Guidelines to optimise the **Ebike charging experience**

Master Thesis

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ABSTRACT

With the rapid growth of the Electric bicycle (Ebike) market, traditional bicycles are gradually being superseded. Originally designed to cater for less-abled individuals and the older population, Ebikes are now widely adopted by users of all ages due to their many advantages including: increased comfort, power, speed, and convenience. However, despite recent developments in battery technology and overall Ebike design, the charging system has often been overlooked resulting in a process which is often perceived as a burden.

Recognizing the need for improvement in this area, Giant, a leading manufacturer of Ebikes, aims to enhance the charging system and its integration with their products. By focusing on improving the user experience, Giant seeks to maintain its competitive advantage and provide a more enjoyable, intuitive, and friendly riding experience for its consumers.

This research aimed to understand how to design a product offering an improved user experience (UX). Typically, the success of products is evaluated through user testing after a physical prototype has been produced as within literature there is a lack of tools to predict and optimise UX during the early stages of design.

This research proposed developing current technology through the study of user experience and user behaviour to generate initial guidelines. The guidelines were then further developed through research which gathered inspiration from different markets. With further refined guidelines, a new predictive design approach to quantify and compare UX components was proposed and used.

By focusing on quantifying the physical and mental workloads different ideated procedures could be compared and the best one selected to achieve optimal UX. Finally based on the optimised ideated concept a redesign of an Electric bicycle (Ebike) charging system was undertaken and assessed to determine whether there had been a significant improvement in the UX. This was evaluated using different measurable components of UX; Usability Metric for UX (UMUX) and emo-cards.

The newly designed Ebike charging system created as part of this research demonstrated a significant improvement to the overall UX with a much smaller variance. With this approach, final guidelines and recommendations were proposed for Giant to implement a charging system which transforms the way chargers are perceived and used.

GIANT GROUP

LIST OF ABBREVIATIONS

APP	Application
BMS	Battery Management System
BLE	Bluetooth Low Energy
BP	Bottom Pivot
BS	Bottom Slide
CAD	Computer Aided Design
CC	Constant Current
CLT	Cognitive Load Theory
CPT	Capacitive power transfer
CV	Constant Voltage
DOD	Depth of Discharge
DS	Docking station
DT-B	Down Tube-Base
DT-M	Down Tube-Medium
DT-T	Down Tube-Top
EV	Electric Vehicle
Ebike	Electric Bicycle
GUI	Graphical User Interface
I	Integrated
IPT	Inductive Power Transfer
K	Coupling Coefficient
LCD	Liquid Crystal Display
LED	Light Emitting Diode
M	Mutual Inductance
MWV	Mental Workload Value
PWV	Physical Workload Value
SEI	Solid Electrolyte Interphase
SOC	State of charge
SR	Side Release
ST	Side Tube
TP	Top Pivot
TR	Top Release
TT	Top Tube
UMUX	Usability Metric for User Experience
UX	User Experience
WPT	Wireless power transfer

CONTENTS

0.0 INTRODUCTION

0.1 Giant Bicycles

Giant Bicycles is the largest bicycle manufacturer in the world, producing and selling 4.4 million bicycles in 2020 of which 300,000 were Electric bikes (Ebikes) [1]. The Taiwanese multinational company is globally integrated within the market with 8 major factories distributed in Taiwan, China, Hungary, and The Netherlands [2]. The scale of the company comes from its success within the bike industry over the last 50 years [2]. During this time Giant has a history for revolutionizing the bicycle industry with their high-volume production of Carbon frame bikes in 1987 [1] and the introduction of the multiple ground breaking technologies such Total Compact Road (TCR) in 1997, Maestro suspension and more recently their Sync Drive motor. The multinational company is segmented all over the world with 38 different affiliated companies allowing Giant to design and develop some of the best cycling products in the world and deliver them to the market in vast quantities. With over 30 different models of Ebike [2], in 2021 Giant made $2.1 billion in revenue [2]. Ebikes making $870 million, an increase of 114% from 2019, highlights the rapid expansion the scalability of the market [2].

0.2 Research Context

Ebikes are a fast-growing segment in the bicycle market and are gradually superseding the traditional bicycle. Originally Ebikes were designed to make cycling accessible for less-abled people or for the older population, however Ebikes are becoming widely adopted by different users of all ages [3]. This is due to the Ebikes advantages including increased comfort, power, speed and convenience [4]; all of which can improve the riding experience which is why the market has, and will, continue to expand [5]. The design of better-looking Ebikes with greater autonomy, higher performance, and more convenience has benefited from recent developments including thinner batteries with in-creasing capacity, system integration and better user interfaces [6]. Improving the overall quality of Ebike design has largely focussed on developing the battery performance resulting in the overall system integration and user experience to lag. One unavoidable required activity, which is still commonly overlooked, is the charging process. This returning procedure is rarely considered a pleasant experience but most frequently as a burden.

Giant has acknowledged the opportunity for improvement of the charging experience. Giant's Ebike technology is not owned or controlled by third parties such as Bosch or Fazua this allows for a more seamless development process. By improving the charging system and integration with the Ebike Giant will be able to maintain their competitive advantage and result in Giant's consumers' experience to be more enjoyable, more intuitive and more friendly, improving the overall riding experience.

0.3 Thesis Focus

Looking back over the last two decades, since the first major introduction of the battery powered products, such as the cell phone, there have been few advances in the design of the battery charger . As battery technology and products have been developed, the charger has not seen significant development. Charging systems have never been a corporate priority in all industries and appear somewhat of an afterthought. Society has accepted chargers and the burdens associated with them, like accepting the "sticker on an apple".

To reduce the burden of charging the user experience must be improved and the charging system redesigned. However, user experience is primarily used as a reflective tool to monitor the success of a product through user testing, KPI's or Usability metrics [7, 8]. All of which involve a product, application (app) or prototype to evaluate an experience as/after it happens, or to predict user experience of web-based applications [9]. There are currently no tools within literature that apply a methodology to anticipate the user experience of a product within the early stages of the design processes before a physical prototype or concept is produced. This research aims to address this gap in research by using Ebike chargers as a case study to develop:

"Guidelines to optimise the Ebike charging experience"

By generating guidelines, a new predictive design approach has been developed that is able to quantify and compare components of user experience to select the concept that will result in improved user experience. The aim of the thesis can be broken up into four points:

1. Gain insight in the current technology, understanding user experience and user behaviour to generate initial guidelines.
2. Further research into the guidelines and how they can be quantified into measurable requirements.
3. Develop and propose a redesign of the charging system, based on the generated guidelines and the components of user experience.
4. Deliver a refined set of guidelines and recommendations that Giant can use as a basis for future projects.

0.4 Thesis Outline

To fulfil the aims of the project and answer the main research question the thesis was broken up into 6 Phases: Gaining Insight, Further Research, Ideation, Development, Final Design and Reflection.

Phase 1: Gaining Insight

To answer the fulfil the research goal, it must first be translated into a question:

"What Guidelines are necessary to optimise the Ebike charging experience?"

This question is the backbone of the thesis and was explored during this phase. To help support this question an understanding into the current technologies, user experience and user behaviour was conducted to help provide a foundation of knowledge and generate preliminary guidelines. The following three categories formulate the basis of the initial research.

Q1: Current technologies:
- What is Giant's current Ebike product portfolio?
- Who are Giant's main competitors?
- What is the distinction between different types of Ebikes?
- What are the relevant components?
- How do these components compare with Giant's Competitors?

Q2: User Experience:
- What is an experience?
- How can an experience be measured and quantified?
- How can an experience be tested?
- What is the user's current user experience of Giant's charging systems?
- What design elements need focusing on to improve the user experience?

Q3: User Behaviour:
- How are the current systems being used?
- What problems do users encounter?
- What context are these systems being used in?
- How are users charging their Ebikes?
- What is their experience with charging systems?

Based on these sub questions a holistic overview of Giant's products, the current Ebike market and user experience was obtained. This allowed preliminary guidelines to be generated.

Phase 2: Further Research

The further research phase took these preliminary guidelines and explored other technologies that can act as a source of inspiration to understand how these guidelines were met in the final design. In this phase the development of the Mental Workload Values (MWV) and Physical Workload Values (PWV) were generated to provide a means of comparing ideations and selecting the best concept so that they would fulfil the guidelines.

Phase 3: Ideation & Concept Creation

The Ideation and Concept Creation phase involved using the physical and mental workload values to optimise the system for achieving a significantly improved user experience. Based on the optimum system selected, different ideas were created to fulfil that system and further iterations were made whilst using the physical and mental workload values as a reference. Three different concepts were created and compared, and a selection process was conducted.

Phase 4: Development

The chosen concept was developed with academic underpinning to ensure that an improvement in the user experience could be fulfilled. During the development, prototypes were produced to receive feedback from Giant's Ebike Development Department together with tests on, and discussion with, users to further develop the design before the final design was proposed.

Phase 5: Final Design

The final design depicts renders of the final design to highlight the benefits of the new charging system and portray the design in marketable way so the added value of the redesign can be interpreted by Giant's Taiwanese Headquarters.

Phase 6: Evaluation

The reflection phase involved conducting user testing with the protypes of the final design to see whether there was a significant improvement in the user experience. These results then acted as a bases to finalise the guidelines, provide recommendations and reflect on the overall thesis.

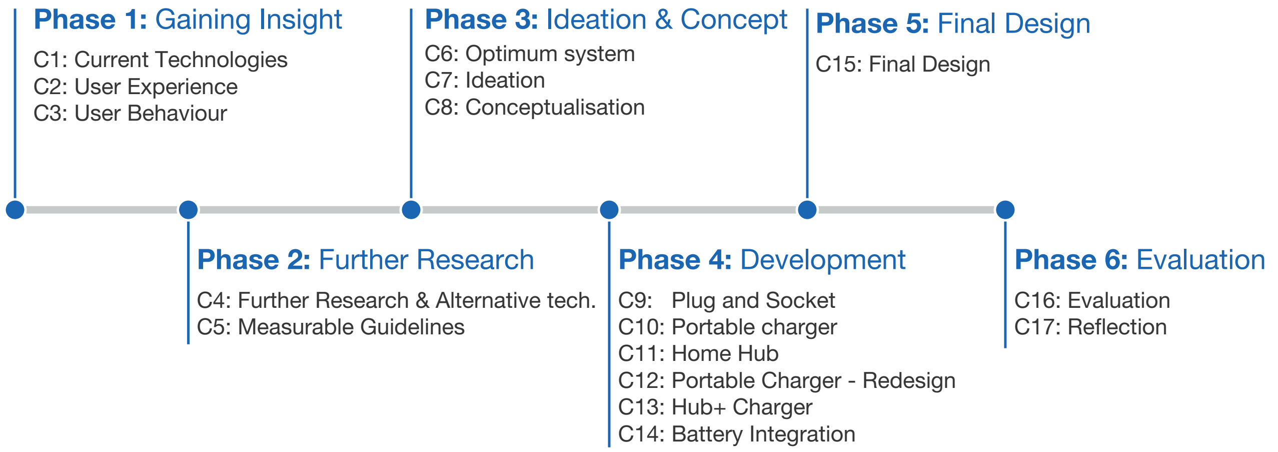


Figure 1: Timeline of the different phases within the project

PHASE 1

GAINING INSIGHT

C1: CURRENT TECHNOLOGIES

To provide a foundation for the thesis this chapter explores the current technologies of Ebikes: both Giant's Ebikes and their competitors. The chapter will highlight the different components within the charging system and what role they play; along with analysing the competitor charging systems to see where Giant sits within the market.

