bar however this would have added a lot more unnecessary weight. This bottom bar did not need to have the same level of strength as the top bar as it did not have to support the weight of the bikes.

Whilst looking at available materials for this project I discovered that angle iron would be an idea material as it would not bend or break but was also a lot lighter than a full square section.





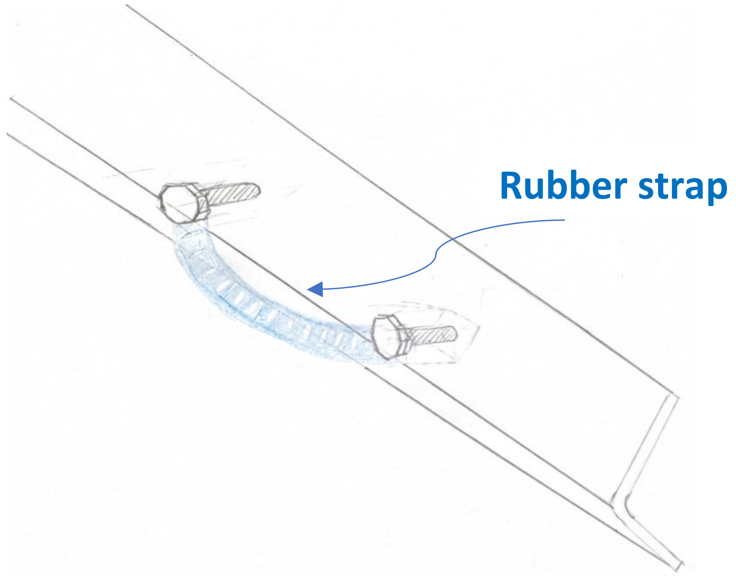
With the rectangular tubing I could have attached it to the upright by simply putting bolts through both parts. Because the angle iron would only be on one side of the upright, I decided I needed another way of



This design change would stop the bike moving towards the car however when accelerating the rear wheel could still swing backwards. To overcome this, I wanted to add some sort of strap system that could quickly be attached and removed.

My initial plan was to weld 2 bolts to the angle iron so I could hook the rubber strap over them and the wheel.

Inspired by the way I planned to attach the top tube I decided I could use the same box section that I used for the upright attachment. This would allow the bottom bar to slide up and down the upright adding a level of adjustment for different sized bikes.



To avoid drilling any holes in the upright I decided to use a bolt clamping mechanism to secure it onto the upright. Initially I planned to drill and tap holes into the square tube which the angle iron was welded to however when I tested this, I did not think the threads looked strong enough to withstand the pressure and torque when the bolts were tightened against the upright. Instead, I decided to drill an oversize hole and weld a nut onto the square tubing. This would allow the bolt to be threaded through and clamp onto the upright.

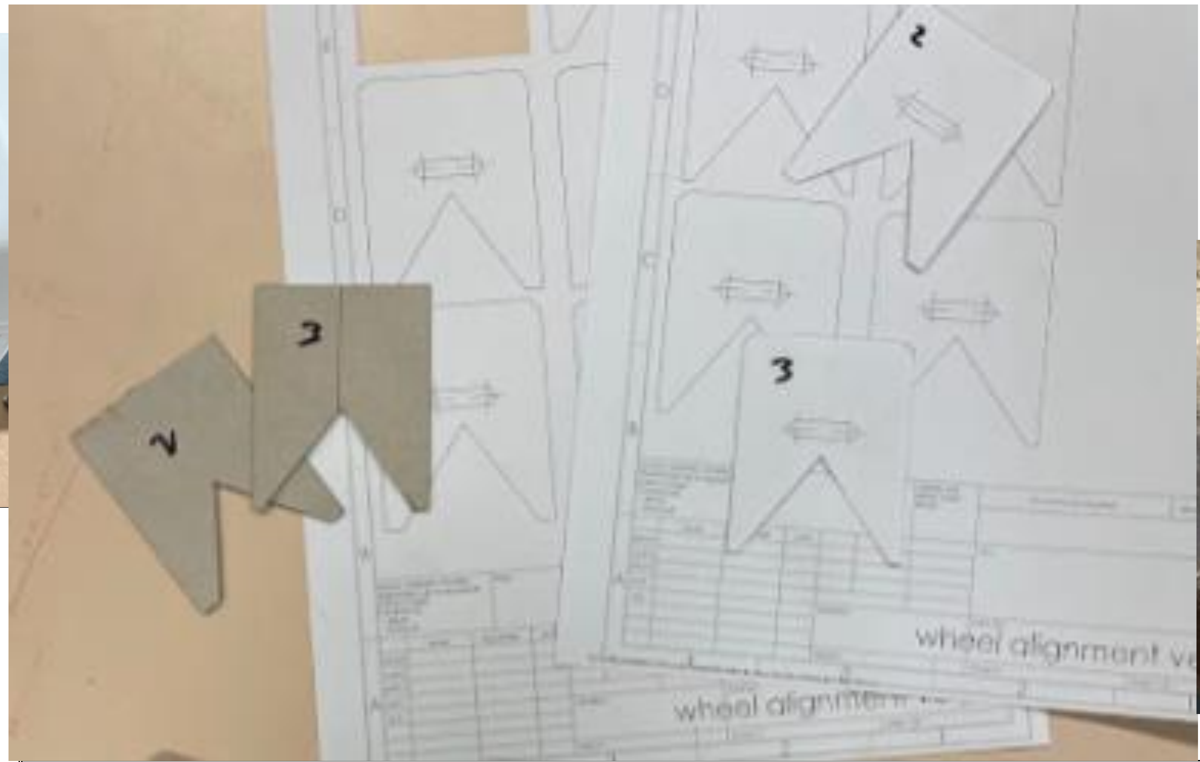
Although welding the nut on was not so aesthetically pleasing I decided to go with function over form and needed to ensure the threads wouldn't strip and the bottom bar would be held securely.

Although this design would have worked there were 2 main problems, the first being that getting rubber straps the correct size was proving very difficult. I also realised this design wouldn't stop the bike sliding from side to side.

To stop the bikes sliding from side to side I need to add some sort of slot for the wheel to sit in. To make the holder compatible with different tyre widths I decided to angle the holder to align the wheel correctly.

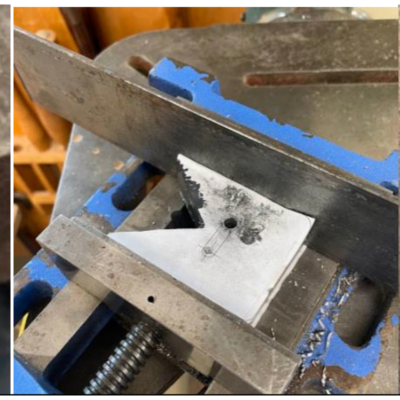
Because I couldn't get the correct sized rubber straps, I started thinking of other solutions, my initial idea was to use a tow strap that could connect to both sides of the bottom bar and secure all the wheels. The problem with this was if I wanted to remove 1 bike, I would have to take the strap off all 3. This would then mean that my design didn't conform to my design specification as I wanted the bikes to be quick to load in any order.

Instead, I decided to go back to my individual strap design. Instead of a rubber strap I realised I could use Velcro-one wrap. This would allow me to quickly and securely hold down the rear wheel.



When I initially designed and made these plates, I hadn't factored in that they would not meet the angle iron perpendicularly. Because of this my first design did not work as the corners of the plates did not sit against the angle iron so this piece would not have looked good or been easy to attach.

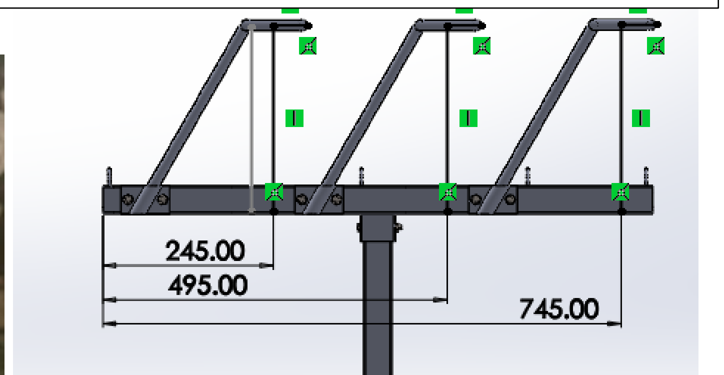
To ensure my next iteration of this deign fitted correctly I tested different combinations of angles and spacing on the plate using grey board to make quick models. I could then make this new design out of the plate steel.



Because I needed all of these parts to be uniform, I decided to use some steel plate that was the correct width. I cut all of these to the right length before using superglue to hold all the 6 plates together. I could then use the template to make the 2 angled cuts using an angle grinder. Because the angle grinder blade is circular, I did have to use a hacksaw to finish off the cut.

