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Electric Vehicle Charger

Design and Production

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All figures: (Davies, 2022)

Introduction

In 2020, transport was the largest emitting sector of greenhouse gas emissions, with 24% of the total emissions produced by the UK coming from transport (Department for Transport, 2022). The 99 million tonnes (Department for Transport, 2022) of carbon dioxide that domestic transport produced in 2020 is having an impact on climate change that will put the world at risk for future generations. The earth's surface temperature is now "1.87 °F (1.04 °C) warmer than the pre-industrial period (1880-1900)" (Dahlman, 2022). This may appear a very small change in temperature, but this rate of warming is unsustainable in the long-term and already causing regional and seasonal temperature changes: impacting sea levels; causing extreme weather and habitat changes for plants and animals alike.

With such a large impact on the emissions produced in the UK, coupled with the need to reduce transport emissions globally, the demand for electric vehicles (EV) and more sustainable ways of transport is greater than ever. The EV market in the UK is on the rise, especially after an announcement from the government that in 2020, all new vehicles coming off the production line must be electric, in a bid to phase out petrol and diesel vehicles by the year 2030 (Department for Transport, 2020). Whilst this is a step in the right direction to gradually phase out petrol and diesel vehicles, it begs the question: does the infrastructure exist, and will it be ready by 2030 to usher in the new generation of all EVs? According to government statistics, in Wales alone, by the end of September 2022, there were 38,482 electric vehicles (EV) and plug-in hybrids (PHEV) registered (Department for Transport, 2022). Also, as of the 1st of January 2022, there were 28,375 public EV charging points, with only 5,156 of them being rapid chargers (Department for Transport, 2022). There is a clear deficit between the amount of EV's registered and the amount of publicly accessible charging points. Furthermore, the government's plan to phase out petrol and diesel vehicles in 7 years' time is putting increasing pressure on designers and electrical engineers to find a prompt solution.

When approached by the clients Bass Energy, they proposed plans to revolutionise the EV charging infrastructure in the UK with new technology developed by their team. Therefore, the opportunity arose to create a lightweight, portable charger to fit with the new infrastructure that Bass Energy is hoping to create. The task was to produce an aesthetic, yet functional EV charger that the user would be responsible for, with the charger being transported in the boot of the vehicle to be used at charging points set on pavements around cities and towns. The charger needed to be small and lightweight enough to be stored, and safely manoeuvred around, with user interaction on the side of the charger being crucial in product operation. The on-street presence of the EV charger also needed to be considered, as a small object on the pavement could cause health and safety issues. Therefore, a large on-street presence was needed without increasing the size of the charger.

Background Research

As discussed in the introduction, the need for EV is at an all-time high, with EVs being a prominent solution to rising concerns about pollution caused by the transport industry. With the government's pledge to stop producing all new petrol and diesel cars by 2030, the market is developing at an accelerated rate and solutions need to start being presented now to ensure the planned phasing out is successful. The car manufacturing industry is already ahead of the curve when producing EVs due to the increased demand, as well as the predicted market growth, fuelling this growth. One example is Ford, who recently announced that they would be discontinuing the Fiesta model, instead opting to expand their range of EVs (Karr, 2022). The Ford Fiesta is the most popular car of all time in the UK with over 4 million manufactured, and over 1.5 million still registered on UK roads (Motorway, 2022) (Bishop, 2019). This is a car with huge market potential that Ford are discontinuing, to instead opt to replace it with an all-electric version of their Puma model, emphasising the decision to manufacture more EVs. Ford are also moving to improve their infrastructure as a company, changing their factory in Cologne, Germany into the 'Cologne Electrification Centre' where "a new midsize battery-powered crossover will be manufactured starting next year" (Karr, 2022). Out of this factory, Ford wants to produce 1.2 million EVs within the next 6 years leading up to 2030 (Karr, 2022). With major car manufacturers like Ford increasing spending to improve their infrastructure to better suit the future targets of the company and the predicted growth of the EV market, does the UK have the means and infrastructure in place to handle this new wave of EVs?

In one simple answer, no. The UK currently has "more than 660,000 battery-electric cars" registered on public roads and with the increase of EV registrations growing by 40% in 2021-2022, plus this figure is predicted to skyrocket over the next 10 years (S, 2023). Many EV owners will have some sort of home-based charging system in place, for example the 'Pod Point' system from EDF Energy, which is attached to the house and utilises the power coming from the house to charge the car. However, many drivers still rely on publicly available chargers to charge their EVs. According to government statistics, as of the 1st of January 2022, "there were 28,375 public electric vehicle charging devices available in the UK" and of these devices only 5,156 were rapid chargers (Department for Transport, 2022). With more than 660,000 EVs currently on the road, the number of EVs greatly outweighs the number of chargers publicly available. This lack of charging infrastructure is a major challenge, restricting the UK from moving forward to reach government targets. Without this charging infrastructure in place, it runs the risk of an overall decline in EV sales due to the lack of suitable charging options. This may instil concerns from the public that they won't be able to access a charging point as easy as it is to access a petrol station, leaving drivers without charge or in extremely long queues. Another factor of the infrastructure that needs to be improved is not only the need for