1.1 Giant Group

The Giant Group is built up of three brands: Giant Bicycles, Liv and Momentum. Giant bicycles were the original brand of bicycles established in 1972. In 2008, Liv bicycles, the sister brand of Giant was created with its sole purpose to focus on supplying bikes that are tailored for the female market [10]. The most recent company to be created by Giant is Momentum. Momentum was launched in 2015, it focuses on urban and commuter bikes, with the goal to generate "a whole new experience in urban mobility" and help people get across the city in style and comfort [11].

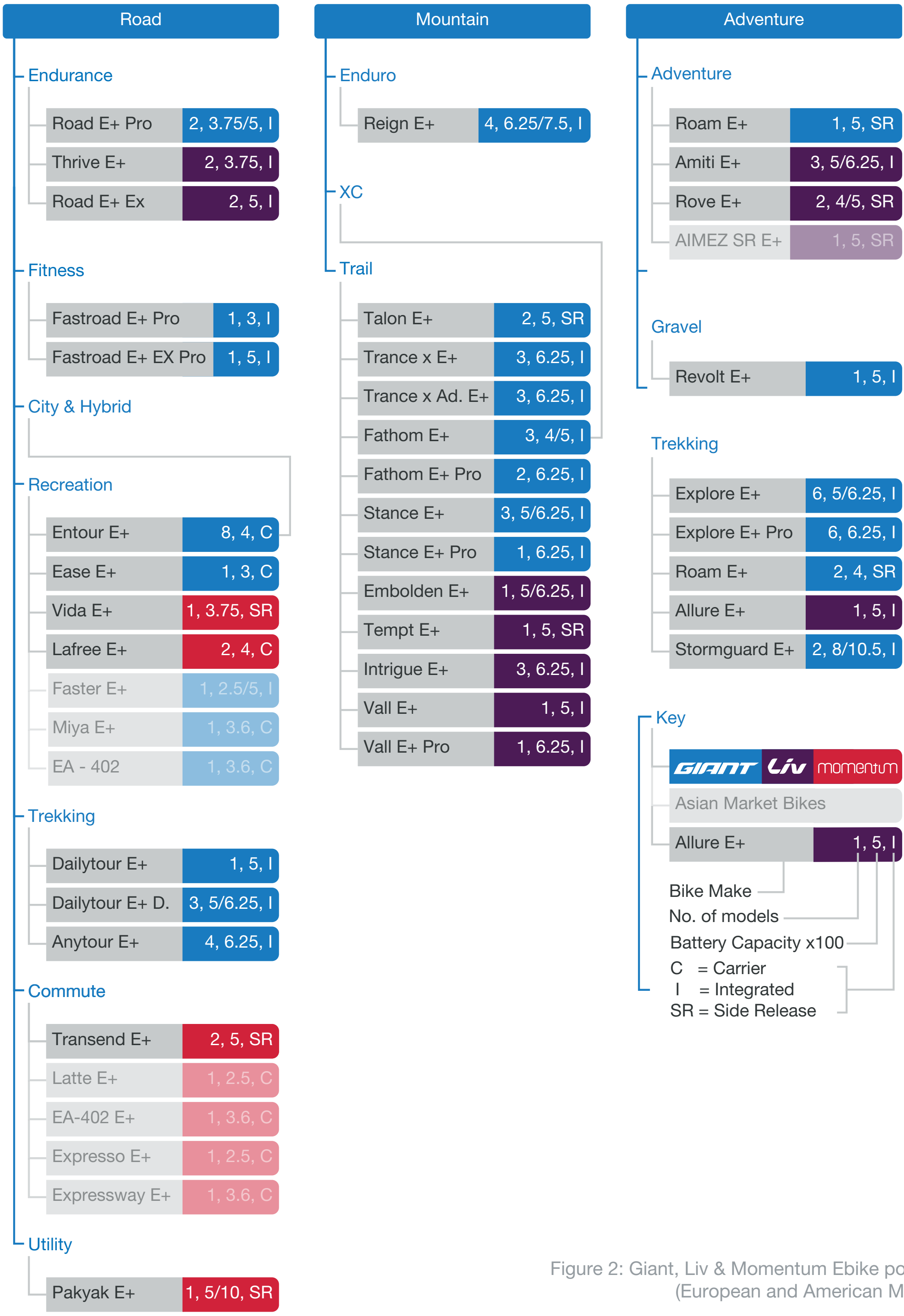


Figure 2: Giant, Liv & Momentum Ebike portfolio Dec 2022 (European and American Market) [1, 10, 11]

Giant has a wide range of Ebikes suited to every type of cycling. Their bikes can be categorised into three major groups: Road, Mountain, and Adventure. Figure 2 highlights Giant's product portfolio focusing on the European and American market. This categorisation between the bikes is important because it highlights the distinction between the different contexts Giant anticipate their Ebikes to be used.

Along with the portfolio of bikes mentioned, Giant also produced other variations of bike for the Asian market, these additional bikes are also depicted in the figure 2, the main difference of these bikes is that they are smaller, more compact, with smaller sized batteries and 24-inch wheels. 1.1.2 Competition

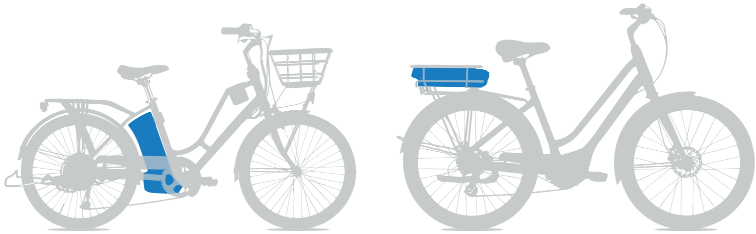


Figure 3: Latte E+ (Taiwan) with a 365Wh EP Vs Lafree E+ (American) with a 400Wh EP [11]

Giant has 5 major competitors: Trek, Specialized, Canyon, Cannondale and Merida bikes. Compared to these companies' Giant's bikes are generally more affordable, without compromise to the performance and quality. Since Giant design and manufacture all their frames as well as a large proportion of the components they do not need to outsource manufacturing, helping keep the bike cost lower. Being a multinational Company, the way Giant is perceived and its brand positioning varies depending on where you are in the world therefore a direct comparison of Giant brand position is of little value and out of scope for this project. However that said, Giant's competitors and other bike brand products will be discussed and compared to Giant's technology.

Looking at Giant's company values is important to ensure that the project and product designed aligns with them. Their values are based on 5 aspects [1]:

Celebrate the journey:	Giant believes in enjoying the moment, and that the ride matters as much as the destination
Push the boundaries:	Giant are constantly innovating. They create products to help riders reach new levels of performance and fun.
Expand the Experience:	Giant encourage people to seek fresh perspectives and new experiences through cycling.
Keep it Real:	Giant believe in being as honest and uncomplicated as the idea of cycling itself.
Respect the Planet:	Giant are committed to reducing our impact and promoting cycling as a responsible activity.

Figure 4: Example of Giant's Recreation E bikes [1]

1.2 Legislation

To understand further how Ebikes are different compared to other Electric vehicles (EVs) the legislation within Ebikes is discussed. While there is not a distinct legislation on the charging system of Ebikes the motor power and level of assistance is regulated.

EU directive 2002/24/EC and the assessment standard CEN/ISO EN15194:2009: In Europe, Ebikes/ Classic Pedelecs/ EPACs, (Electrically Power Assisted Cycles) are exempt from motor vehicle-type approval, provided the bike has a maximum continuous rated power of no more than 250 W. This power must be progressively reduced and cut off as the vehicle reaches 25 km/h (16 mph) or if the cyclist stops pedalling. In Europe a throttle is allowed on EU market Ebikes if they only provide “start-up” assistance and cut out at 6 km/h [12].

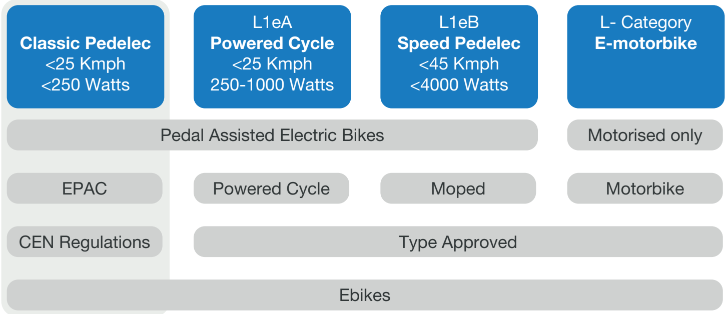


Figure 5: Distinction between the Ebike categories [13]

Currently within Europe Giant focuses only on the first types of Ebikes, of the classic Pedelecs. However, in the future there is opportunity for them to expand into the Speed Pedelec market to help users travel further distances on longer commutes to work.

1.3 Giant’s Components

Focusing on the charging system, there are five main interfaces which contribute to the charging system these include:

1. Mains power to Charger
2. Charger to the Bike
3. Charger to the Battery
4. Bike to the Battery
5. Bike with the phone application

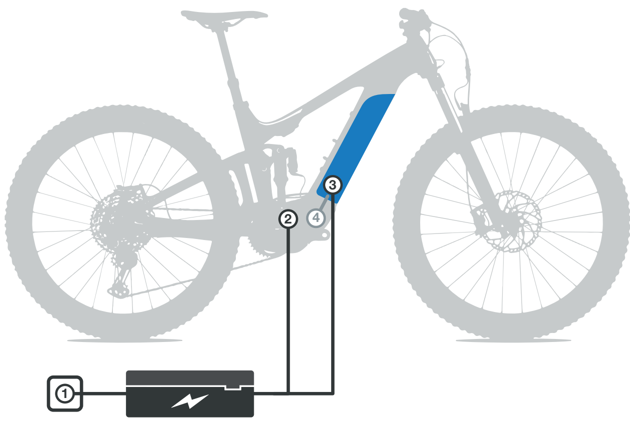


Figure 6: Overview of four of the interfaces on the Ebike

These interfaces lead to three primary Components as well as an app which assists this technology. These components will be explored in more detail:

Charger: Provides means to connect the Ebike battery to the mains and charge the battery either by plugging into the Ebike directly (which charges the battery) or removing the battery and charging the battery directly.

Battery: This stores the energy and provides power to the motor, and other electronic features of the bike such as the display and/or braking system, suspension and lights depending on the model.

Frame: This is the backbone of the system and houses the electronic components. The frame and its geometry have the greatest impact on the riding style and the experience. The focus will be how the bike frame integrates with the battery and charger to improve the experience.

App: The app communicates with the Ebike and allows the user to customise their level of assistance, plan routes and monitor their ride.

1.3.1 The Charger

Types: Giant has three charger types: a smart charger (6 amp(A)), a smart-fast charger (4A) and a fast charger (4A) which is does not contain the “smart” functionality. The 4A charger is more compact and designed to be taken on the move.

Smart Charger:

The Smart Charger works with Giant is most recent systems and is the quickest method to recharge the EnergyPak (625KWh battery). The 6A and 4A chargers are ‘Smart’ because they can increase the longevity of the battery, by utilizing a lower voltage when the EnergyPak is charged more than 500 times [1]. This ensures that the battery is charged in a way which puts less strain on the cells, increasing its longevity. The Smart Charger can also be set on ‘storage mode’ so that the battery is only charged to 60% for storage [14]. This helps reduce the strain on the battery cells as well.