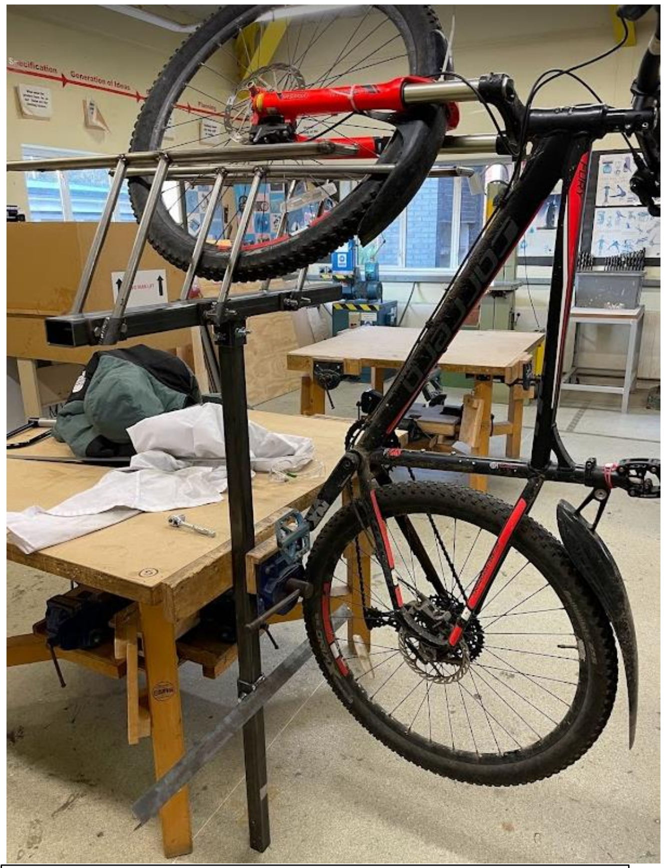
Whilst the pieces were still glued together, I drilled the 5mm holes. I then had to separate the pieces which I did by heating up the metal which burnt off the superglue (I needed to make sure that this was done with a fume hood to ensure I didn't breathe in any fumes). After the pieces were separated, I could join the 2 holes using a small cut off wheel on a Dremel.

I could then weld the brackets to the bottom bar using my 3D printed jig to ensure the angle was right. Once again, I had to only do tack welds with the jig near as it would have melted if it got too hot.



End of primary manufacturing

A week later than I had planned I had finished off the main manufacturing of the bike rack. This meant that the frame was all made and could hold the bike and attach to a tow bar.



The next steps in the manufacturing process were adding the straps to hold down the bikes, adding a method of locking the bikes and also to get all the welds cleaned up and ground down.

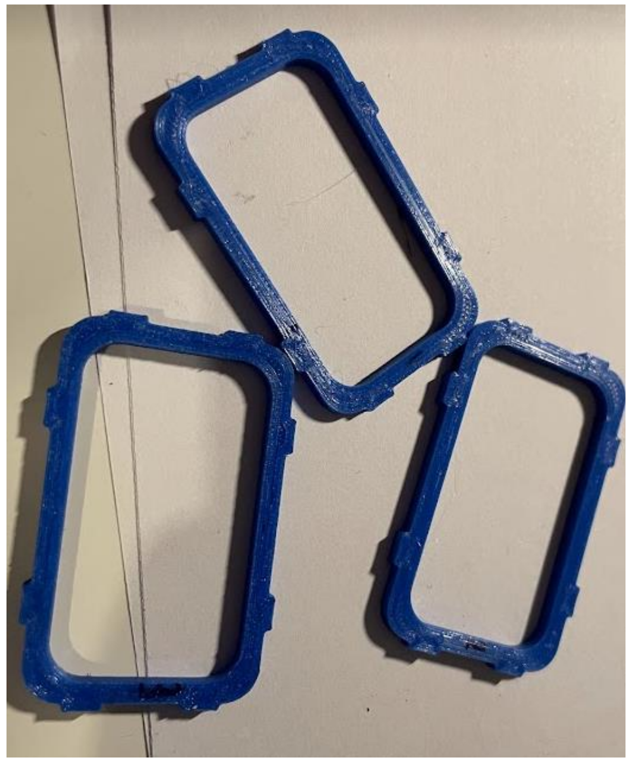
The main reason for going past my expected deadline was because I was waiting for M8x100mm bolts to arrive. I couldn't fully assemble the rack without these as I had no way of attaching the wheel cage holders to the top bar.

During this time, I managed to solve some of the problems I had run into during the manufacturing process.

There were also some parts to finish, such as the pin for the tow ball attachment, at the moment I had just used 2 M8 bolts.

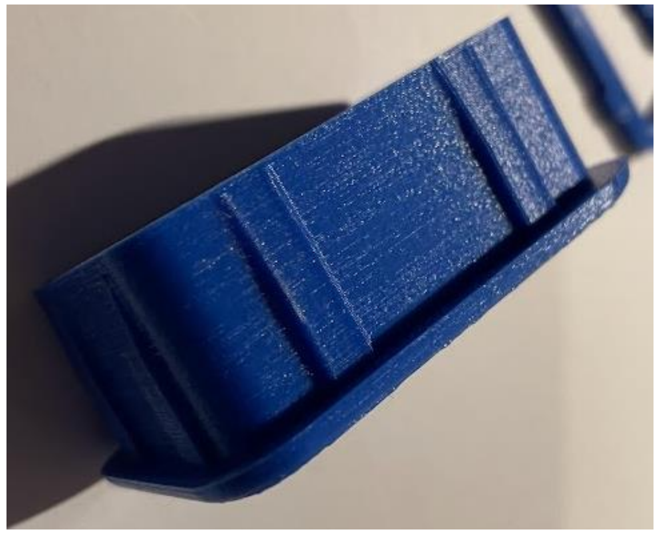
As I discussed in my Researching Manufacturing, I planned to powder coat my project. However, because of the cost associated with this and the fact that I didn't plan on this being the final version and still wanted to make some modifications I decided to not powder coat this prototype. To protect this prototype from corrosion and to give it a more desirable look I decided to apply a layer of Hammerite paint. Which would both protect the steel from rusting and also give a more aesthetically pleasing look.

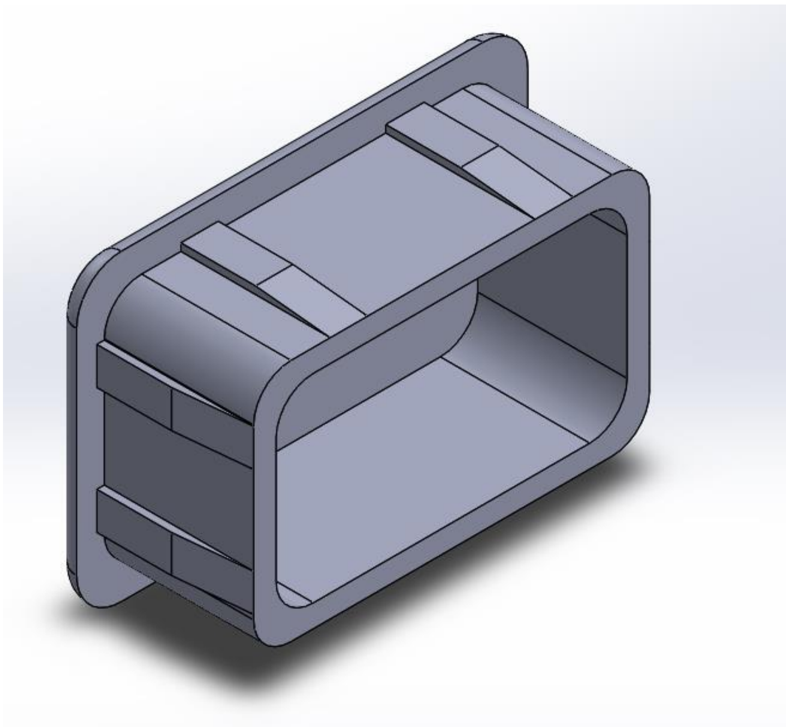
Finishing Touches



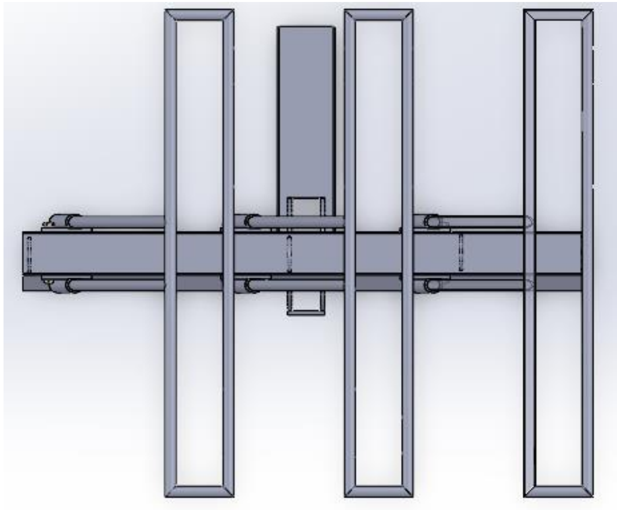
After getting my bike rack assembled and finished there were a couple of finishing touches, the first of this was adding caps to the end of the top bar. This not only gave a cleaner look to the bike rack but also stopped water getting inside the metal section which would help prevent rusting as the inside of the bar couldn't be painted.
I made these end caps using my 3D printer however it would be possible to order them in pre, I chose to make my own as I only needed 2 so it was a lot cheaper making my own. I designed them to be friction fit so they don't require any fasteners or adhesive. Because 3D printing is a time-consuming process, I decided to prototype these end caps I only needed to print a slice of them to ensure they fit in the tube securely and wouldn't fall out.