more chargers, but to make them rapid charging chargers. The current average time to fully charge an EV with a 40kWh battery, on a standard 7kW fast charger using a Type 2 charging cable is around 4-6 hours (Lilly, 2022). These types of chargers are the typically found outside supermarkets, in car parks or public centres (Lilly, 2022). For many EV drivers, these are the typical chargers they will use most frequently. The average time for a full charge stands at around 5 hours, which is a long wait time compared to traditional petrol refuelling, which takes approximately 8 minutes of idle time at the petrol station (Geotab, 2022). When comparing fast chargers to rapid chargers, the difference in time makes it clear why new rapid charging systems are needed in the UK. The average time, according to zap-map, to charge an EV up to 80% capacity on a 50kW charger is between 20 – 60 minutes (Lilly, 2022). This difference between this and typical EV chargers, of nearly 4 hours to charge the same EV demonstrates the need for the government to produce more rapid charging systems. Availability of more rapid chargers would result in commuters being able to travel longer distances quicker, as the time spent recharging on a long journey is significantly cut down. It would also work to cut the potential queues caused by many EVs all waiting for the same charger, since the turnaround of usage is quicker.

The development of rapid charging and the future breakthroughs in faster charging systems will benefit a project like this one, as the product is designed to be used in short, intermittent periods throughout the day, to ensure a customers' EV is always sufficiently charged. Another reason this product's development is so important to the EV industry is the proportion of chargers in different geographical regions per 100,000 people. At the start of 2022, Wales had 33 public charging devices per 100,000 people, whereas London had 102 public charging stations per 100,000 people (Department for Transport, 2022). Two factors influence this difference. The first is that the population, especially the population density, in London is much higher than in Wales. Wales' population in 2021 was approximately 3.1 million people (Llywodraeth Cymru, 2022), whereas London's population in 2021 was approximately 8.7 million people (Greater London Authority, 2023). The population density in 2021 in London was "5,596 people per square km" (Statista, 2022), on the other hand Wales' population density in 2021 was 150 people per square km (Llywodraeth Cymru, 2022). This stark difference in population is the main reason why the number of chargers in London is significantly greater, since there are likely more EVs. Secondly, the physical landscape of London has an influence on the increased amount of charging points. Compared to the Welsh landscape, the majority of London is flat, paved and usually residential. Therefore, the infrastructure is suitable to install a charging point, making installation of a charging unit simple. Whereas in Wales, the landscape is more rural and geographically dynamic, with far less urban and residential areas. Installing charging units in the Welsh landscape is far harder, as the infrastructure is not always suitable to drop these charging units into. The usage and

convenience of EVs in Wales, is therefore, far more limited, as the density of chargers across the country is far lower than in other major cities. These figures could be linked to the fact that there are no major motorways that link the North to the South of Wales, based on the assumption that more chargers would be placed in motorway services along these routes. The benefit of the chargers designed for Bass Energy is that far less pre-existing infrastructure is required to install these chargers and the main body is carried from point to point by the user, better suiting the infrastructure and market in Wales. These comparisons between London and Wales demonstrate that the Bass Energy chargers are not only suitable in urbanised areas but also in more rural environments which will increase EV accessibility across the UK. Another benefit of the Bass Energy chargers is that most of the technology needed to operate these chargers is subterranean, meaning that the electronics are mostly placed underneath pavements. This is a huge benefit in major cities like London, where space to build on pavements is limited and a large percentage of residents live in flats/apartments, with 43% of Londoners living in apartments in 2017 (Atkin, 2017). The population of London having grown over the past five years (Macrotrends, 2023) and that number is expected to continue to grow. Most residents don't have access to at-home charging systems, meaning if these residents wish to own an electric car, they must rely on public chargers. With a personal charger from Bass Energy, this problem is eliminated since residents who live in apartments have access to their own personal charger, providing a guarantee that they can charge their EV.

Initial Design stages

The initial step taken during this project was to find out the client's preferences and requirements. During a meeting with Bass Energy, they explained the type of charging system they wanted to produce. They wanted a charger that was not only highly functional and user focused, but aesthetically pleasing. Initially, there were no restraints on the design; the early stages were for experimentation and preliminary research to enlighten the clients and broaden their ideas about what could be achieved from this type of project.