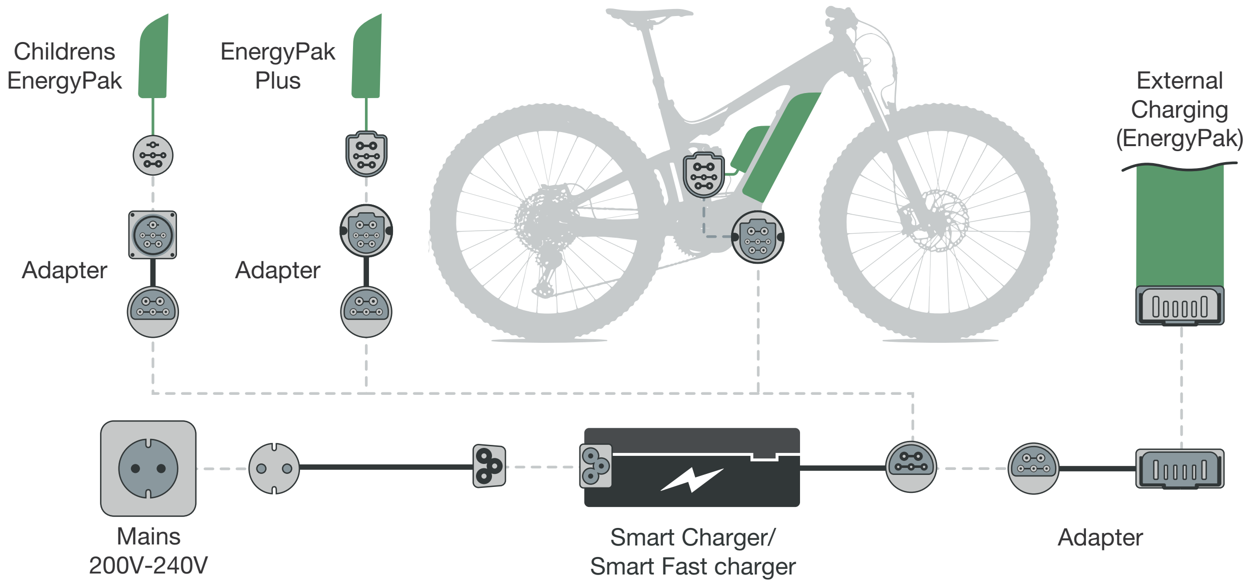


Figure 7: Charging cable interfaces for the smart charger

The smart charging ecosystem currently consists of 6 different plug types:

- The standard mains EU plug to connect to the mains
- IEC 60320 to connect smart charger to mains cable (swappable depending on region which the charger is distributed.
- 5-pin plug which can be connected to the adaptors or directly into the 7-pin plug on the bike
- 7-Pin plug on the bike, suitable for the Energypak plus.
- 6-Pin suitable for using the Energypak plus as the primary motor for children’s Ebike.
- 6-Pin slots for the external charging of the battery.

This variety of pin types has ment multiple adaptors are necessary to deal with the different configurations. The typical consumer will likely only own one or two Ebikes, therefore this ‘adaptor problem’ would be less obvious to them. However, the unstandardised system means Giant must produce multiple adaptors which would be unnecessary if the same plug was used.

Feedback:

When the user is charging the battery, a button is provided (B) allows the user to switch between regular charge mode and storage mode with a feedback LED (A) that informs the user what the status of the charger/battery is in.

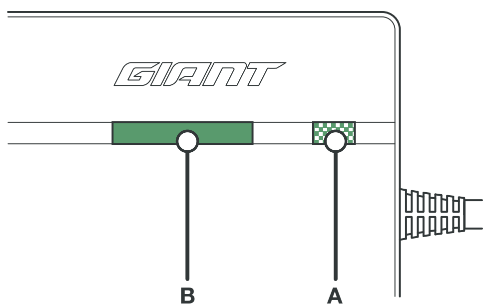


Figure 8: Charging cable interfaces for the smart charger [14]

Based on the user manual the colours and their meaning are described. With 9 different potential configurations of the light, there is likely to be a steep learning curve to fully understand what each LED behaviour means [14].

Mode	LED/Button	Colour	Behaviour	Status
All Modes	A	Red – Green	Sequence	Power on self-test (boot)
	A	Red	On	No battery connected
	A	Red	blink (0.5~1.5 sec. pattern)	Charging issue
Regular mode (charge 100%)	A	Green	Blink (0.5 sec. interval)	Charging active
	A	Green	Blink (1 sec. interval)	Battery temp. Time-out
	A	Green	on	Charging completed
Storage mode (charge 60%)	B	-	-	Activate storage charge (60%) mode
	A	Yellow	Blink (0.5 sec. interval)	Charging active
	A	Yellow	Blink (1 sec. interval)	Battery temp. Time-out
	A	Yellow	on	Charging completed

Figure 9: Comparison of Giant's current chargers [1]

Fast Charger:

The Fast Charger is a smaller, more compact charger with a current of 4 Amps. It is used on the lower cost bikes since the battery capacities are usually lower and it does not contain the smart system (exception of the smart fast charger). Due to its smaller amperage, it is easy to carry, and transport.

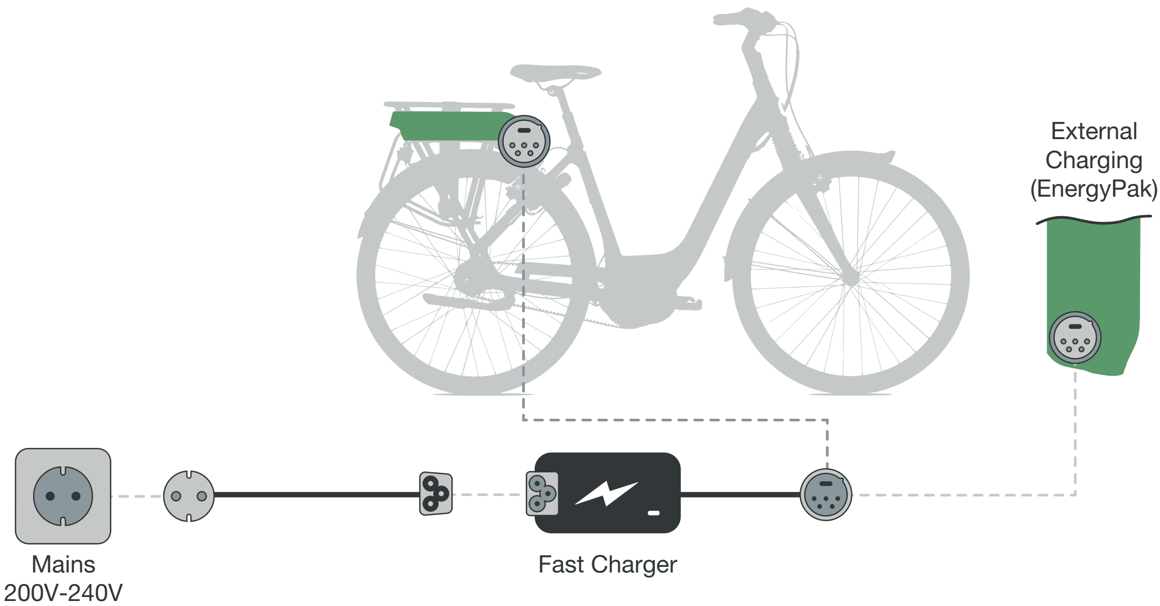


Figure 10: Charging cable interfaces for the fast charger

The Fast Charger is used for non-integrated batteries because of this the need for various pin configurations is not necessary leading to just two configurations: the standard mains EU plug and a 5-pin plug. This means that there is no need for additional conversion adaptors. However, this 5-pin plug contains a different geometry to that of the 5-pin plug on the Smart Chargers, so if this Fast charger is to be used with batteries designed for the Smart Chargers an adaptor is necessary and vice versa.

It is also important to note that the 5-pin plug has replaced the 3-pin plug (different from the 5-pin plug used in the Smart Chargers). This 5-pin plug was introduced for Ebike, from 2013 onwards using the Fast Charger system, since it allows data communication between the charger and the battery.

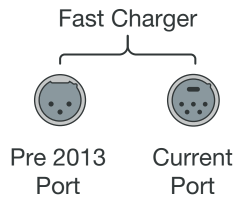


Figure 11: Change in port pin number for the fast charger

Feedback:

The charging feedback for the Fast Charger is less complex since it does not contain smart features. It only contains one LED for feedback of the charger/battery status [14].

LED Colour	Behaviour	Status
Red	On	Charging active
Red	Blink	Charging issue
Green	On	No battery/battery full

Figure 12: Charger status [14]

Comparison between Giant's current chargers:

		Smart (6amp)	Smart (4amp)	Fast
Input	Volts	200-240	200-240	200-240
Output	Amp	6	4	4
	Volts	36	36	36
	Pins	5	5	5
Weight	-	1.4 Kg	0.8 Kg	0.74Kg
Cost	-	199€	199€	100€

Figure 13: Comparison between Giant's Chargers [1]

1.3.2 The Battery

The battery, referred to as the EnergyPak, provides power to the Ebike motor, and comes in a range of capacities. Currently Giant has 4 main types of battery systems [1].

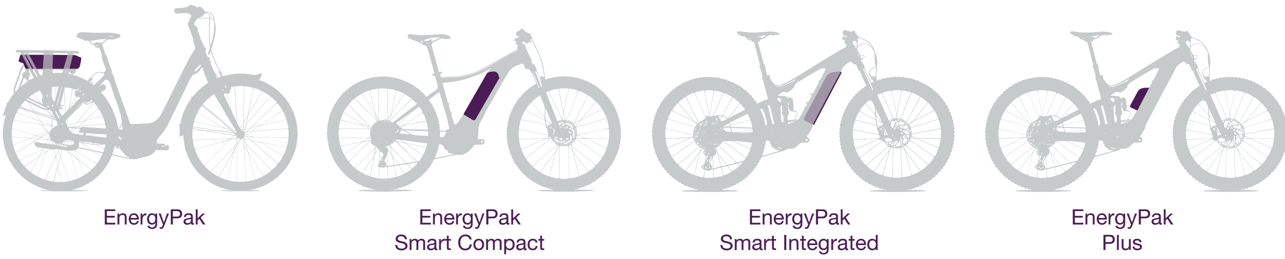


Figure 14: Different Battery systems [1]

EnergyPak (Carrier): 300Wh/400Wh/500Wh these batteries are externally mounted to the frame either on the carrier (C) above the rear wheel or on the down tube where it is side released (SR) or top released (TR) [1]. These batteries are present on the economy Ebikes. These batteries are only charged using the Fast 4 amp charger.

EnergyPak Smart compact: Comes in 375Wh as standard or can be upgraded to 500Wh. The battery has better integration with the bike frame and is more embedded within the downtube. This battery system is present on medium price range Ebikes and is commonly referred to as a side release (SR) battery because it is released from one side of the frame. These batteries are charged using the Smart 4A or 6A charger.

EnergyPak Smart integrated: This battery is fully integrated (I) within the downtube and is either removed from the underside or permanently em-bedded within the frame and can only be removed by a certified mechanic. It is available in four different capacities: 400Wh, 500Wh, 625Wh and 750Wh [1]. This battery system is present on medium price range Ebikes. These batteries are charged using the Smart 4A or 6A charger.