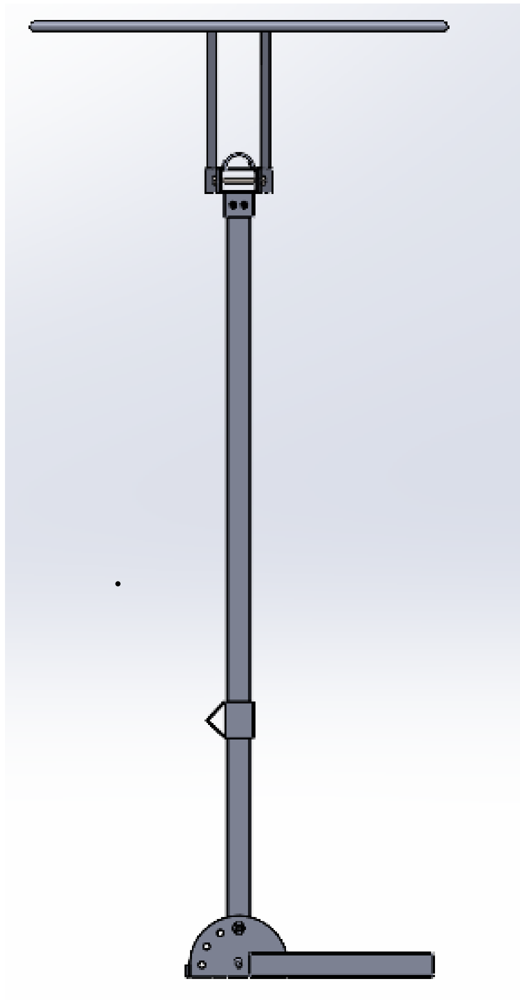
I also added a taper to these friction parts to allow the cap to slide in more easily.