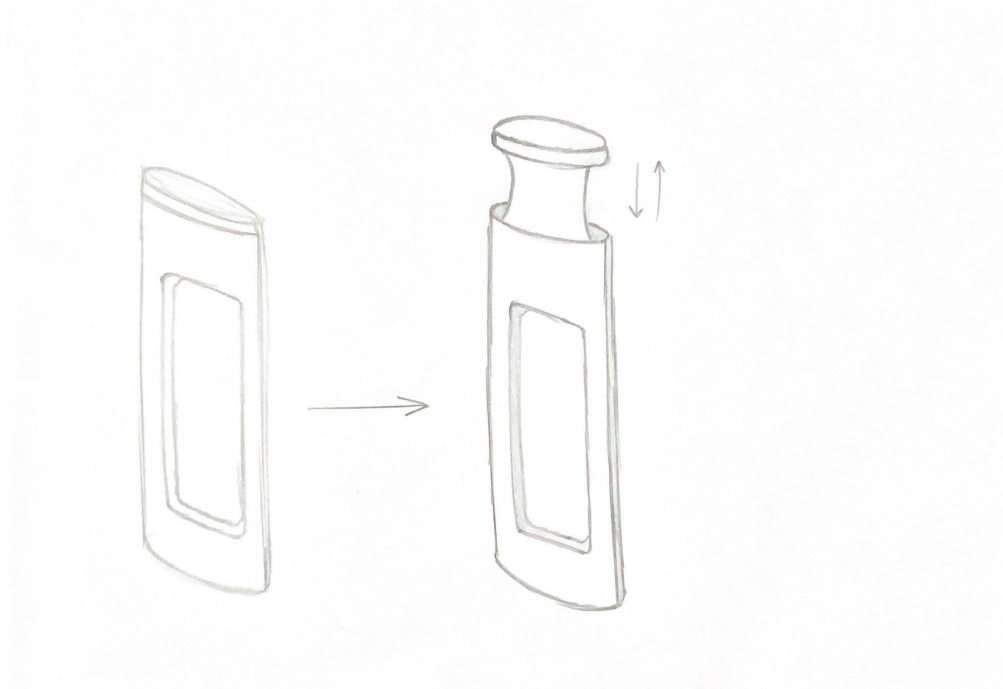


Figure 1 An oval shaped charger body with extending cable management point at the top of the design and large cut-out section.

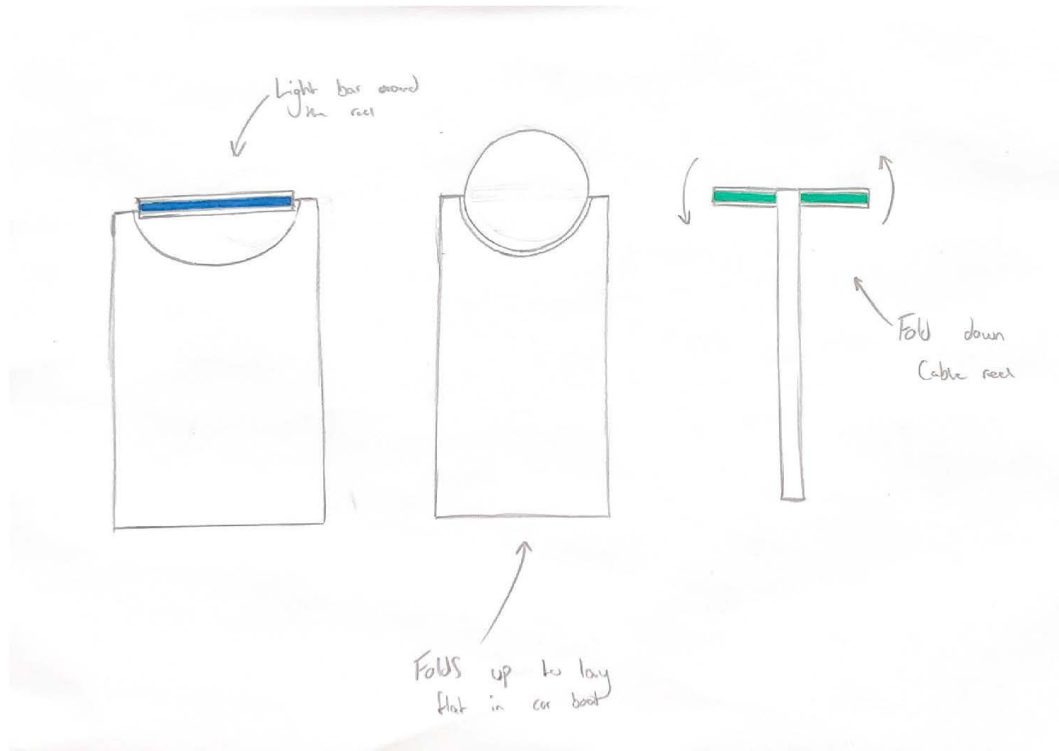


Figure 2 A thin, square charger body with circular table-top cable management feature.