EnergyPak Plus: This is a range extender battery with a total capacity of 250Wh [1]. It can be attached to the top side of the down-tube for certain models. When the main battery loses power, the smart technology automatically switches to the additional patch. These batteries are charged using the Smart 4A or 6A charger.

The battery specifications listed below are batteries which are currently available for purchase from Giant's website or are incorporated on bikes manufactured from 2017 onwards [1].

EnergyPak Type		Carrier			Smart Compact		Smart Integrated					Plus
Capacity (Wh)	-	300	400	500	375	500	250	400	500	625	750-800	250
Weight	-	3.1kg			3.1kg		4.2 Kg				4.4kg	1.8Kg
Dimension	(L X W X H) mm	345 x 117 x 88	345 x 117 x 88 or 360 x 85.5 x 85		435 x 77.5 x 67			378.5 x 83 x 85	435 x 77.5 x 67		440 x 85 x 78	56 x 99.9 x 87.4
Cells		40 /18650			30/18650		40/ 18650	20 / 18650	40 / 18650		21700/ 22700	20 / 18650
Cost		399 €	549 €	699€	507 €	799 €			799 €	949 €	1099 €	449 €
Fast Charger (4 amp)	80%	1:45 h	2:00 h	2:45 h								
	100%	3:30 h	4:30 h	5:00 h								
Smart Charger (4 amp)	60%				1:20 h	2:00 h	1:20 h	1:50 h	2:00 h	2:30 h	2:50 h	1:20 h
	80%				1:50 h	2:50 h	2:00 h	2:30 h	2:50 h	3:30 h	3:50 h	2:00 h
	100%				3:40 h	5:10 h	3:30 h	3:55 h	5:10 h	5:50 h	6:40 h	3:30 h
Smart Charger (6 amp)	60%				1:05 h	1:30 h	1:20 h	1:20 h	1:30 h	1:50 h	2:30 h	1:20 h
	80%				1:35 h	2:10 h	2: 00 h	2:00 h	2:10 h	2:35 h	2:55 h	2:00 h
	100%				3:20 h	4:10 h	3:00 h	3:30 h	4:10 h	4:40 h	5:10 h	3:30 h

Figure 15: EnergyPak comparison, Data collected Nov [1, 14, 15]

For all Giant Ebike batteries, the connection with the bike is situated at the end of the battery via 6-pins at the bottom. This allows the battery to be slid into the frame at an angle and clipped in. For more detail on this movement refer to section 1.4

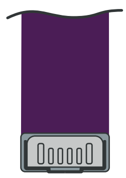


Figure 16: battery pin location

Feedback:

The current feedback the user receives for the battery is either through the app (which displays the battery percentage), through the LED on the user's cockpit or via LEDs on the bottom of the battery.

Figure 17: Giant's battery displays

1.3.3 The Frame

Looking at Giant's different bikes, depending on the battery integration within the frame, the insertion and removal process differs slightly, determined by whether the bike contains a battery that is either a carrier, side release, integrated battery with or without a top tube. All of Giants Ebikes come with a key to release the bike for additional security, or a torx release pin which has a more subtle appearance. Below shows the procedure and movement of the battery, depending on the Ebike battery type.

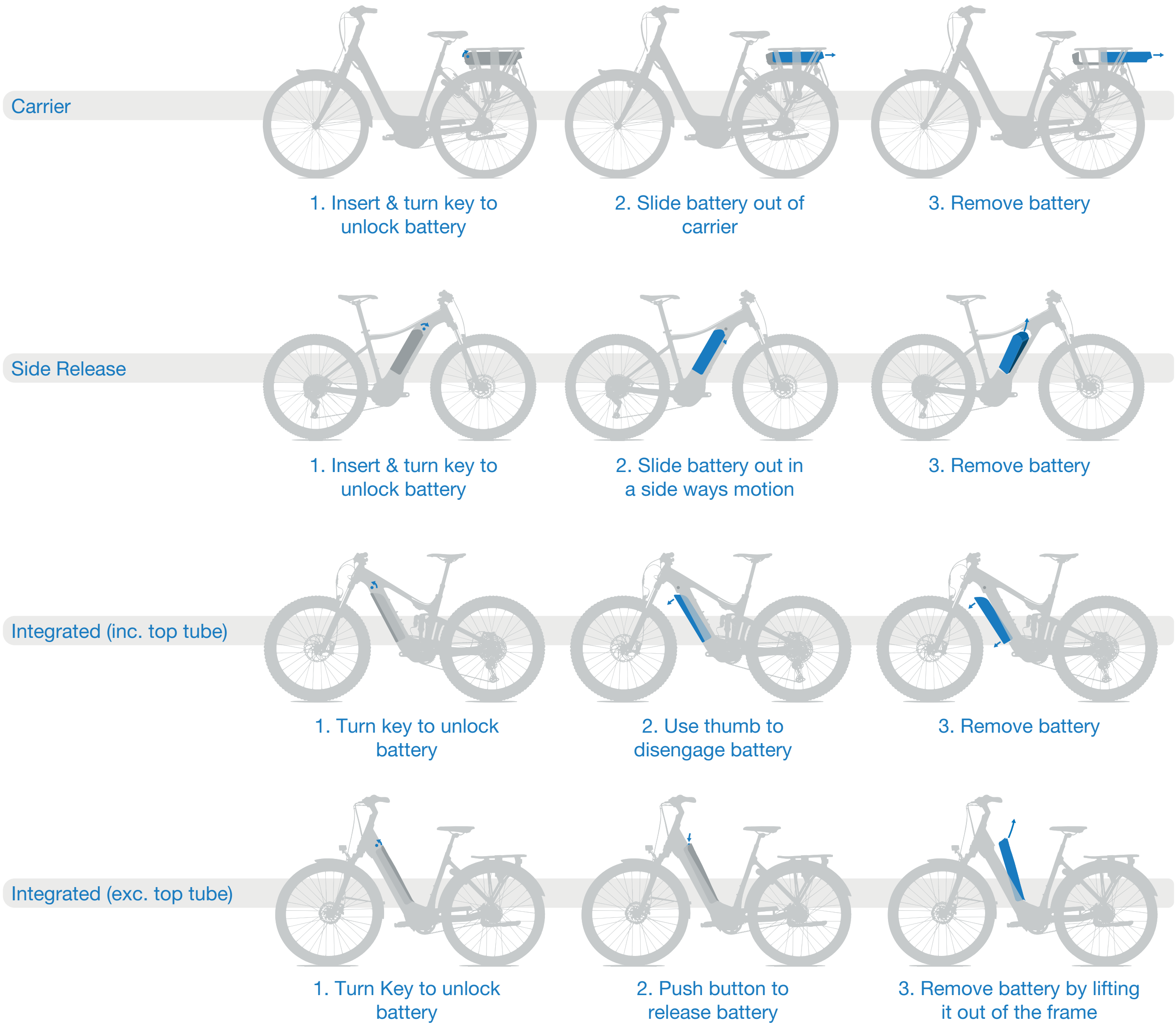


Figure 18: 4 battery removal processes in Giant's Portfolio

Displays:

There are several different cockpit display variations depending on the bike used. For example, the Ridecontrol Ergo 3 is used for mountain biking with the Ride Control Go has as little information as possible on the handle bar (just 3 buttons) and the LED information has a minimal display. Whereas the Ridedash EVO has an LCD display that is built into the stem of the bike [1, 14]. This is used for more relaxed leisure/commuting bikes and displays much more information, along with providing the opportunity for navigation information to be displayed.

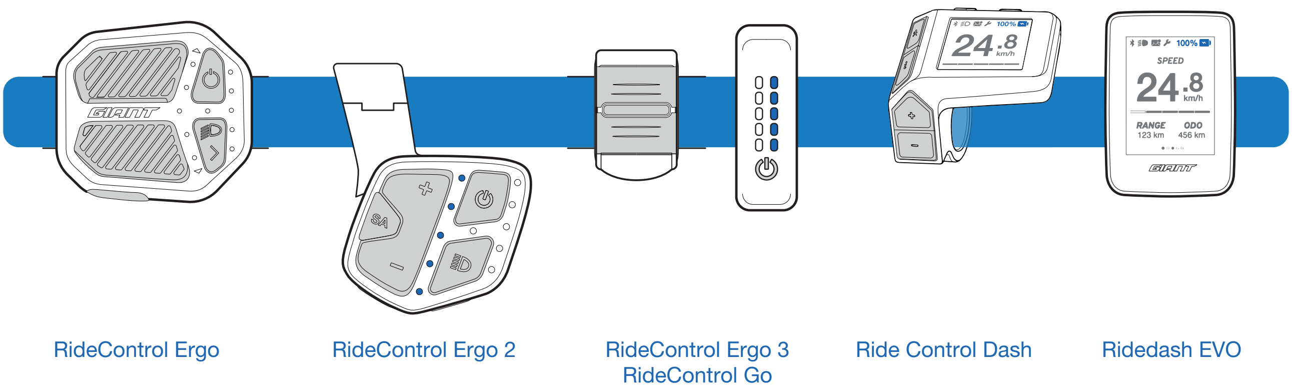


Figure 19: Display variations produced by Giant [14]

1.3.4 The RideControl App

Giant's RideControl App is a phone application that allows the user to connect their phone to their bike and fine tune the motor setting (level of assistance) to fit better to the user's riding style. Within the app the user can plan and record their ride and upload it to Strava. The app gathers all typical riding data such as distance travelled, elevation and average speed as well as the user's cadence and power. The navigation can also be used with the RideControl Evo display, where the user can synchronise their navigation to the display so their phone does not need to be quickly accessible [1]. From a charging point of view the app currently provides little feedback, only displaying the battery percentage and how much range is available, but only when the phone is connected, switched on and used as a dis-play during riding.

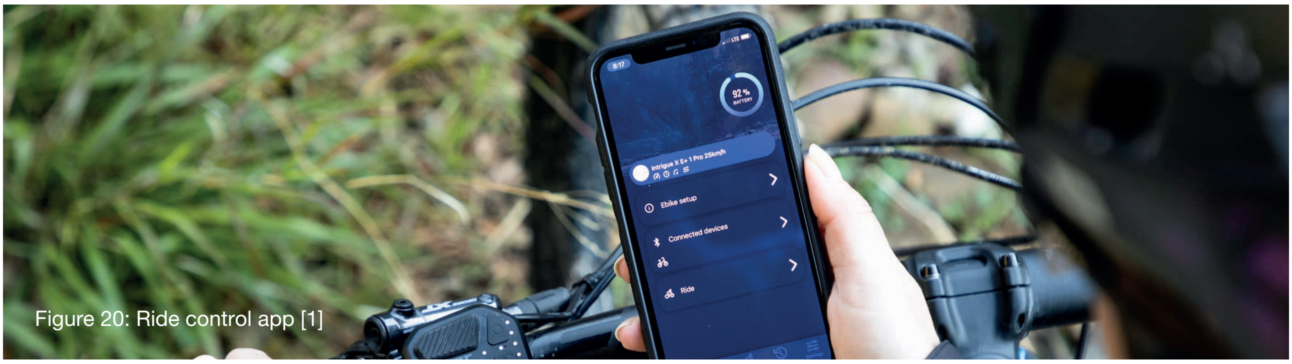


Figure 20: Ride control app [1]

1.4 Competitors' Components

As previously discussed, Giant has 5 main competitor companies. However, these companies are less relevant when looking at the charging system. Since the charging system is at a component level the brands which design, and manufacture are different companies. There are currently 7 major Ebike motor manufactures, this is Yamaha, Shimano, Specialized, Bosch, Fazua, Brose and TQ. Giant uses Yamaha's hardware but the software is fully con-trolled by Giant, which is why their motors are branded with Giant graphics [1].