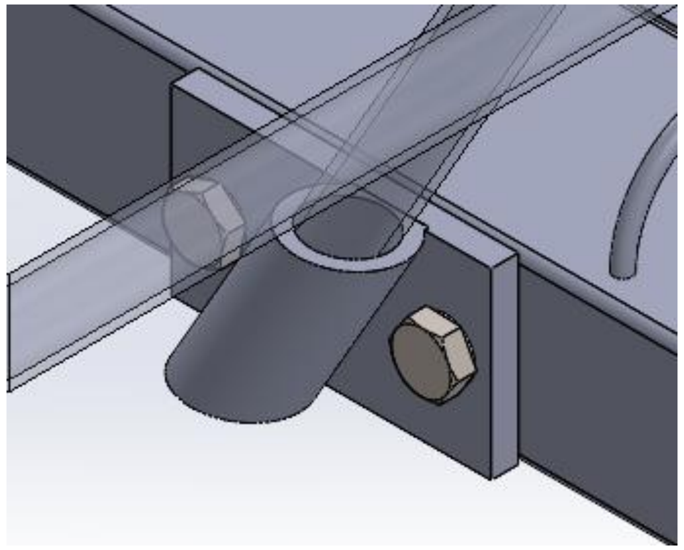


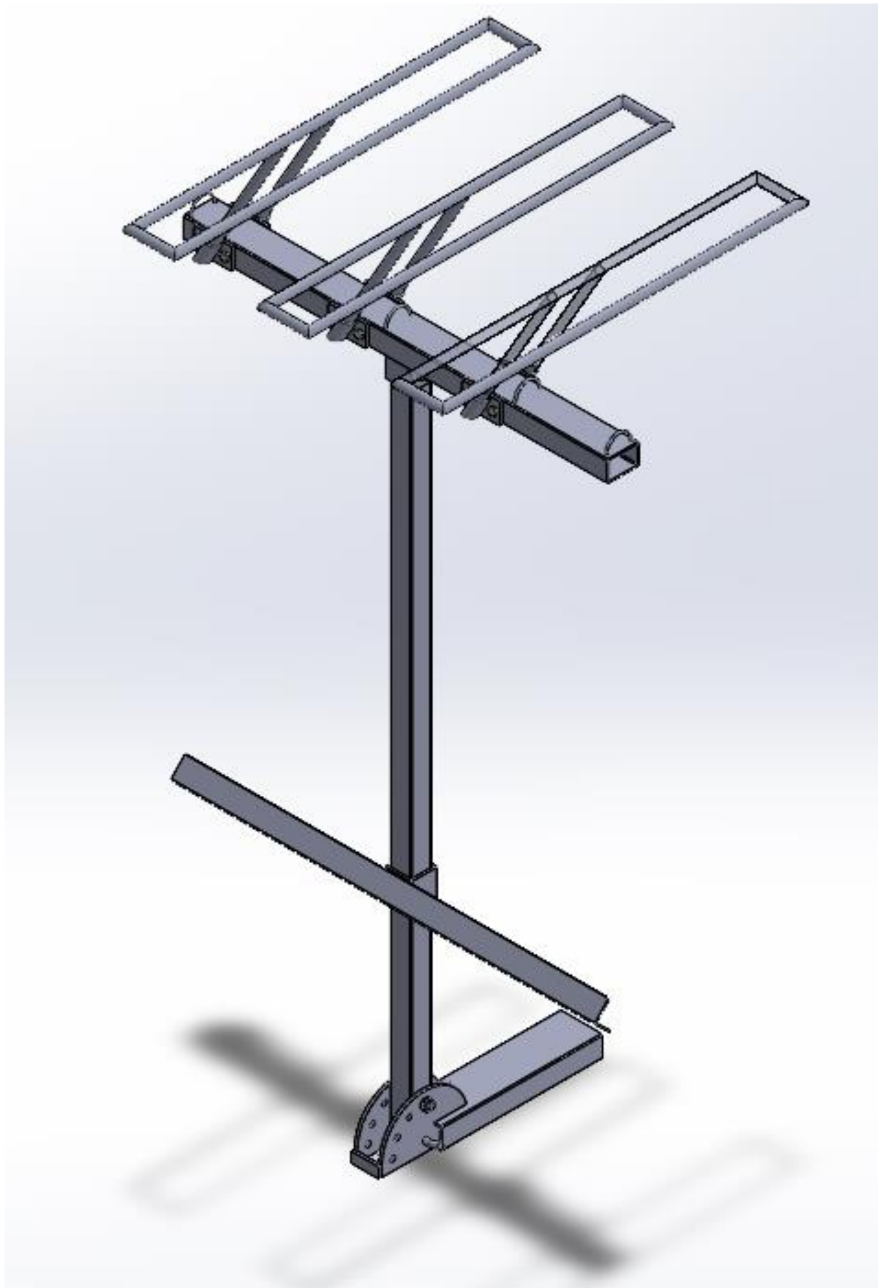


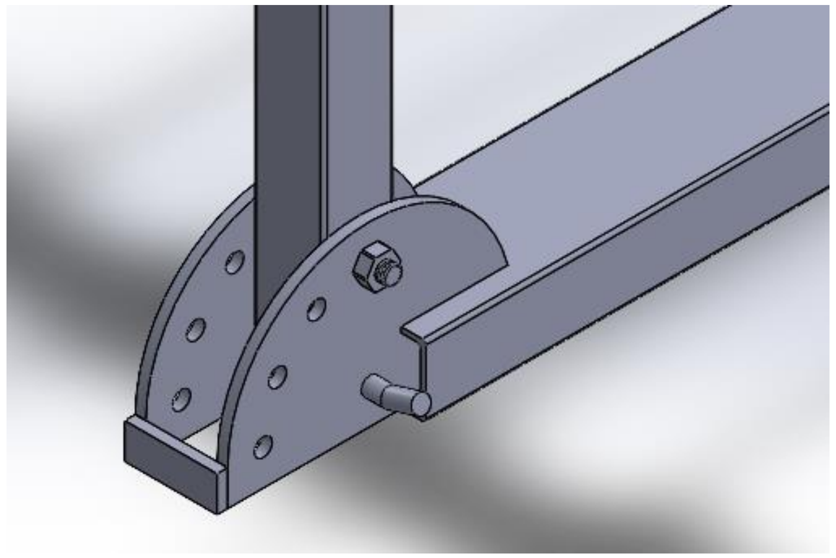
Final CAD Drawings

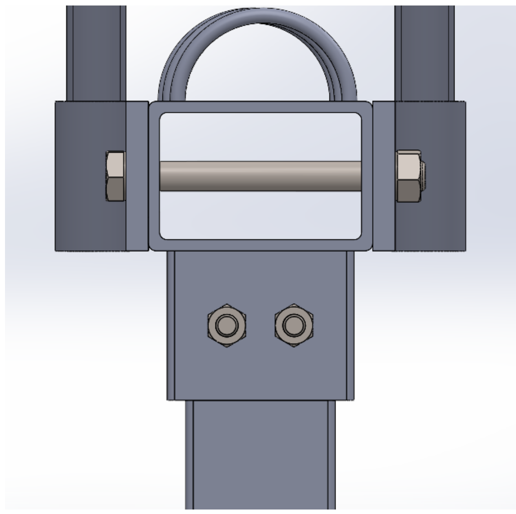




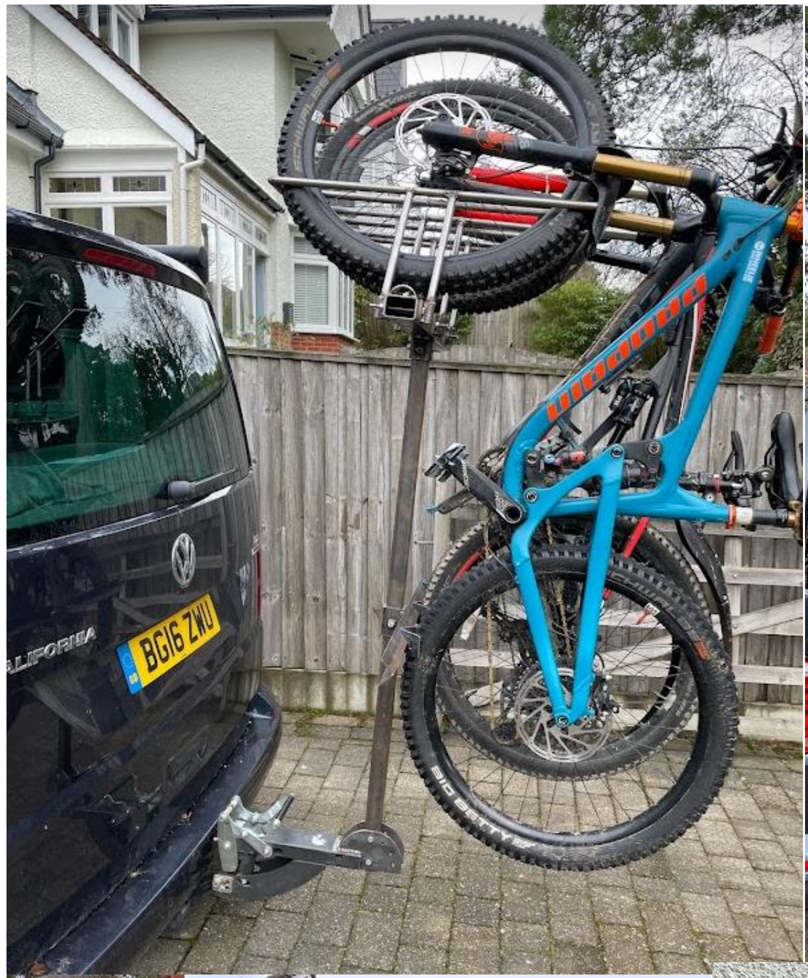


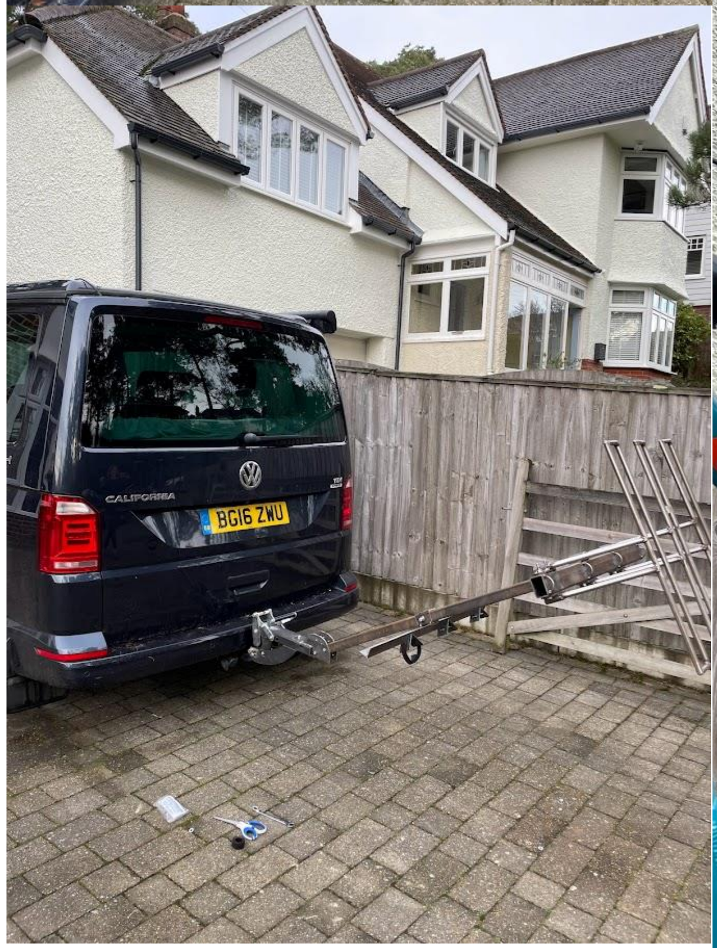






Testing Photos





Prototype Initial Evaluation

Quite alot of wobbly

Add straps from inside of boot to bike rack

They can attach to the loops that were for the straps

Bikes were very securely held

was no need for straps to hold them down

Tow ball mont was secure

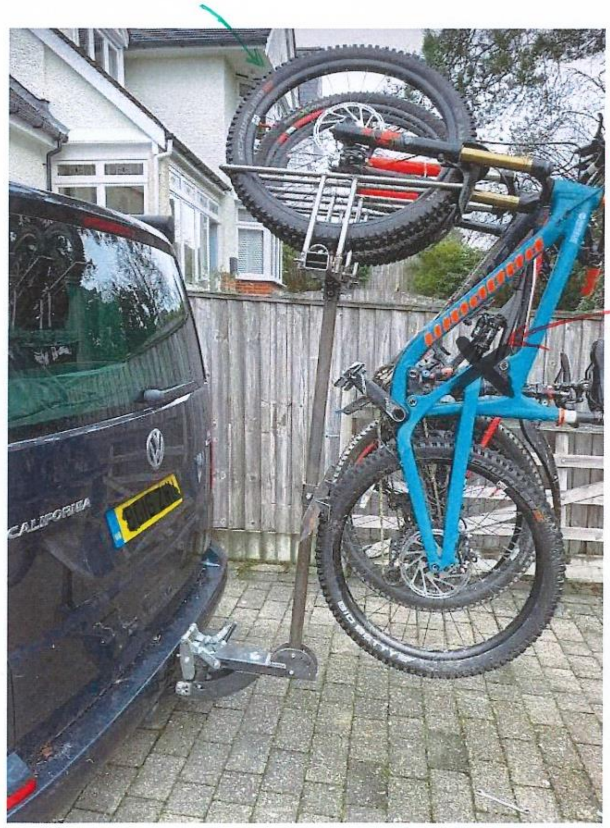
Fitted 27.5" & 29" wheels of different widths

Tilting mechanism worked allowing access to the boot

Bikes were not touching at any point

Although they weren't touching bikes were very close which made loading + unloading harder than it needed to be

Use a longer top bar and increase the distance between the cages



Made it difficult to load

Bikes stuck up very high which would probably prevent car park access

Shorten the upright

Centre of mass of bikes is very far from car

Use different tow ball mont

Tilt the upright

Velcro Strap worked perfectly + didn't come undone when pulled

Manufacturing Evaluation

Lessons-Divided into 30-minute segments	2.11.22	2.11.22	2.11.22	2.11.22	3.11.22	3.11.22	3.11.22	3.11.22	7.11.22	7.11.22	10.11.22	10.11.22	11.11.22	11.11.22	11.11.22	11.11.22	14.11.22	14.11.22	16.11.22	16.11.22	16.11.22	16.11.22	17.11.22	17.11.22	17.11.22	17.11.22	21.11.22	21.11.22	22.11.22	22.11.22	22.11.22	22.11.22	24.11.22	24.11.22	25.11.22	25.11.22	25.11.22	25.11.22	28.11.22	28.11.22	30.11.22	30.11.22	30.11.22	30.11.22	1.12.22	1.12.22	1.12.22	1.12.22	1.12.22	1.12.22	1.12.22	1.12.22
Materials arrive																																																				
Wheel Cage																																																				
Wheel cage jig construction																																																				
Wheel cage material cut to size																																																				
Wheel cage material mitred on mill																																																				
Grooves filed into uprights																																																				
Wheel cage welded																																																				
Wheel cage holder																																																				
Back plates cut to size																																																				
8mm holes marked and drilled																																																				
Tube holders drilled out on lathe																																																				
Tube holders flattened on mill																																																				
Tube holder welding jig																																																				
Tube holders welded to back plates																																																				
Top bar																																																				
Holes drilled for wheel cage mounts																																																				
Upright attachment welded on (drill holes first)																																																				
Upright																																																				
Holes drilled																																																				
Towbar attachment																																																				
Cutting out slot in tow ball clamp																																																				
Cutting out ARC pieces																																																				
Drilling holes in arc pieces																																																				
Welding towbar assembly together																																																				
Bending and drilling hole in bottom bar																																																				
Final Touches																																																				
Dry assembly'																																																				
Any modifications																																																				
Paint/dipcoat																																																				

As I was moving through the manufacturing process I decided to add when I actually started and finished certain tasks. As you can see some things were done slightly further in advanced however many were done later. This was either due to me underestimating the time it would take to complete a task or due to availability of materials, tools and workshop space. The purple indicates when the task was carried out.