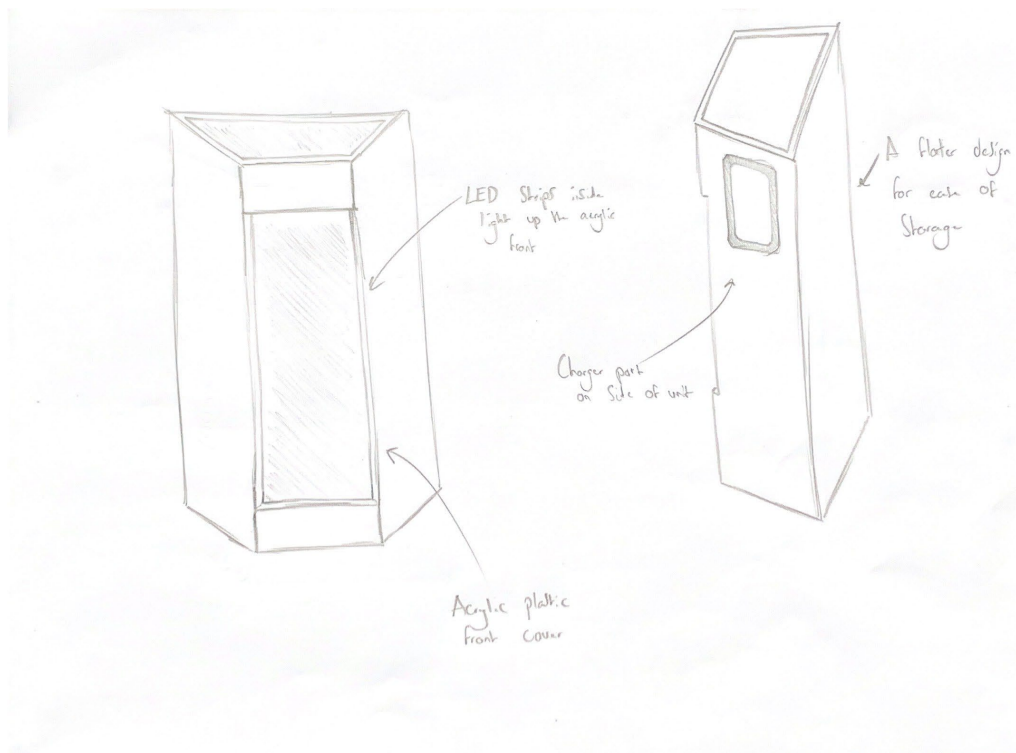


Figure 3 A trapezium shaped main body, with charging point at the side of the device and a large light fixture on the front of the design.

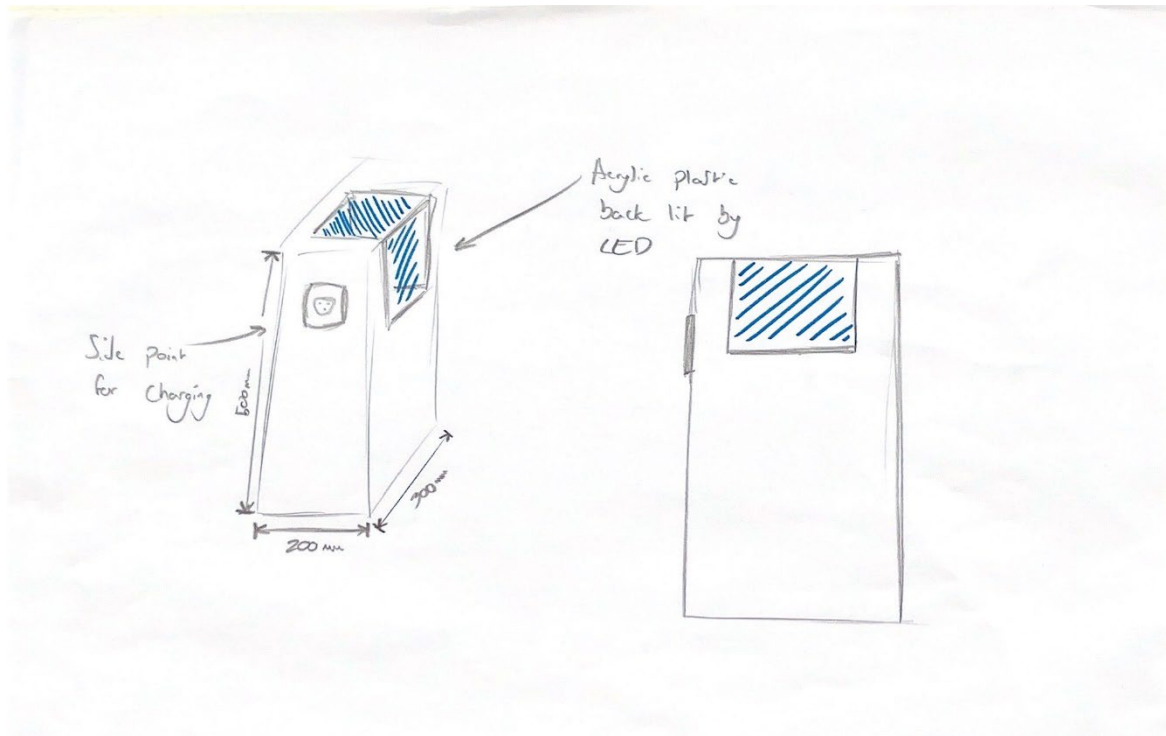


Figure 4 A rectangular shaped body, with a large square light fixture on top of the body and a side charging point.

Figures 1 to 4 are the preliminary sketches submitted to Bass Energy, which intended to demonstrate a varied range of designs to investigate what would work and highlight the clients' preferences. The designs range in footprint shape, body shape and the different use of light. After reviewing these initial designs and receiving feedback from the clients, some aspects required attention and refining in the upcoming design stages. These were: size, cooling solutions; sustainability; lighting options and carry points. The need to keep the design simple and sleek were major points to keep in the following designs. Whereas aspects such as moving parts, which can be a weak point in the design that must be fixed if broken. Low charging points, making it harder for the user to connect their charging wire, and large gaps, which can cause safety issues due to entrapment points, were not needed in any of the designs moving forward.