The most popular Ebike system is Bosch, their system is used by over 90 brands, including Batavus, Trek and Haibike to name a few [16]. Giant's competitors like Trek and Cannondale do not produce Ebike systems so they select which Ebike system they will use. This allows them to focus solely on the bike itself, but means they are limited with the level of Ebike innovation, since this is determined by their partners. In this section the 7 motor manufacture systems will be explored and compared in the context of the Charger, battery, and app. To look at the frame integration, the major bike manufactures such as Trek and Specialized will be explored, since they control how the system is integrated within the frame.

1.4.1 Charger

Generally, the motor system used determines the batteries, charger and plug connections that are used. However, there are exceptions and companies can collaborate with the motor companies to create specific plug types and batteries etc. An example is Orbea who uses motors from both Shimano and Bosh but have their own charging system and adaptors. The performance of these chargers is comparable to their motor brands however the main difference is the connector types. With over 100 different Ebike brands currently on the market the categorisation of the different chargers and their adaptors is endless, the 7 motor brands have been compared in the table below.

Looking at the table (figure 21) there is a clear range of chargers, with the most popular size being either 2 or 4 amps. Few brands offer chargers that are 6 amps or more. The average price is around € 145 for a replacement charger. Depending on the level of complexity of the charger designed, it ideally should not cost more than 200€.

Make	Charger Type	Input	Output			Weight (Kg)	Cost	625-630wh (100% charge)	Reference
		Volts	Amp	Volts	Pins				
Giant (Hardware by Yamaha)	Smart (6amp)	200-240	6	36	5	1.4	199 €	4:40 h	[1]
	Smart (4amp)	200-240	4			0.8	199 €	5:50 h	
	Fast	200-240	4			0.74	100 €		
Shimano	Steps E5000	100-240	1.8	42	3	0.523	60 €	5:30h	[17]
	Steps E6000	100-240	4			0.93	84 €	10:12h	
	Steps E8000	100-240	4-4.6			0.672	175 €	4:50h	
Specialized (Hardware by Brose)	SL charger	100-240	4	54	6	0.9	190 €		[18]
	turbo charger	100-240	4	42		0.9	170 €		
	SBC-C04	100-240	2	42		0.8	100 €		
Bosch	Compact	110-230	2	36	3	0.6	99 €	8:48 h	[19]
	Standard	230	4			0.8	160 €	4:54 h	
	Fast	220-240	6			1.1	160 €	3:42 h	
	4A charger	220-240	4			0.7	130 €	4:54 h	
Fazua	Charger X	100-240	3	42	6	0.6	99 €		[20]
Brose	BMZ 2A	100-240	2	42	6	0.45	55 €		[21]
	BMZ 4A	100-240	4			0.55	132 €		
	BMZ 5A	100-240	5			1.1	140 €		
TQ	4A	90-264	4	58.9	7	0.7	-		[22]
	10A	100-240	10	50.4		2.35	349€		

Figure 21: Comparison of the competitor chargers

Charger Feedback

When comparing the charging feedback of different chargers, there are a few significant differences between brands. For example, to indicate the charging status Bosch solely relies on feedback from the battery or Ebike interface, whereas other brands have indication on the charger [23]. For the other brands the information on the charger informs the user about the termination steps (battery full/empty) and for a more accurate reading of the percentage charge of the battery the battery level indicator, located on the battery, must be pressed. The comparison highlights the differences and irregularity between the charging symbols, with little consistency between the brands.

Note: In the table below Smart Charging feedback has not been included since all the other brands do not offer this capability.

Make	Device	No Battery	Charging Active	Charging Full	Problem	Battery Defective	To warm/ cold	Charger not charging	Source
Giant (Hardware by Yamaha)	Charger								[14]
Shimano	Charger & Battery								[24]
Specialized (Hardware by Brose)	Charger & Battery								[25]
Bosch	Battery								[23]
Fazua	Charger & Battery								[22]
Brose	Battery								[25]
TQ	Charger								[20]

Figure 22: Comparison of charger feedback

Fitting Types:

Looking at the Fitting types used on Ebikes from the brands compared above, there is a wide variation in charging adaptors geometry and pins. The motor system used does not necessarily determine the adaptor connections and some brands collaborate with the motor system companies to develop own adaptors and system. For example, Orbea uses a Bosch or Shimano motor drive and charger but different plug connector [26] . The same applies for Trek's (Fuel Exe 9.9 XX1 AXS) uses a TQ motor drive and battery but their own adaptors [27]. The types of adaptor geometry used varies greatly:

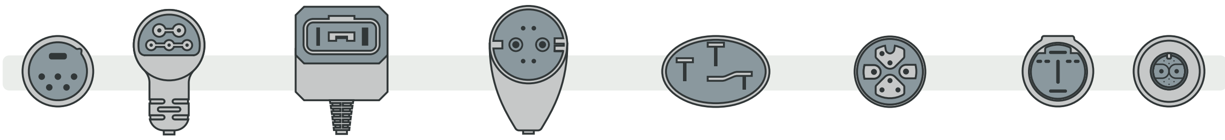


Figure 23: Different Plug profiles from Motor drive (MD) brands and independent charging plugs from Giant, Trek and Orbea

These can be grouped into two categories: Pin or Rosenberger; Specialized, Fazua and Brose all use the Rosenberger adaptor whereas the others use Pins.

The Rosenberger is a popular choice of Ebike connectors because of its ease of use due to its magnetic features. The magnetic connection results in a secure fastening with a self-mating connection and if the cable gets caught or pulled it easily unclips, preventing damage to the connection [28]. These additional benefits come at a price with each Rosenberger Plug costing €16,03 for 500 in bulk, this is significantly higher than the cost of a standard 5 pin plug costing €1,66 per unit for 500 in bulk [29, 30].

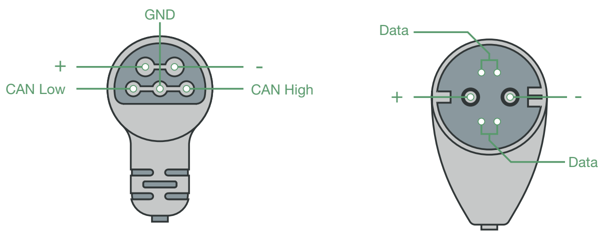


Figure 24: Giant 5 pin plug compared to the Rosenberger [28]

Despite the difference in characteristics between the Rosenberger the data and power transfer is the same. Most of the adaptors contain two power pins and data pin(s) to exchange data between the battery and the charger, known as the Battery Management System (BMS).

Side profile:

Looking at the side profiles of the plug there are two variations; either the cable leaves the plug parallel to the direction it is plugged in (Bosch) or the cable is perpendicular to the direction it is plugged in (Giant). Originally Giant also had a plug that ran parallel, however the perpendicular design is preferred because it adds better clearance when it is plugged in around the cranks. Comparing the advantages and disadvantages these two plugs, see table below:

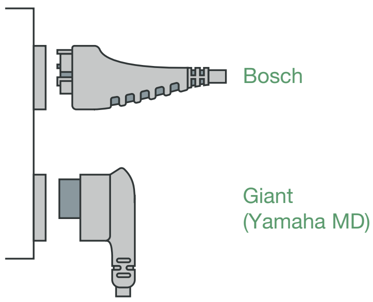


Figure 25: Difference between parallel and perpendicular plug type

Charge location	Advantages	Disadvantages
Parallel	If the cable is pulled the plug will disconnect easily.	Cable stick further away from the interface, making it more likely for the cable to get snagged
Perpendicular	The cable is much closer to the interface meaning there is less chance for it to get snagged.	If the cable is pulled there will be a turning movement and it is likely that the plug gets damaged

Figure 26: Advantages and Disadvantages with plug handle geometry

Plug Feedback:

It is difficult to comprehend the difference between the plugs, without user testing, and if there would be a significant difference between the user experience. For example, the magnets within the Rosenberger cause this self-mating and clipping action the same sensation is created with the Bosch plug but using a plastic protrusion rather than a magnet doe the clipping sensation. This gives the user feedback that the plug is fully inserted, and the user receives feedback that they no longer needs to keep pushing the plug in.

1.4.2 Battery

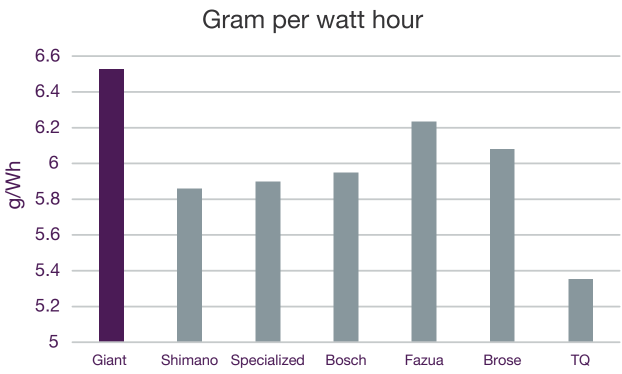
The batteries used are mainly determined by the motor system, therefore the distinction between them will be the same as the chargers. For the comparison Carrier batteries will not be explored since Giant is shifting their focus to integrated batteries.

Make	Spec.	Integrated										Plus			Source
	Batttery Capac.	250	360	400	430	500	600	625/630	700	750	800	160	250	500	
Giant	L x W x H			379 x 83 x 85		435 x 78 x 67		435 x 77.5 x 67		440 x 85 x 78			56 x 100 x 88		[1]
	Weight			3.2		3.2		4.2		4.2	4.2		1.8		
	RRP					799		949		1099	1053		449		
Shimano (Darfon battery supplier)	L x W x H			359 x 78 x 64		359 x 78 x 64		427 x 78.2 x 63.8							[17, 31]
	Weight			2.8		2.9		3.7							
	RRP			599		675		784							
Special.	L x W x H					-	-		-			-			[18]
	Weight					3.14	3.3		3.9			1.07			
	RRP					950	1160		1260			460			
Bosch	L x W x H					345 x 84 x 65		345 x 84 x 65		345 x 84 x 65				325 x 92 x 90	[19]
	Weight			2.9		2.9		3.6		4.3				2.6	
	RRP			445		500		640		1015				899	
Fazua	L x W x H	295 x 80 x 75			-										[32]
	Weight	1.78			2.3										
	RRP	429			650										
Brose	L x W x H							387 x 84 x 72							[33]
	Weight							3.8							
	RRP							74							
TQ	L x W x H		48 x 64 x 370									0.95			[20, 34, 35]
	Weight		1.83									0.9			
	RRP		-									600			

Figure 27: Comparison of the different batteries of Giant and its competitors

Looking at the table above, the most common battery sizes are 500Wh and 600Wh-630Wh batteries. Fazua and TQ offer the most compact motors which is why their batteries are smaller and thus lighter, to create a bike with assistive technology, but does not look like an Ebike and are commonly referred to as ‘light’ Ebikes. While these are the batteries that the motor brands produce, many bike brands also decide to produce their own batteries to provided more tailored dimensions of different ranges.

To analyse this data further the compaction (volume) and cost effectiveness is calculated as a ratio against Power (Wh) to determine where Giant positions itself within the market. The costing of the batteries was taken from multiple sites and the undiscounted (RRP) was used as a basis to try to achieve consistency between results.