Overall, manufacturing of the bike rack went fairly smoothly, I managed to get it finished by the end of December which was my deadline. I could follow my gant chart for the correct order to make parts and use my CAD Drawings (see page 42) for all the correct dimensions of parts and how they are assembled. All parts aligned with the tolerances I had allocated in my manufacturing specification, all welds were tested for their strength and inspected for cracks, he bolts were also checked to all be tight after all the parts and subassemblies had been assembled.

Wheel Cage Holder Problem

One of the most time consuming and frustrating parts of this project was manufacturing the wheel cage holders. not only was it a very time-consuming process I realised it was also not necessary. The worst part was making the larger tube for the wheel cage to slot into. From the start the steel bar was fairly expensive due to how heavy it was, it was then very difficult to cut being so thick yet the pieces being so short made using the power hacksaw difficult. Once the pieces were roughly cut to the correct length, I then had to drill the 16mm holes through this solid steel. Once again this was incredibly tedious and time consuming. I then moved onto the mill where I could get the angle on the ends of the pipes cut in, this was not such a time-consuming process, and I was well practiced as I had cut angles onto the wheel cage pipes. As I said in my manufacturing diary, I had initially planned to flatten the face using the milling machine, however when I tried doing this it simply wouldn't work, I wasn't sure if the end mill was blunt or if the scale on the rod was too hard to cut through but the mill simply wouldn't cut the metal.

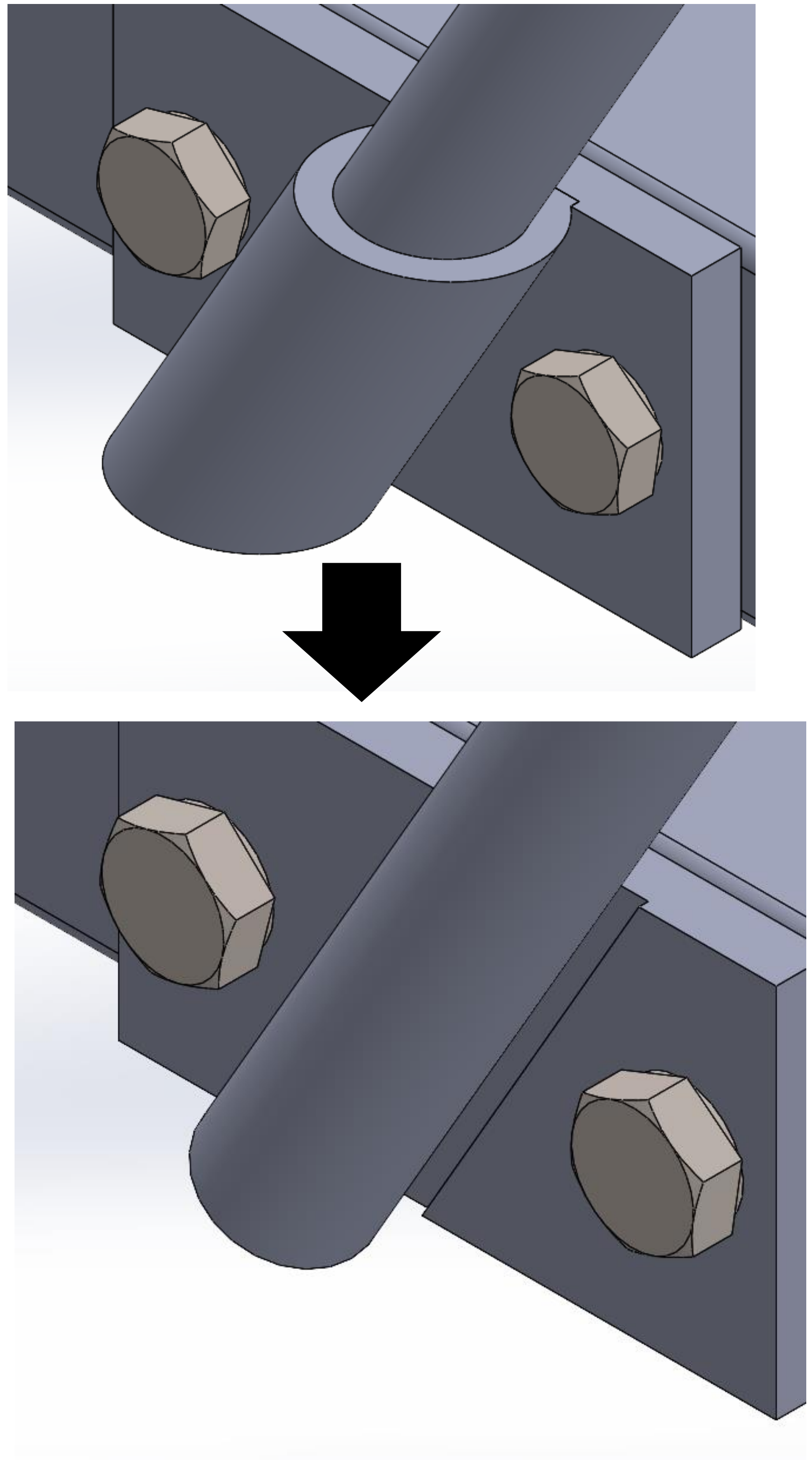
Overcoming the problem

As you can see from my manufacturing diary, I used an angle grinder with a flap disk to get the face flat instead of using the mill, whilst this technically would have been as accurate, it worked perfectly and still kept the dimensions of the part within the tolerance.

Even though this worked I decided I should look into the problem and find a more permanent solution and make a modification to my design.

When I came to assemble the wheel cage and this wheel cage holder I realised I had to weld the wheel cage to the holder, this still meant the wheel cage could be removed (as per my specification) it just meant the wheel cage holder would have to be removed at the same time.

Because of this it meant the whole wheel cage holder rod was unnecessary and I could have just welded the wheel cage to the backing plate. The only affect this would have had is that I would have had to use a jig that could latch round the wheel cage and backing plate and then be removed once they had been welded together.



Client/Target Market feedback/survey

I decided to take my prototype back to the bike shop where I initially conducted my survey and ask the same people for their thoughts on the bike rack.

Name	How much would they pay?	Would they use it?	Positive Thoughts	Negative thoughts/ improvements I could make	What I can do to improve
Michael (Bike shop mechanic)	£300	Yes, if it had some refinement	Would be ideal for trips to bike parks as it is fast to load and unload. Also would keep the inside of his van clean. Also likes that the bikes don't touch and can be loaded/unloaded in any order. Loves the ability to work on your bike when on the go or at bike parks	Add straps to make it more secure when on rough terrain. Bikes are close together and is worried they could potentially touch each other on rough terrain Bikes sit far away from the boot	Add straps. Increase the space between the wheel cages and therefore the bikes. Decrease the tow ball mounts size
Val	£200	No as he doesn't have a tow bar	Would definitely be easier to load and unload than putting in the car. Still allows access to drive throughs	Use a different coating as paint won't last. Quite heavy to lift on and off the tow bar.	Powder coat the final product Look into using a lighter material such as aluminium.
Archie	£350	Yes	Having this bike rack makes it a lot easier to load E-Bike onto opposed to putting it onto roof racks. Likes that he can still access his boot	Still requires bike to be lifted quite high up. Bike also sits far off the ground	Shorten the main upright
Liz	£300	Yes	Much easier than having to use an entire trailer. Bikes can be loaded/unloaded in any order. Still allows bikes to be securely locked	The paint doesn't look durable, and the steel means its heavy.	Use a different finishing product (i.e. powder coating) and research into other materials such as aluminium

Repair Clamp Feature Evaluation

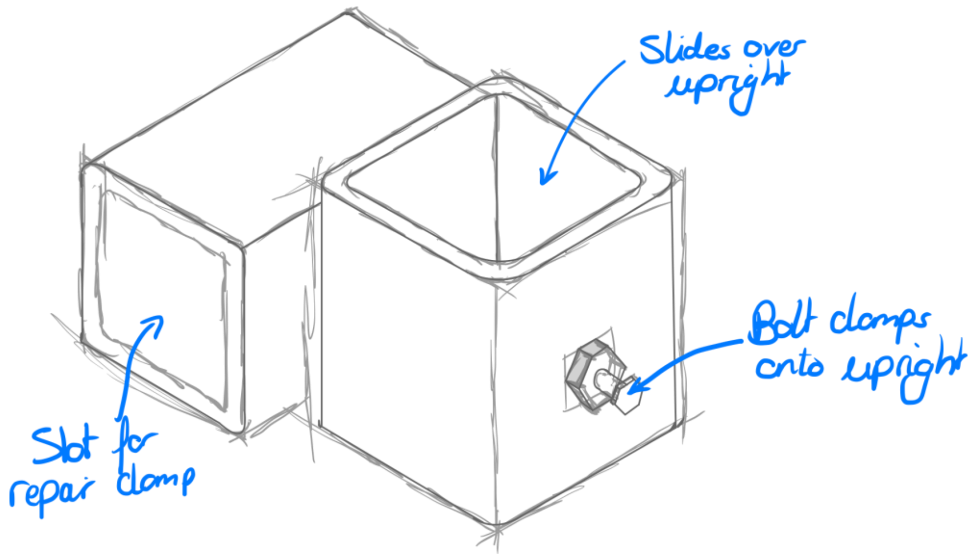
The bike repair clamp feature worked very well, it securely held the bike at a comfortable height allowing the components to be inspected and to check everything is working, for example to check the gears smoothly shifted. The clamp is also compatible with all mountain and hybrid bikes as it uses a clamping mechanism that can easily be tightened to different seat post sizes.