After analysing feedback from the clients and identifying any changes, a personal ethos for the design was created: a clean and simple design that appears lightweight, with user interaction a main focus, and a need for minimal aesthetics, such as simple colours and lighting solutions to aid the user and create a presence on the pavement. It should be produced with sustainable aspects considered. This design ethos led to the decision to focus on developing the design from Figure 3 due to its simple shape, minimalistic features, good manufacturability potential and the potential to expand its user interaction potential.

Model Testing

In this section, a series of test models were conducted to compare the designs to real life scenarios to aid the configuring of the next design stages.



Figure 5a, 5b and 5c Displayed from left to right, three cardboard cut-outs to show height and scale at different measurements: 500mm, 700mm and 950mm tall.

First, cardboard models were used to better understand both the height and floor footprint of any future designs, to ensure that it would be suitable for the design intention; to be freestanding and suitable for storage in car boots. Figures 6a, 6b and 6c clearly exemplify that the shorter the design was better for storage and manoeuvrability for the user, since it increased boot space and would be easier to handle. It was decided to use the shortest piece (6a) as the guide for the product, but the overall scale was still needed to be determined from the other cardboard models.



Figure 6 Full scale cardboard model with handles and kick shielding for testing.

Figure 7 shows the overall footprint of the design and was used as a test model for handle placement, focusing on user interaction as it is a guide to show the scale of the design in real life. Figure 10 shows the scale of the model in comparison to an EV, this provoked investigation into the height and possible charging point placements on the charger. The height was elevated 550mm, which was discovered during the original cardboard cut-out testing to be the optimal height for user interaction and storage. Figure 8 shows the testing of the model charger being placed into a car boot to show the useability and the space the charger would take from boot storage.



Figures 7 and 8 (from left to right) Model testing using a VW Golf E as a comparison.



Figure 9 Handles on the side allowing for a full range of movement

After testing this model, a few design directions were taken. The first was to remove the kick shielding from the bottom of the charger. Initially, this intended to provide protection to the bottom of the charger for example if the user were to kick or nudge the charger into position, when placing the charger onto the plate on the pavement. However, the shielding could in fact encourage the user to be more forceful with the charger, as the shielding made it seem as if it were a design feature rather than a design precaution. The second direction was to ensure the final product must be a light and simple colour, highlighted by brown of the cardboard which made the model look heavy and dull.

Another outcome from the model testing was the need for the charger to be made slimmer. The original depth of the cardboard model was 200mm, which could be streamlined to reduce the design looking bulky and heavy. This links to a further user interaction challenge as the in-boot profile of the model takes up a large amount of boot storage. This model would decrease the storage to approximately 50% in the Golf e, which could risk more items being stored on top of the charger, resulting in potential damage, and making it more difficult for the user to retrieve the charger.

Furthermore, the type and positioning of the handles on the charger were investigated during model testing. The initial design was set to have one large 'post-box' style opening at the rear of the design as a single point of carry (See Figure 10). While this allowed the design to keep its sleek front side, with no extruding or visible handles, the opening at the rear provided limited movement on the Z axis. This means the user would have issues when wanting to tilt the charger forward and backward. The addition of the external handles on the side changed the sleek, smooth design, but increased the user's movement of the charger, by allowing the user to manipulate the charger across X, Y and Z axis (See Figure 9). The external handles made a vast difference to the manoeuvrability of the charger but reduced the overall aesthetic value of the design.

Therefore, to develop this design further, the weight and 'bulkiness' of the design must be taken away, with a feature to the rear panel of the design being added. The 'Walkie-Talkie' skyscraper in London, designed by Rafael Viñoly was used as inspiration to achieve this. The building uses a concave side, which reduces its size and gives it a lighter feel from the road, making the building look smaller yet also providing maximum space on the higher levels. A concave panel on the rear of the design, would make the charger look lighter through the middle of the system, whilst also keeping plenty of space at the bottom for electronics and at the top for handles, lighting and charging points. Secondly, to reduce the size of the footprint the charger had, it was decided that the depth of the charger would be cut down by 50mm. This would create a thinner, sleeker design that would take less storage space, while also maintaining enough of a footprint for good

stability on the ground. Thirdly, to better the aesthetical values the charger would be kept to light, grayscale shades with white being the most attractive colour for the charger, helping the charger appear larger while also keep to a clean, crisp colour due to the higher colour saturation between the white charger and its background (Henrik Hagtvedt, 2017). The lighting solution would also have to be re-worked as the previous sketches had varying light solutions that would not have the desired outcome when placed upon this design.