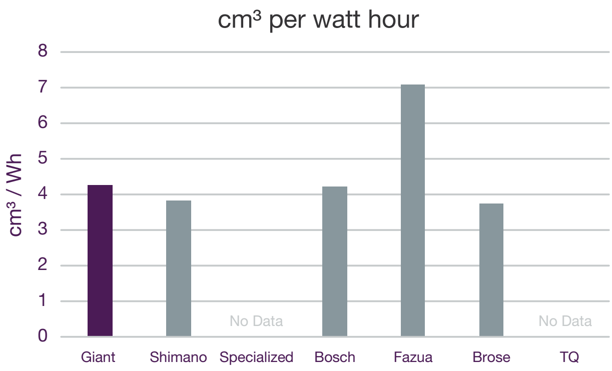


Figure 28 & 29: Comparison of Giant's batteries compared to their competition of weight per watt hour and volume per watt hour.

Based on the above graph we can see that TQ has significantly lower g/Wh compared to Giant and the other competitors. This calculation is not necessarily the result of cell technology used (18650 or 21700). The weight difference will likely come from the compaction and external frame that the batteries are fitted in along with the Battery Management System and the safety precautions that are made. With regards to the volume, Giant's battery size is comparable to Bosch batteries.

Battery Feedback:

To display the battery charge status, the batteries usually have a level indicator that lights up when a button is pressed. The battery level is also displayed at the rider's cockpit so they can see the battery status whilst riding, through a Graphical User Interface (GUI) or LED indication. Since the GUI is not the focus of this project the LED information used as a charge indication on the battery will be focused on.

Most of the brands have 5 LED used to represent a percentage increment of 20%, however Specialized has 10 LED's, providing the user with a more accurate understanding of the battery percentage. To be able to view this battery percentage, the power/circular button adjacent to the LED must be pressed or held down.

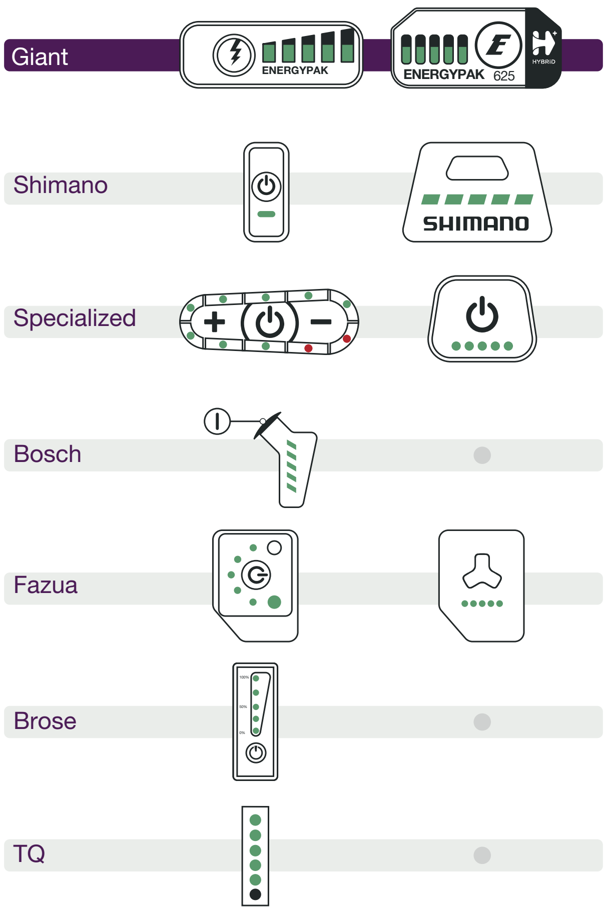


Figure 30: Difference in battery charger interface between brands [14, 20, 22, 24, 25, 36]

1.4.3 Frame

Charging Port Location

Most bike brands locate the charger at the base of the frame around the motor, or at the base of the seat tube. This is so the charger is situated closest to battery and the motor, improving manufacturing simplicity, and reducing the amount of internally routed cables. On the other hand, some of the charging ports are situated at the top of the down tube such as the BMC four-stroke and Trek Fuel Exe. This location is likely to have a more complicated manufacturing and assembly resulting in the high cost of these two bikes starting at €6,900 & €6,400 respectively [27, 37]. Another common location is the topside of the top tube which is present in the pivot shuttle.

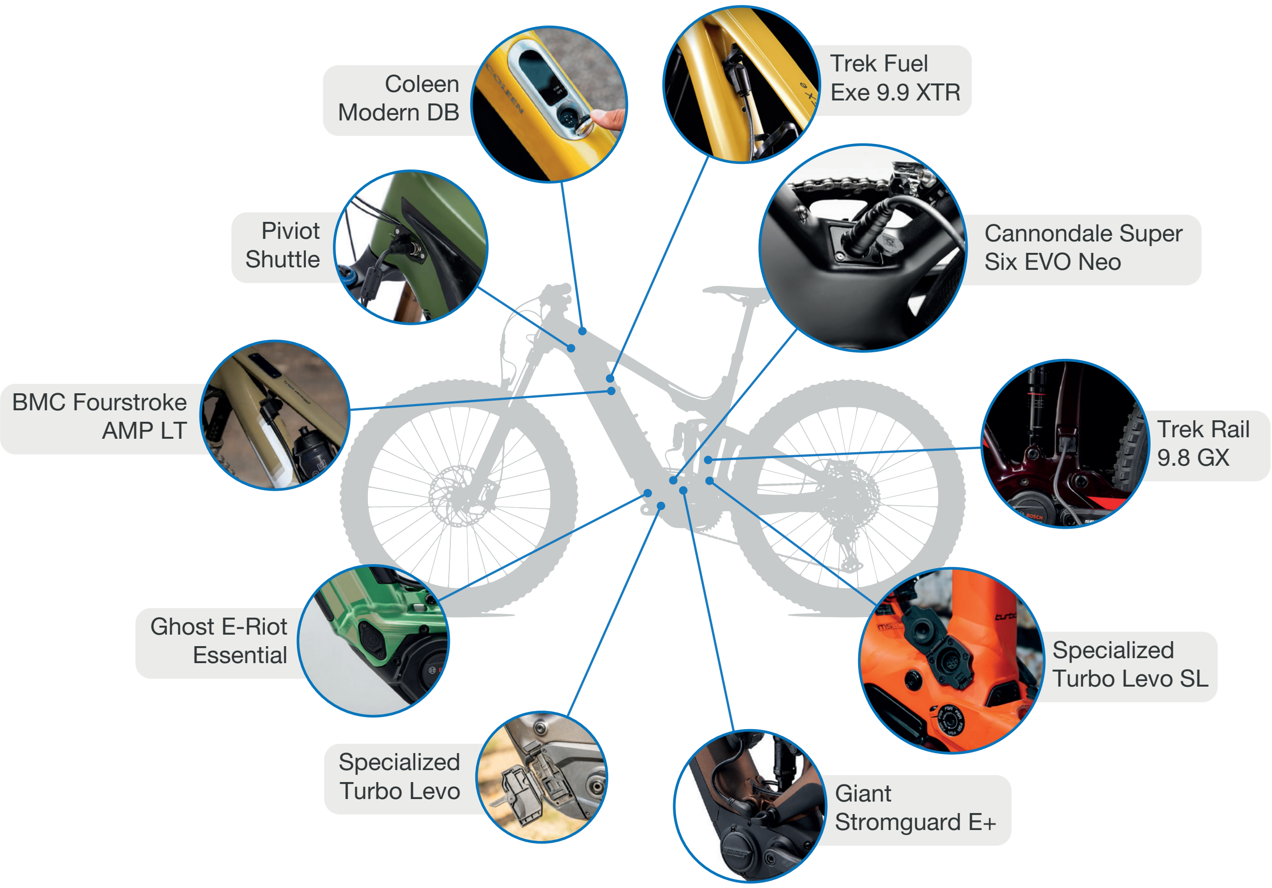


Figure 31: Common charging port locations on Ebikes. References from Trek fuel clockwise [27, 37-45]

To summarise these locations into categories, there are 5 potential locations:

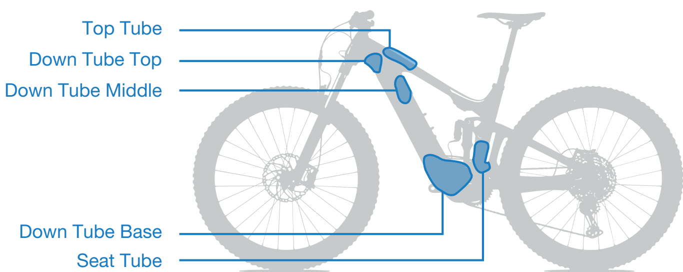


Figure 32: Locations of the charging plug

Analysing these different locations, we can assess the advantages and disadvantages of each location for the current system.

Charge location	Advantages	Disadvantages
Top Tube (TT)	• Very convenient height to plug in.	• Average distance from the expansion battery • Potentially a visual eyesore • Furthest away from other electronics
Down Tube Top (DT-T)	• Convenient height to plug in • Small likelihood for water and dirt contamination • Plug in orientation to how cable would naturally fall	• Visual eyesore • Close to the battery but not the motor
Down Tube Middle (DT-M)	• Convenient height to plug in • Small likelihood for water and dirt contamination • Plug protected by top tube Close location to the expansion battery • Plug in orientation to how cable would naturally fall	• Top tube may create difficulty in inserting plug in • Visually exposed, poor aesthetics
Down Tube Base (DT-B)	• Close to battery and motor electronics • Connector is integrated with the components and does not reduce the aesthetics.	• More susceptible to water and dirt contamination • When charging on some model's cable collides with the cranks • User must bend down to charge bike • Plug susceptible to damage
Seat Tube (ST)	• More convenient height to plug in • Reduced likelihood for water and dirt contamination	• May interfere or be obstructed by the suspension system • May interfere with the seat post • Far away from the additional power pack

Figure 33: Comparisons between the charging port location on the bike.

Having analysed the advantages and disadvantages above – several potential requirements based on the location are highlighted

1. How much does the user need to move to plug in the connector?
2. Is it is an eyesore?
3. Is there a risk of contamination (water and dirt)?
4. Is there a risk of damage – collision with objects and/or bike frame components?
5. How close is the connector to the range extender*?

**While there are potential problems such as the distance the plug connector is from the expansion battery (range extender) this may not be a problem with the new system where the expansion battery does not need to use the connection port. This will be addressed during the design phase.*

Plotting these advantages and disadvantages on a graph below to compare the different locations, highlights the conflicting requirements. For example, the distance from the power pack and motor contradicts with the risk of contamination, damage risk and user movement.

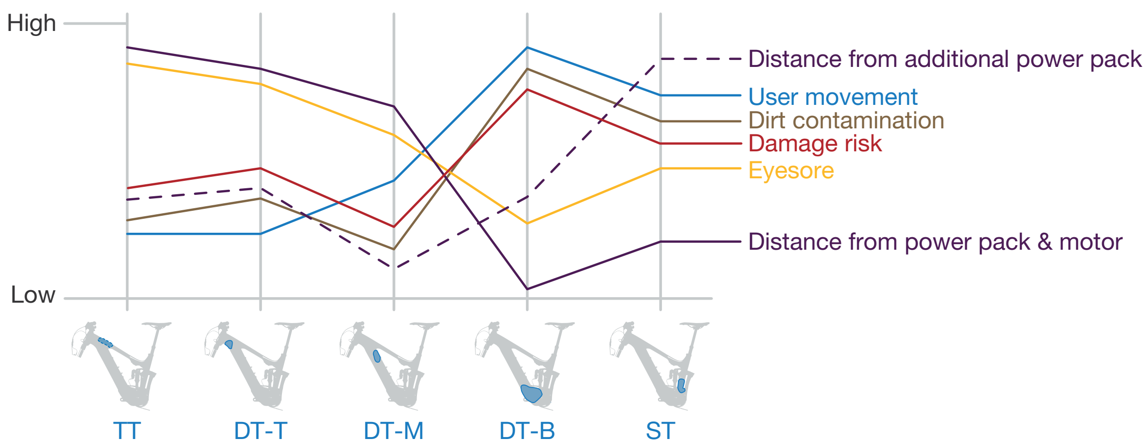


Figure 34: Location of the charging port in relation to certain parameters.