The soft rubber jaws of this bike clamp ensure the bike doesn't get scratched during its repairs.

The repair clamp can easily be installed and removed by slotting it into the tubing, it was held in by friction and the weight of the bike which stopped it sliding out.

I believe this feature works amazingly, if I was going to change it, I would add the ability for it to slide up and down to make it more comfortable for people of all heights to work on their bikes. I could do this by using a similar method to how the bottom bar attaches.

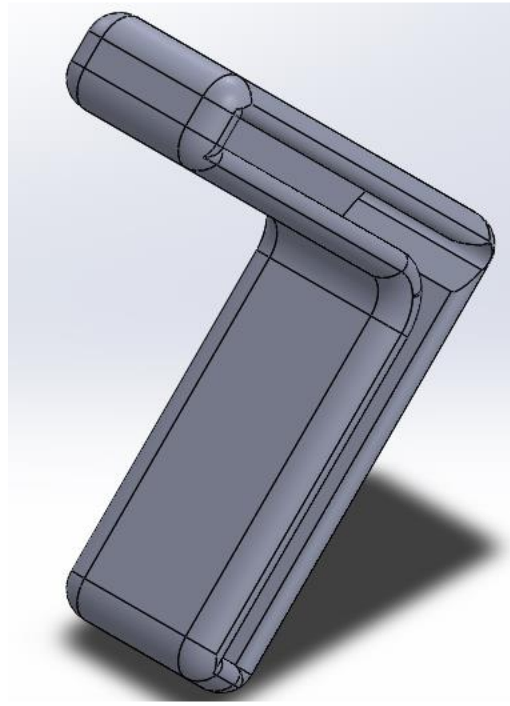
The clamp could also quickly be rotated meaning the bike could be held at different angles to aid with some repairs such as break bleeding.



When the repair clamp isn't in use its holder can be used to attach a bike lock through. This can either be for storing the bike lock or so the bikes on the bike rack can all be locked together and to the rack. I believe this is a great solution to wanting security on the bike rack as the bikes can now be secured using a gold standard lock.

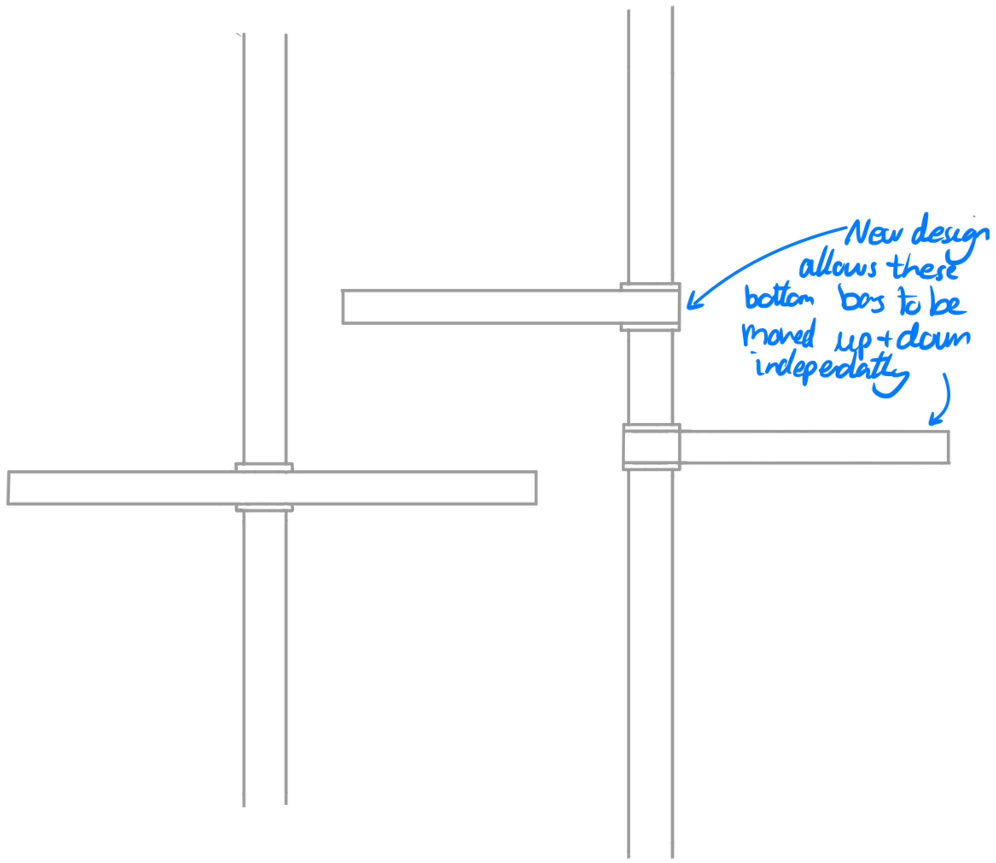
Bottom Bar Evaluation

The bottom bar worked incredibly well, it stopped the bikes from sliding from side to side and also stopped them from swinging out. The Velcro straps worked well and provided a strong and easy to attach solution. One problem with using angle iron for the bottom bar was the fact that it left exposed sharp edges which meant someone could catch their leg on it leading to bruising or a cut. To try and make it safer I decided to add little 3D printed caps to cover up the sharp edge.



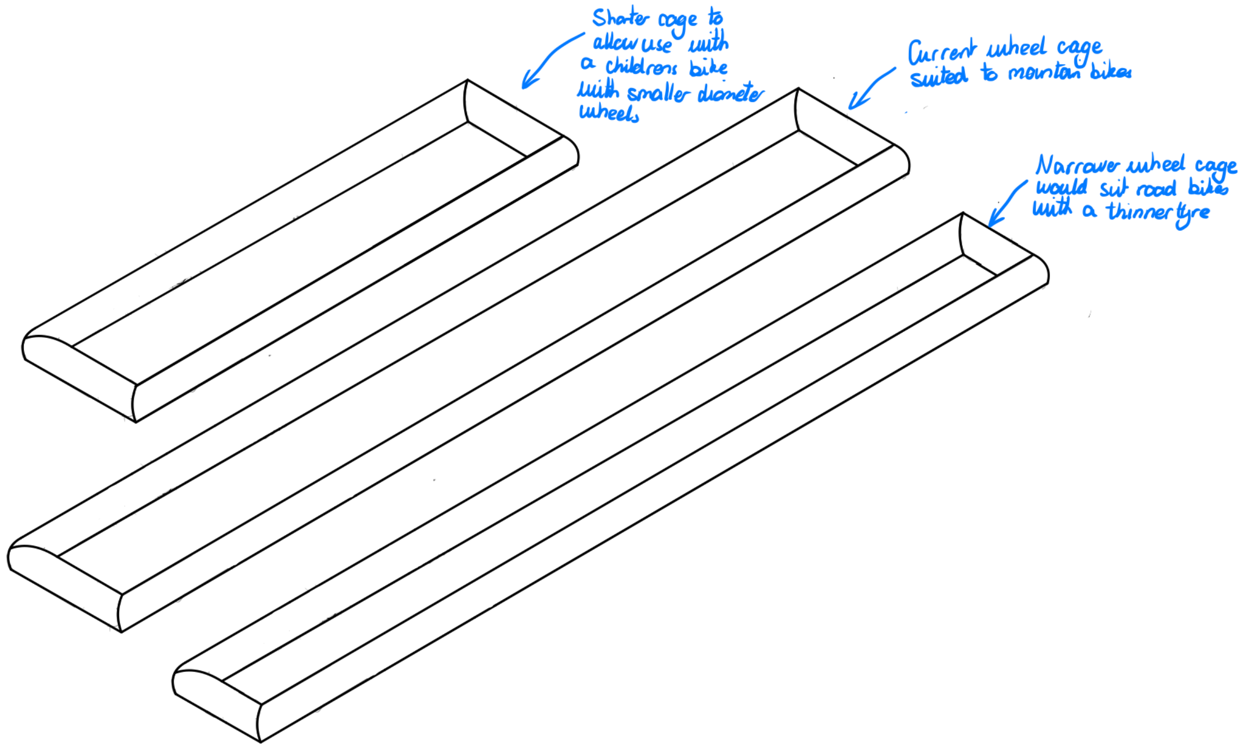
I was initially worried that the Velcro straps would fall off if no done up correctly however because of how they thread through the hole in the steel which is the same width as the Velcro there is enough friction to hold the pieces in.

Having the bottom bar able to slide up and down worked very well as it allowed the bar to be lined up with the centre of the rear wheel which helps to hold the bikes more securely, it also means that bikes of different sizes can be catered for, combined with the different wheel cages this would make it possible to transport children's bikes securely. One problem with the existing bottom bar design is that if you wanted to transport both a children's bike and an adult bike then the bottom bar would not securely attach to the rear wheel of both bikes due to their differences in length. To overcome this, I would have the bottom bar as 2 separate pieces allowing both children's and adults bikes to be transported simultaneously.