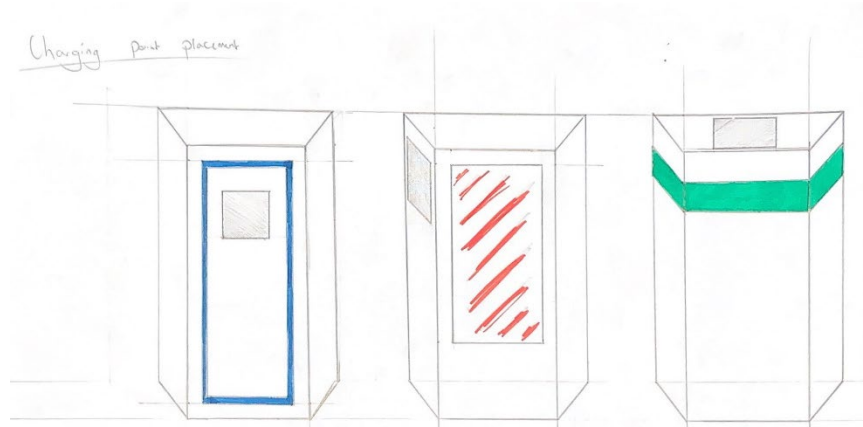


Figure 10 Sketches showing different lighting solutions.

Design Development

This section explores features discussed in the initial stages and model testing stages of the project. The models were developed on Autodesk Fusion 360, which is a CAD modelling software that allows to design, create, and render in one package.

Version 1 of the charger design development features no concave back, redesigned internal handles to increase the sleek aesthetic values on the design and a large ring of light around the top of the charger (See Figure 12). Version 1 still explores using the kick shielding at the base however with the shielding size reduced.



Figure 11 Version 1 of design development

The white colour of the charger means the design looks light, while also allowing the light from the LED light fixture to not get lost in any other colours. This improves the overall presence the charger has on the pavement.

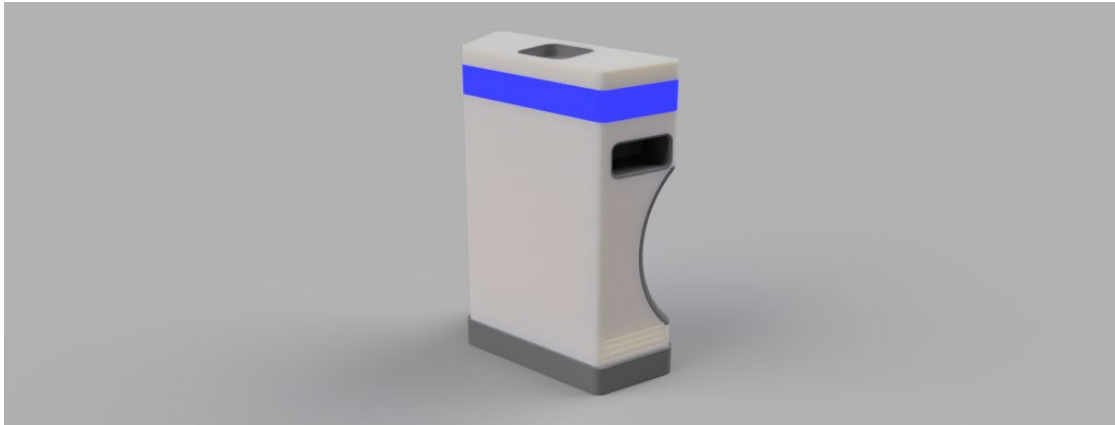


Figure 12 Version 2 of design development

In Version 2 the concave has been added to the rear panel and has also cut out the sides of the charger. This vastly reduces the weight as well as making it look far lighter and less blocky than Version 1. The kick shielding has been reduced further down to a sliver at the bottom of the charger. Here the kick shielding no longer promotes the user to kick the charger but is now also too small to provide any real protection.



Figure 13 Version 3 of design development

Version 3 sees a drastic redesign due to design and manufacturing requirements. The concave panel is kept only to the rear panel, with the sides of the charger remaining as flat pieces. The reason for this change is the design was required to look sleek and light, but in the previous version, the concave gave the charger a strange front view, due to the side panels also being cut-out for the concave. The top and bottom parts in Version 3 are slightly wider than the main body. This gives the narrow light fixture at the top, an overhang to project its light downwards towards the charger's main body showering the

charger in light leading to a larger street presence. The internal handles have also had a redesign, having them extrude slightly around the rim of the handle providing opportunity to fix them onto the main body. These changes allow the design to be manufactured easier than previous versions, due to the 4 separate parts created, while also still improving the aesthetics of the design.

Materials and manufacturing

When creating a design ethos for this project and looking at the clients' requirements sustainability is at the forefront. A sustainable design was paramount to the success of the charger, as aforementioned, the need for an eco-friendly form of transport is vital to reduce global carbon footprint. Plastics were targeted for their lightness, as any other material was deemed too heavy as the design was required to be moved with ease from car to pavement and back, possibly several times a day. Additionally, the design needs to be weather resistant as the charger will be used outside and needs to be long-lasting in changing weather conditions. Likewise, it must be durable and impact resistant to withstand accidents such as being hit by pedestrians or during manoeuvring, plus resist electrical fault risk, which must be observed with caution.

Encompassing these requirements, three material options were considered. The first option was ABS plastic, which with its high impact strength it is an ideal choice for the charger. ABS is highly suitable due to its robustness, while also being easy to manipulate into shape. From a sustainability perspective, ABS can be recycled with ease up to two times, without any loss to durability (Vihaan, 2022). Despite this, the disadvantage of ABS is its low melting point of $\approx 105^{\circ}\text{C}$ (Rogers, 2015), which could cause problems if the electronics inside the charger aren't cooled adequately. This could cause serious problems if a fire were to result inside the charger as the smoke generation from ABS is very high. The low UV resistance of ABS (adresco plastics, n.d.) could also cause problems to both the structure and aesthetics of the design as it could cause weakness and discolouration in the plastic.