Battery Integration

As mentioned before, the batteries used in Giants portfolio of products are carrier (C), side release (SR) and integrated (I) [1]. Within the Ebike market carrier bikes are gradually being phased out. Within the midrange – High cost Ebikes SR and I are the most widely used, however the way in which these batteries are integrated within the frame, inserted, and removed from the bike differs between brands. To explore the different integration several mid-high end Ebikes were explored and compared see (Appendix A). There are five main ways the battery can be removed:

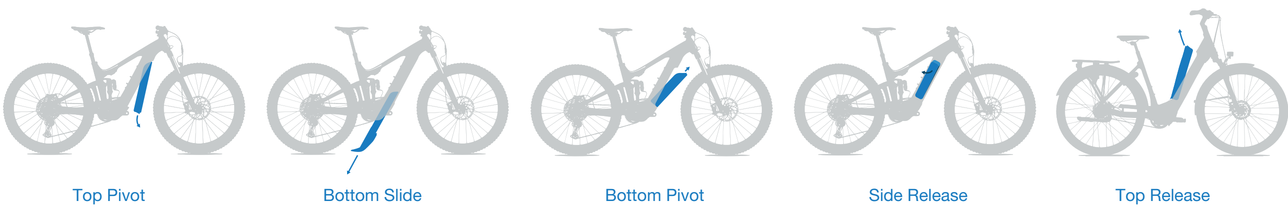


Figure 35: Five main ways to remove a battery

Removal method	Advantages	Disadvantages
Top Pivot (TP)	• Does not interfere with the front wheel • Weight of battery causes it to automatically come out of the frame.	• For easiest removal bike must be flipped over onto seat and handlebars • Release mechanism close to the ground, increased likelihood of damage • More user movement necessary • More complex battery connector since a single linear movement
Bottom Slide (BS)	• Weight of battery causes it to automatically come out of the frame • Fully integrated within the frame, battery is less vulnerable • Simple battery connector since a single linear movement. • Battery is not visible	• For easiest removal bike must be flipped over onto seat and handlebars • Internals of the frame less accessible likely increasing manufacturing complexity. • Release mechanism close to the ground, increased likelihood of damage • More user movement necessary
Bottom Pivot (BP)	• Weight of battery causes automatically come out of the frame • Little user movement required	• Front wheel could Interfere with removal process • More complex Battery connector since a single linear movement.
Side Release (SR)	• No interference with bike components. • Little user movement required	• Bike aesthetics are not symmetrical
Top Release (TR)	• User can easily lift battery out of the frame and drop the battery back into position. • Little user movement required • Frame protects the battery where it is most susceptible to damage	• Top tube restricts movement therefore commonly on bikes without top tube

Figure 36: Comparison between removal methods

Having analysed the advantages and disadvantages above several potential requirements based on the battery integration are highlighted for removal and insertion of the battery.

1. How much bike needs to be moved/ user movement is required?
2. How visible is the battery/ is it an eyesore?
3. Does the battery interfere with the bike frame?
4. How vulnerable is the battery to damage?
5. How easy is the battery integration to manufacture?

These requirements can be shown on a graph to visualise and highlight contradictions between them:

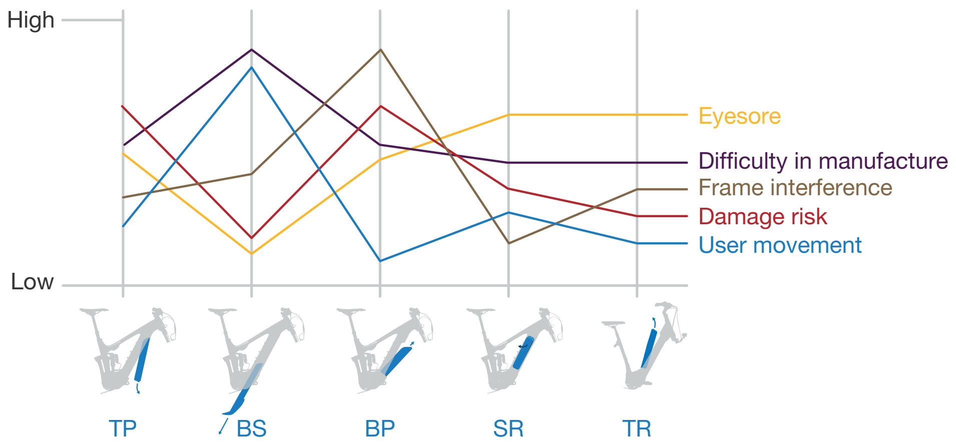


Figure 37: Battery Removal method in relation to certain parameters.

Looking at the graph above, the location of the battery chosen for one model has no clear significant benefit over another. This means that the location is highly dependent on what the Ebike brand chooses to prioritize, whether its manufacturing simplicity or reducing the amount the bike needs to be moved (user movement) to remove/insert the battery. The battery removal tool used to change the battery also differs depending on the brand, there are three chosen tool types:

Removal Tool	Advantages	Disadvantages
Allen Key	• Most likely have an Allen key within bike repair toolkit. • Solutions like the Marin Alpine trail have a small subtle insert making the removal very discrete	• On some bikes e.g. Specialized Turbo Levo can be time consuming to remove bolts • Could lose small bolts • Anyone with an Allen key can take the battery – poor security
Key	• High security with unique key • Intuitive to use	• If key is lost cannot remove the battery • Key must be remembered if the battery needs to be removed on a ride
Through bolt	• Most likely have an Allen key within bike repair toolkit. • Securely attaches the battery	• Could lose through bolt • Anyone with an Allen key can take the battery by loosening the through bolt - poor security

Figure 38: Comparison between Removal tools

Frame Displays:

There are several different of frame displays as shown in the figure below. The displays are categorised into several columns

1 & 2: Compact displays with small amounts of feedback via LEDs.
3: Compact user input buttons, little/no feedback (require a separate display)
4: Minimal Display with only LED feedback to be paired with column 3
5: Minimal Display with LCD screen for more feedback to be paired with column 3
6: User input combined with LCD screen
7: Larger LCD screen displaying more information at one time to the user

Giant has a wide variety of displays, with the exception of currently not having a LCD compact display primarily, designed for mountain biking. Giant's have a wide range in form of the user input buttons and how the feedback is given to the user. A few notable designs is the Fazua display only contains one row of 5-10 LEDs, these LED inform the user about the battery level. To inform the user what mode they are in the LEDs will either be white, green, blue or pink. This helps reduce the amount of information on the cockpit, however it may be slightly less intuitive to remember which colour correlates to which mode.

Another interesting display feature is by TQ, which has a timer displayed. This informs the user how much time the user has until their Ebike will run out of battery [20]. A feature which provides a more tangible approach to how much battery is left, however this may induce a level of anxiety for the rider as the clock will be going down continually. The clock may also not reduce at a constant rate depending on the level of assistance. An alternative to this could be how many Km the rider has remaining.

The LCD displays offer a high level of customisation and allows the user to select what information they want to be displayed within boundaries, for example if they prioritize their speed over battery percentage this could be shown larger on the display.

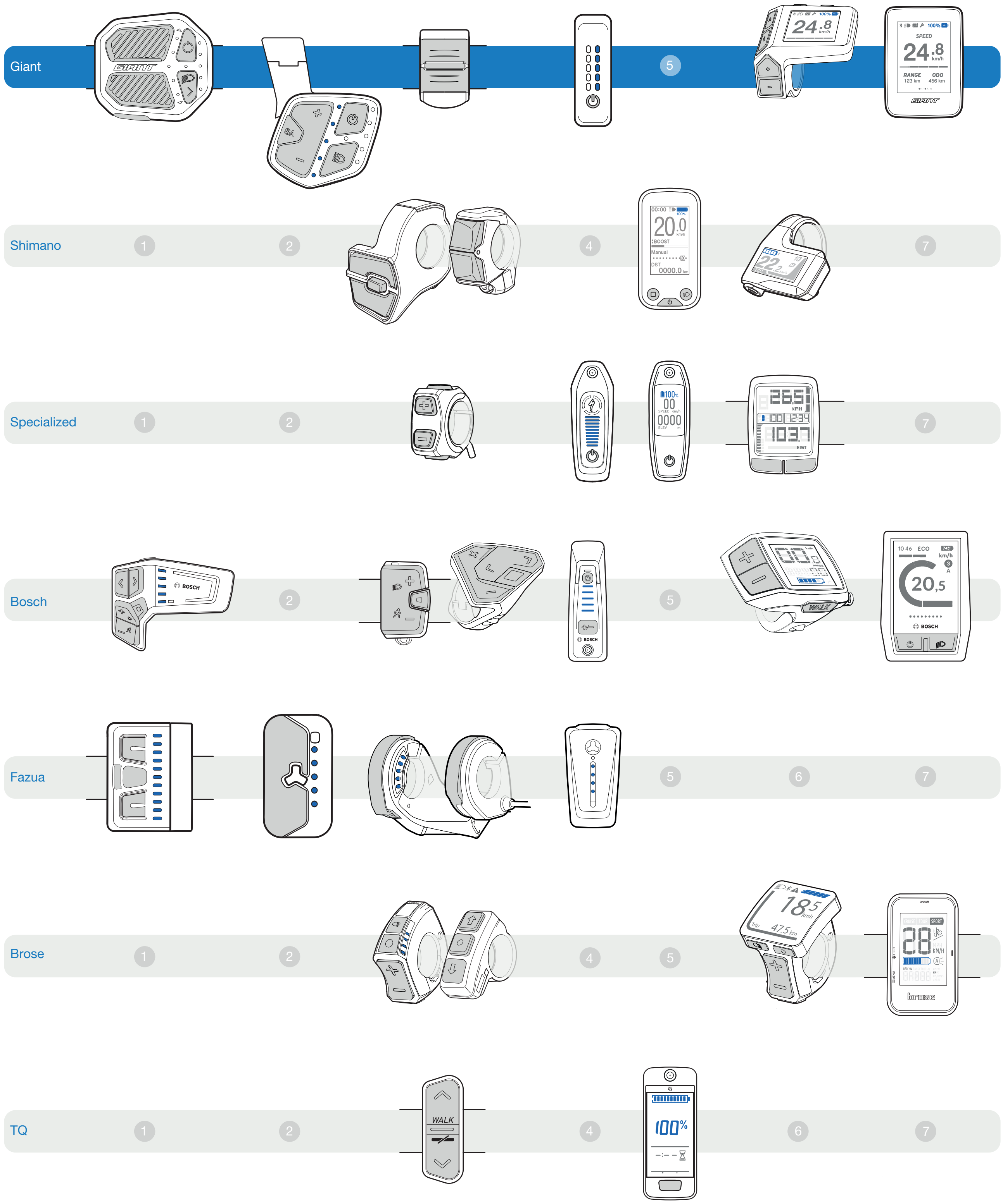
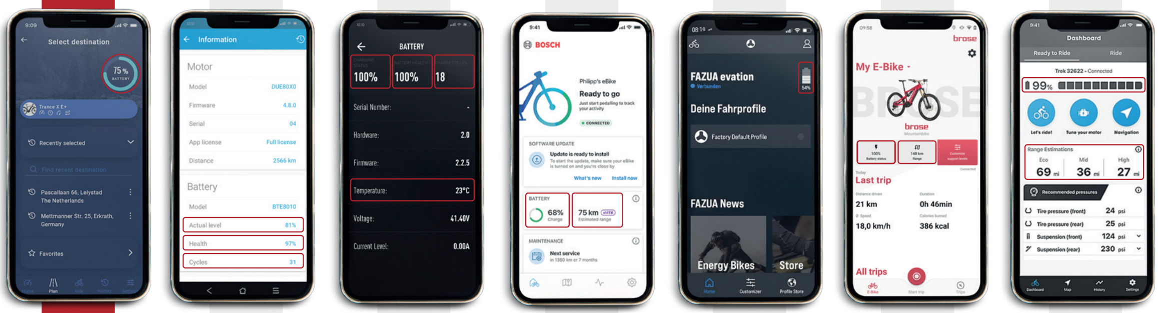