Wheel Cage Evaluation

The Wheel Cages conformed to my design specification well, they could hold wheels of different sizes including 27.5" & 29" and different widths ranging from 2.2" to 2.6". The cages securely held the bike, the fit was so good that I don't think straps weren't necessary to hold the bikes in. Because the cages held the bike busing the tyres this meant there was no contact with any painted parts so the bike would not be scratched or damaged. The wheel cages could also easily be swapped out to allow the use of children's bikes or other more specialised bikes simply by undoing 2 bolts and replacing it with a different sized cage.



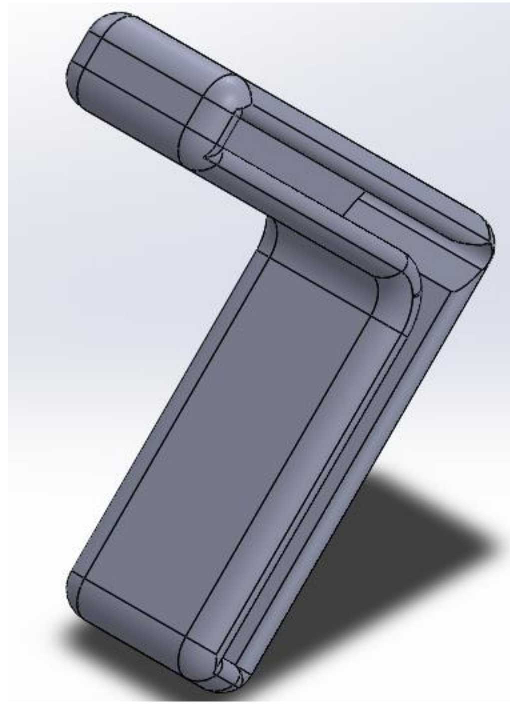
I could also develop an adjustable wheel cage which would allow the dimensions of it so change to make it compatible with a larger variety of wheel sizes and widths.

The wheel cages held the bikes at the correct angle ensuring the handlebars didn't collide and also sat at the correct height ensuring there was a suitable gap between the top bar and the bottom of the front wheel, this ensured the wheel was fully sat in the wheel cage.

One issue I ran into was the fact that the bike can be more difficult to fit into the wheel cages if it has a mudguard fitted as it gets in the way, whilst this isn't a massive problem as it doesn't stop the bikes being held securely it could result in the mudguard becoming deformed. Whilst this may be an unavoidable problem, I will research different methods I could use to stop it happening.

I also thought I could make a smaller, lighter wheel cage by bending a smaller diameter steel pipe, this bend would take up less time during the manufacturing process and because there wouldn't be any joints or welds the cage would be stronger. Using a smaller diameter steel might also stop it interfering with a bike with a mudguard fitted.

Bottom Bar Evaluation



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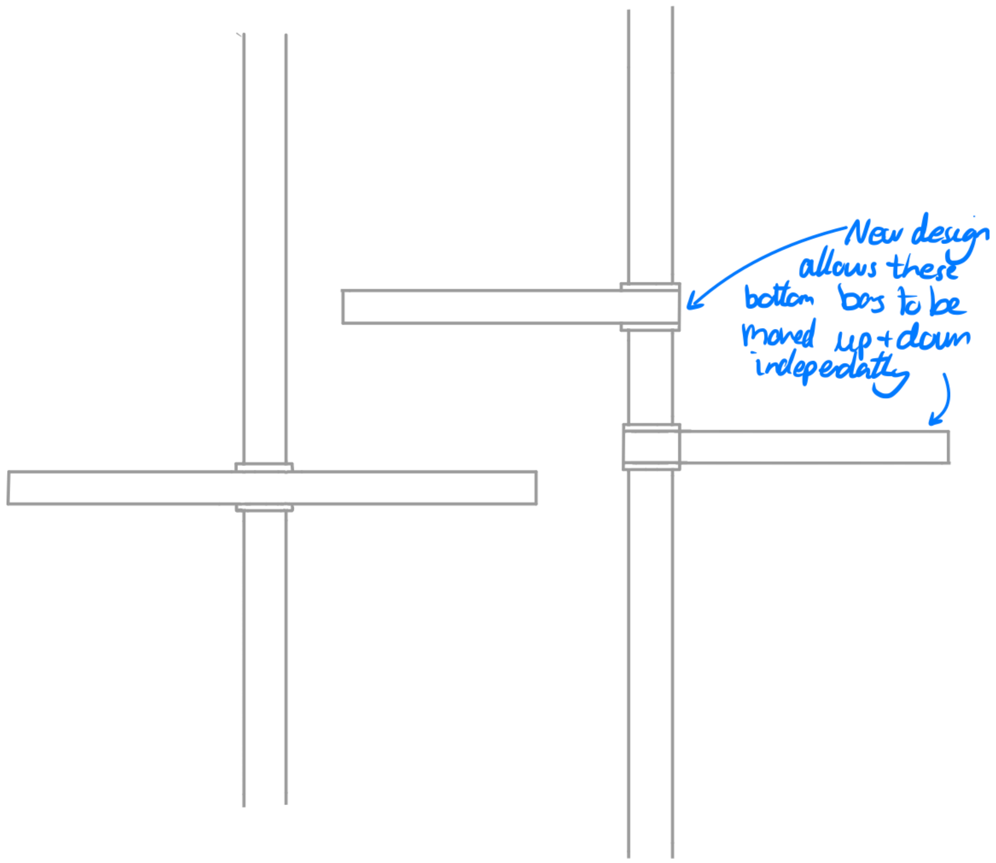
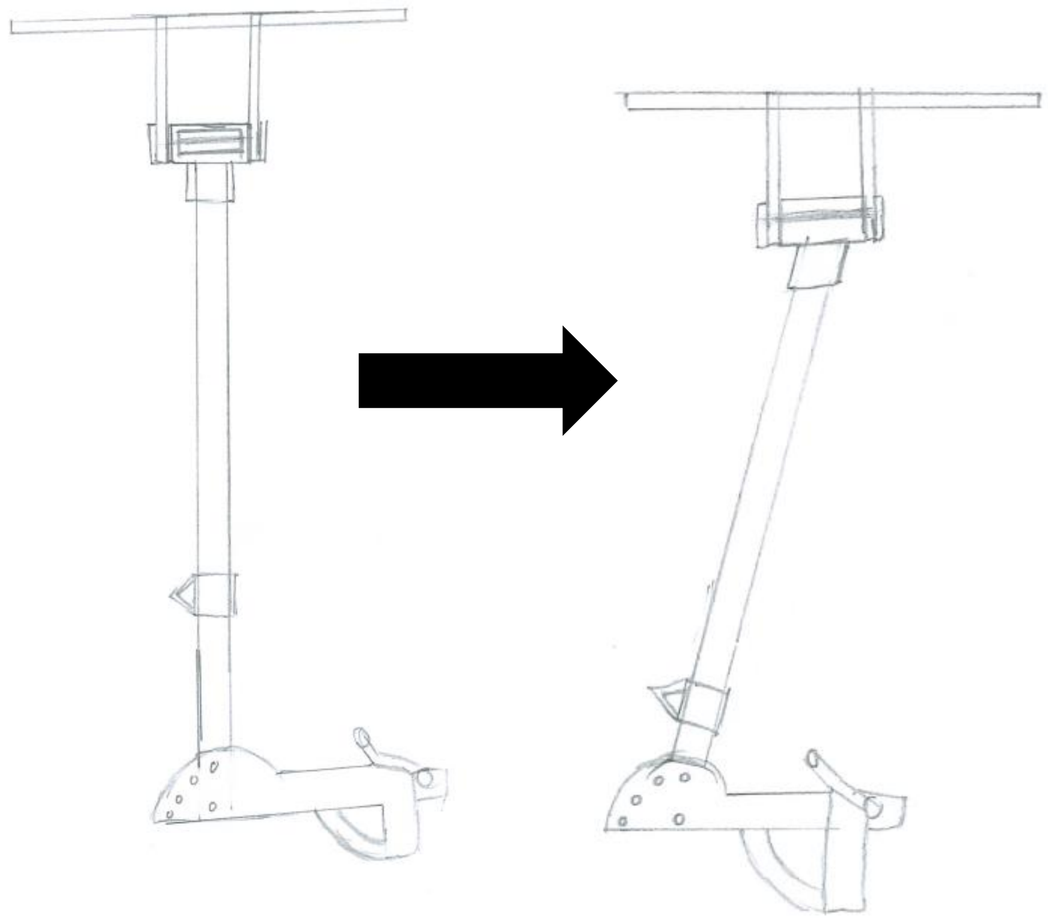


Final Improvements & Modifications



As well as the improvements and modifications above, in the evaluation of the individual parts and subassemblies, I also didn't look quite right with my design was how far away the bike rack was from the back of the van. There are 2 solutions to this problem, the first way would be to use a different mount for the tow ball, so it didn't stick out that far. That would both make the rack look better and would once again reduce the force on the tow ball.

As well as the bike rack not looking quite right it also means that the centre of mass of the bikes is very far away from the tow ball. Another way to solve both these problems would be to have the upright at an angle leaning towards the back of the car. This would add another level of complexity and would require the upright and the top bar mounting bracket to be adjusted to allow the wheel cage to still sit parallel to the floor. This would also solve both Michaels and Archies Concerns of the bike rack.

By spare width I mean the fact that my rack was still a lot narrower than the rear of an average car.