The second option on material was polycarbonate. Polycarbonate is a strong, stiff material which is very easy to machine (Thomas, n.d.). The plastic also has good impact resistance, good electrical insulation, good UV resistance and its chemical and moisture resistance (Sabana Ara Begum, 2020). The lightweight nature of this material, alongside the ability to recycle this material completely, several times, without losing any structural properties, makes it an ideal candidate for the design. However, material is prone to scratching, which could result in damage to the charger and reduce aesthetic appeal.

The third option was Acrylic. This lightweight material has good UV resistance while also being very easy to manufacture. Acrylic is a strong and durable material with good weathering properties, making it a good option for outdoor products. The plastic is very versatile, being used for several items and has great re-useability, meaning it can be made into other objects easily. On the other hand, it cannot withstand high temperatures, much like ABS, which aforementioned performs poorly in high temperature environments. Furthermore, acrylic is not a sustainable material. The production of acrylic sheets can

release highly toxic fumes into the atmosphere, and it is not easy to recycle, with specialist handling and equipment required to recycle the material (Proctor, 2017).

The manufacturing of these materials is also an important concern in both designing and producing the product. The design must consider manufacturability allowing the product to be created in a sustainable and realistic way. Three manufacturing methods were considered: Plastic Injection moulding, CNC milling and thermoforming.

Plastic injection moulding was the first option considered, as it is the most common technique for the mass production of products (Hubs, n.d.). It is achieved by pouring molten beads of plastic through a screw, which pushes the plastic into a mould, which is then left to cool until the plastic becomes hard (Hubs, n.d.). Using a singular mould, the repeatability to create identical items can be done with ease, and if produced in large numbers the cost per unit can be very low. The main issue with this manufacturing method is the set-up cost can be a large sum. The moulds used in injection moulding can range from £2,500 to £4,250 for a cheaper aluminium mould, which last for approximately 5,000 to 10,000 cycles. Alternatively, manufacturers can invest in tool steel moulds that can withstand millions of cycles but can cost over £85,000 for one mould (Hubs, n.d.). The wall thicknesses need to be uniform and thin throughout the design to ensure even cooling.

CNC milling is a manufacturing process that involves a CNC router cutting away pieces of material using a computer controlled drilling head (The Federal Group USA, 2021). This means that the repeatability and accuracy is extremely high as the computer is running the same path every time. It is an incredibly refined manufacturing process delivering high precision cutting leading to very smooth surfaces, reducing the need for finishing processes. Like plastic injection moulding, CNC has a high set-up cost for the machine and the skilled workforce required to run the machines and produce an accurate CAD file for the machine to use.

All previous material options are thermo-plastics and the benefit of choosing a thermo-plastic to create the charger is that thermoforming is an easy process to use to bend pieces of plastic into shape. The lower melting points combined with the ability thermoplastics have to be heated and reheated make thermoforming a great choice of manufacturing. Therefore, the final manufacturing process that was considered is plug-assisted thermoforming. Plug-assisted thermoforming is the process of heating a sheet of plastic till the plastic is soft and malleable. At that point, it is inserted over a mould, where a plug is then used to sandwich the plastic into the mould. The plastic then takes the moulds shape after cooling. The advantage of this method is that the repeatability is

good as the same mould is being used continuously. The disadvantages, like the other options, is the set up cost to create a mould.

Final Design Stages

After analysing all previous steps and options, the final model was ready to be created with all the knowledge gathered helping to finalise the charger's design.

The final version is akin to Version 3. The overall shape has been kept, with the top and bottom acting as the main fixing areas and the piece is kept as one part, with the concave section sliding into the back of the front piece. The design has followed the ethos that was created in the initial stages of production. There is a sleek and light design throughout, with user interaction elements at the heart of the process.



Figure 14 Final version of the design

As seen in Figure 14, only a few slight changes have been made from the previous version 3, one change is the height of the cooling vents on the side of the charger body. The original designs (see figures 11 and 12) had cooling vents on the charger body, due to the requirement from the clients and from a design perspective to aid the cooling of the internal electronics inside the charger. In version 1 and 2 of the CAD models, the vents were placed low down on the charger, so the vents were closer to the electronics. However, it was revealed that this placement could lead to a blockage from leaves or rubbish on the pavement. Furthermore, in wet conditions water may be able to enter the charger. Therefore, for the final design these vents have been lifted up the sides of the main body to counteract these issues. A further change to the final version was to dull the white colour of the body to a light grey. This was done to maintain the contrast between a bright object against a darker pavement and also match the duller tones of the city. This means the design remains noticeable without causing an eye sore.



Figure 15 Rear view of the final design

As seen from the rear, the concave has been kept with slight changes to the curvature to not interfere with the internal structure or the side handles.