I was very happy with how compact the bike rack was with all 3 bikes on, they didn't touch each other or rub anywhere however because I still had a lot of 'spare width' I would have chosen to space out the bikes by an extra 100mm, this would have made it significantly easier to load and unload the bikes as the bikes couldn't get caught on each other. Whilst this would slightly increase the sideways force on the tow ball, the weight of the 2 bikes should cancel out. This would overall increase the weight of the bike rack as more material would be required for the top & bottom bar however it would be a marginal increase.

Another problem I had was the paint wearing away on the upright around the tow ball clamp, whilst this would have been less of a problem if the bike rack was powder coated it would still happen where there are moving parts, for example where the upright pivots on the tow bar clamp. To help combat this I would add a 0.5mm clearance to each side of the upright. This would stop the paint being scratched off but would also still be strong as when the bolts are done up the steel plate would slightly bend still providing adequate clamping force. This would solve Liz's concerns.

Material & parts price breakdown

My budget for this project was £500, this covers, materials, fixtures and finishes. I come in way under budget at a total of £176.76

Rough breakdown:

Metal	£108.41
Paint	£9.13
Paint Roller + Brush	£3.13
3D Printed parts	≈ £10.00
MDF for jigs + template	£11.60
Test material	£0.00
Nuts + Bolts	£15.00
Bike repair clamp	£14.99
Velcro	£4.50

Used recycled chair legs

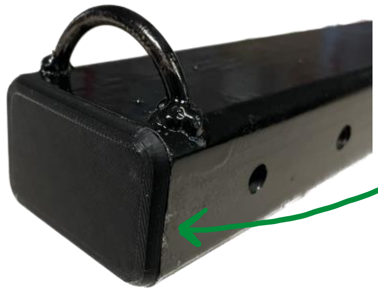
I managed to cut down my costs using a number of methods, for a start I ordered pre-cut materials, usually this comes at an expense however the company I ordered the materials off charged a fixc rate per metre. This reduced my costs as I only payed for the materials I need, It also reduced the labour time, produced less waste.

It's quite hard to gauge how much I spent on 3D printing jigs but I knew I used roughly 750g of PLA which is about £10 excluding energy prices to run the printer

Product Name	SKU	Price (ex VAT)	Qty Invoiced	Subtotal (ex VAT)	
100mm x 6mm Black Mild Steel Flat **Length** 600mm **Weight** 2.83 kg **Length** Custom	2072-0	£10.21	1	£10.21	Towball mount arcs
40mm x 6mm Black Mild Steel Flat **Length** 400mm **Weight** 0.75 kg **Length** Custom	2063-0	£2.40	1	£2.40	Wheel cage holder plates
50mm x 50mm x 5mm Mild Steel Box Section **Length** 100mm **Weight** 0.71 kg **Length** Custom	2309-0	£3.00	1	£3.00	Top + Bottom bar attachments
50mm x 50mm x 5mm Mild Steel Box Section **Length** 100mm **Weight** 0.71 kg **Length** Custom	2309-0	£3.00	1	£3.00	
15.8mm x 1.6mm (5/8" x 16 swg) Mild Steel Tube **Weight** 1.68 kg **Length** 3 Metres	2323-1	£7.48	3	£22.44	Wheel cage tube
22mm Black Mild Steel Round **Length** 500mm **Weight** 1.49 kg **Length** Custom	2364-0	£6.02	1	£6.02	Wheel cage holder tube
60mm x 40mm x 3mm Mild Steel Box Section **Length** 800mm **Weight** 3.58 kg **Length** Custom	2310-0	£20.53	1	£20.53	Top Bar
40mm x 40mm x 3mm Mild Steel Box Section **Length** 1300mm **Weight** 4.58 kg **Length** Custom	2301-0	£16.89	1	£16.89	Upright
40mm x 40mm x 3mm Mild Steel Angle Iron Hot Rolled **Length** 800mm **Weight** 1.41 kg **Length** Custom	2273-0	£5.85	1	£5.85	Bottom Bar

Checking 'Final' prototype against specification

Materials:
The rack should be primarily constructed out of mild steel with stainless steel bolts and plastic finishing details.



Capacity:
The rack should be able to accommodate a variety of bike frame sizes and styles, including full suspension and hardtail mountain bikes. It should be able to hold a minimum of 3 bikes securely.

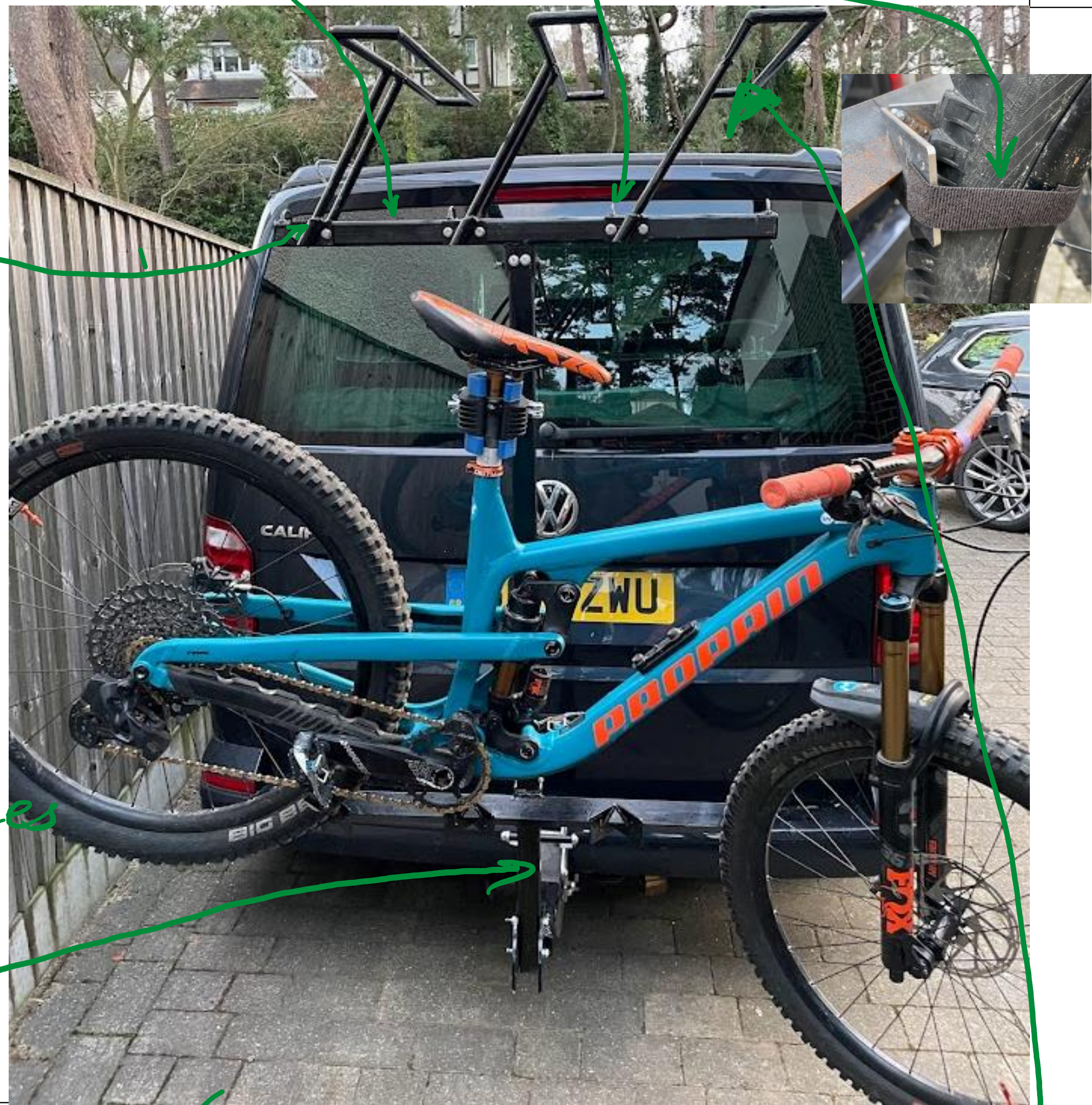
Tested with 3 different MTB's with different wheel sizes

Mounting:
The rack should be easy to install and remove, with minimal tools required. The rack should be designed to be mounted on the tow ball of a car.

Tow ball clamp which uses a hand operated lever system

Safety:
The rack should be designed to ensure that the bicycles are secured in a stable manner, to prevent them from falling off while in motion. It will use Velcro & tie down straps to ensure they're secured.

eyelets for tie down straps



Security:
The rack should be able to securely hold the bikes in place during transport, with minimal movement or sway. It should integrate an existing locking

Dimensions:
The rack should not exceed the dimensions of the rear of an average car: 1.65mx1.49m

Weight:
The rack should be lightweight and compact, taking minimal space on the car. It should not exceed a weight of 30kg.

Aesthetics:
The rack should be designed with a sleek and modern aesthetic, that will appeal to mountain bikers.

Simplistic black finish

Durability:
The rack should be durable and able to withstand the elements, as well as the bumps and vibrations of off-road travel. It should be designed to resist rust and

Coating of hammerite prevents rust

User-Friendly:
The rack should be easy to use, with clear instructions and intuitive design.

Bikes easily slot in and out of the wheel cages


TDI
AD10 DNX

BG16 ZWU

BG16 ZW