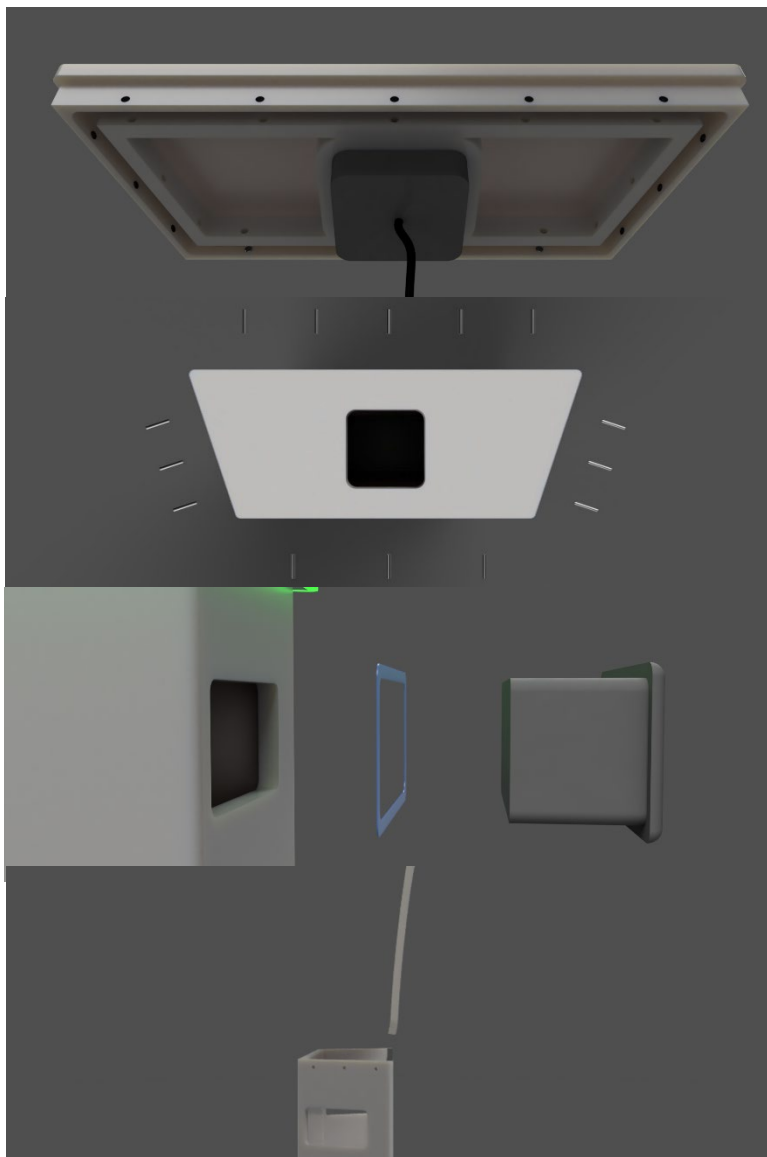


Figure 16a, 16b, 16c and 16d Renders showing fixture placements and fixings

As seen in Figure 16 the materials and manufacturing research has been used to create an easily manufactured design that uses the correct materials throughout, for both properties and manufacturing abilities. As shown in figure 16d, the rear of the design, (which is a polycarbonate sheet that has been thermoformed to give it its curve), slides down the trench in the front piece, (which is also a polycarbonate sheet that has been CNC milled to cut out the slots for the handles, vents, and fixture points). Now the 2 main body pieces are connected it is time to attach the top and bottom pieces of the charger. These are both made out of thick polycarbonate blocks milled down on a CNC machine to create the trenches seen in figure 16a. Once placed on the top and bottom, 14 x 25cm M5 bolts are placed in to secure all pieces together. All other fixings are then added, including 2 x 10cm M5 bolts to secure the charging point in place, in addition to epoxy resin being used to secure the internal electronics storage area in place. Epoxy is also used to secure the injection moulded ABS handles into the holes on the side of the charger (see figure 16c).

Conclusion

The final design shown can be considered a successful outcome of the project. As stated in the introduction, the need for EVs and the associated infrastructure, is needed now more than ever. With this type of charger, the emissions created by the transport sector will drastically reduce, benefiting the environment. The charger is suitable for all types of landscapes, as mentioned earlier with the difference in infrastructure between London and Wales. This could therefore facilitate thousands of new electric vehicle drivers with limited changes to existing infrastructure.

From a design perspective, the charger has achieved the design ethos required, by being design light, with the light colours used for the body. Additionally, the concaved back reduces the visual size and internal handles are hidden inside the charger. The charger is user-friendly with handles giving movement in all directions, a small size for easier storage, a high charging point on top of the charger and a simple lighting fixture around the rim of the charger, providing easy understanding of the charging status of the vehicle. Aesthetically, the charger has remained a large presence on the pavement with the light grey colour contrasting the pavement and road, and the light fixture providing 360° light, giving presence on the pavement, as well as off the road. The materials used are sustainable due to the recyclability of the materials, which may lead to future chargers being produced through recycling previous chargers.

Companies such as Bass Energy should be pushing forward with their plans to mass produce charging solutions imminently, and the final design can hopefully become a step in that process.

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