Figure 39: Display variations produced by Giant (the blue components highlight the battery charge feedback)[14, 20, 22-25, 36]

1.4.4 App

All 7 companies offer an application (app) to go with the Ebike system. The app contains multiple different features such as; route planning, navigation, recording ride statistics and customising the level of assistance for the different Ebike modes. Since the charging system is the focus, the apps have been analysed based on what feedback they give involving the battery. The figure below highlights the comparisons.



	Giant	Shimano	Special.	Bosch	Fazua	Brose	TQ (Trek)
Percentage	✓	✓	✓	✓	✓	✓	✓
Range	–			✓		✓	✓
Temperature			✓		✓		
Charge Cycle	✓	✓	✓		✓		
Health	✓	✓	✓		✓		
Smart control			✓				
Charge assistance							

Figure 40: Comparison between ebike applications [14, 20, 22-25, 36]

Comparing the different applications, Giant's app does not contain the most information for battery charge feedback or the least. The range is displayed within the Giant app, however it is difficult to find which is why it has a yellow line. To determine the range the Ebike must be switched on and connected to the bike. The range is then visible on the RideControl Dash or RideDash Evo. With the RideControl Dash the only way to view the range is once the ride has begun, then the range will display.

Specialized is the only app with a Smart Control feature, this enables the user to programme the amount of battery they want remaining at the end of their ride. The user inputs the distance/duration and elevation, and the 'Smart Control' adapts the amount of support so that there is the requested amount of battery is at the end of the ride. This ensures that the user does not run out of battery mid ride.

What is also notable is that within all the apps there is no charging support or assistance to aid the user during charging. The most assistance is obtained from Giant's 'Storage button' on the Smart Charger which will charge the bike to 60%.

1.5 Conclusion

Based on the research into the Giant's product portfolio their current Ebike system and their competitors' charging systems differ greatly highlighting areas which need more research. This primarily includes gathering information from users to determine what their charging system preference is, but more importantly why they prefer it and what their priorities are. The preferences which need to be explored are:

- Charging location
- Battery removal Vs bike charging procedure
- What feedback (information) is important for users when charging
- The location where this feedback should be displayed (Battery/Bike/Charger/App)

Note: These questions are focused on in Chapter 3 in the user behaviour survey.

C2: USER EXPERIENCE

In this chapter theory on 'user experience' will be explored, to understand what makes-up an experience and how this user experience can be quantified and measured. Based on this approach user testing on a Giant Explorer E+ Ebike will be conducted to see how the charging system is perceived by users, as well as observing how the user interacts with the Ebike to determine potential areas of improvement.

2.1 Understanding User Experience

User experience can be quantified in multiple ways, but is generally understood as a multi-dimensional construct [7]. Consisting of multiple aspects such as learnability, aesthetics, and efficiency [7]. User experience is defined by ISO 9241-210 as *'A person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service'* [46].

Within literature there are several different ways user experience can be classified:

1. **Holistic view:** This classification focuses on all types of physical, cognitive, or emotional reactions which are formed before, during or after engaging with a product [7].
2. **Extension of usability:** This classification involves the addition of affect and emotions to usability. Addressing the human needs for competence, stimulation, relatedness, popularity, and autonomy [47].
3. **Primary focus on emotion:** This classification focuses heavily on the affective outcome of the interaction between user and product. It considers users' experience as specific emotions such as joy, excitement, anger which are caused because of factors such as the aesthetics, usability, and significance of the product to the user[47].

The holistic view provides a broader overview whereas the primary focus approach is very focused on addressing a specific emotion felt by the user [7]. The user experience is very broad topic so to help understand it further a study by Sauer, 2020 provided a higher-level concept called 'user interaction'. This involves the incorporation of usability and accessibility within the user experience. Traditionally the term usability is used for everyday products, accessibility in housing environments and user experience is used within software development context [47]. For the redesign of a charging system the incorporation of software, physical interfaces, as well as the environmental context all play an important role; which is why exploring the usability and accessibility as part of the user experience will help provide more depth to understanding how to improve the user experience [47].

2.1.1 Usability

Usability is defined by the International standard ISO FDIS 9241-210 as the: *'Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'* [46].

Compared to user experience usability does not consider the anticipated use or pre-usage phase and only focuses on the direct interaction of the user. When the user is interacting with the product they contain two types of goals, Pragmatic and Hedonic. Pragmatic goals refer to the physical goals such as the functional components such as 'charging the bike 'where as hedonic goals refer to the emotional qualities and the perceived ability to support achievement such as, being competent as evaluating the level of autonomy, competency and mental stimulation [45, 46].

The definition of usability is commonly constructed from four different perspectives [47, 49]:

1. **Product-oriented:** Usability is a trait that is built into the product [47].
2. **User-oriented:** Usability is a result of the user's mental effort and attitude toward the product during use referred to as workload.
3. **Performance-oriented:** Usability is determined by the interaction of the user with the product. How easy it is to use (efficiency), whether success occurs (effectiveness) and whether the product will be accepted in the real world [47].
4. **Context-oriented:** Usability depends on the user group that is studied, tasks that the users are performing and the environment in which it is completed. All of which are needed to be considered when defining usability [47].

While these approaches follow different perspectives they include the same elements, highlighted in the ISO standard [46]. The objective outcomes relate to how well the product performs in relation to the user's expectation and pragmatic goal. This is evaluated on effectiveness (whether the task is successful) efficiency (how fast is success obtained) and the workload (how easily the product can be interpreted by the user). There are also subjective outcomes that relate to the user's hedonic goals like satisfaction, joy and pleasure. Combining both the objective and subjective outcomes provides the overall user experience [47].

2.1.2 Accessibility

Accessibility is defined by ISO 9241-210 as *'usability of a product, service, environment or facility by people with the widest range of capabilities'* [46]. This definition provides an extra layer and broadness to usability, ensuring that the product will remain usable in different contexts and with different user types.

Accessibility focuses on the importance of barrier-free access, including users with impairments, use within buildings and required infrastructure. This encompasses concepts such as design for all, or inclusive design [50]. Accessibility is closely linked with usability. A product can be designed to have good usability within one context but in a different context (i.e. a change in environment or the user) the product may no longer be accessible, and the usability becomes poor.

In the context of an Ebike charging system, to ensure the design is accessible it should be easily usable for all users with different capabilities/knowledge, as well as ensuring that the context/environment does not hinder this accessibility. For example the context varies greatly whether the user lives in a high-rise apartment with little to no bike storage facilities or in a large house with a garage [47].

2.1.3 Usability, User Experience and Accessibility

To visualise the relationship between user experience, usability, and accessibility a diagram based on Sauer, 2020 has been proposed. The model has been tailored slightly so it can be used as a basis for evaluating the user experience of the charging system [47].

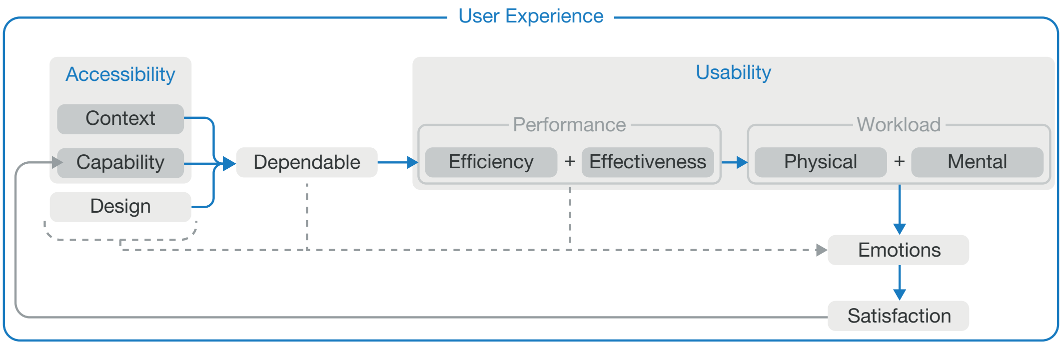


Figure 41: Relationship between user experience, usability, and accessibility inspired from Sauer (2020) [47].

Accessibility: Is constructed from three components; Context, Capability and Design. The Context involves where the charger will be used and whether the battery is removed or retained within the bike. The Capability involves the user's knowledge, how experienced are they with Ebike charging systems, whether they have used the system before. As well as their physical ability such as how strong they are to manoeuvre the battery and charger. The design involves how the product looks and how it functions.

Design: The design has big impact on how the product is interpreted. While aspects of the design cannot be directly measured, a consensus from the user such as the aesthetics can be. For example, how attractive is the product? Ideally the system should look attractive, enjoyable, friendly, and pleasant and assist the user in performing the task.

Dependable: Based on the design, context, and the user's capability the dependability of the product will vary. This involves how predictable, reliable, and trustworthy the product is. Ideally the interaction with the product should be predictable, reliable, secure and meet the user's expectations to ensure that the performance is high and the workload low.

Usability - Performance: This is built from a combination of efficiency and effectiveness. Efficiency involves how long it takes to perform the charging task of the bike; ideally the task should be performed quickly, in a logical way, and the user should reach their pragmatic and hedonic goals [47]. Effectiveness involves how helpful the feedback is to inform the user of success. Ideally the user should understand when success has occurred and receive feedback on the status of the system.

Usability - Workload: This entails how much effort is required to charge the Ebike, both physically and mentally. Ideally the charging system should be easy to understand, clear, simple, and easy to learn, reducing the number of decisions that are required to use the product, as well as limiting the user's movement [51]. The amount of workload is a result of how accessible, and dependable the design is and how well it performs.

Emotions: This Involves how the user is feeling during and after the product use [47]. There are emotions which will be generated during the use (highlighted by dashed lines in figure 41) of the product as well as after the task is performed.

Satisfaction: Finally, once the task is performed, the combination of all aspects will lead to a certain level of satisfaction [47]. The satisfaction gives an overview of the user experience however by testing each individual component of the user experience mentioned above will help develop a deeper understanding into the level of satisfaction. After the user experience there is a feedback loop, since the capability (knowledge) has now changed and they will tackle the problem in a different manner resulting in a slightly different emotion or level of confidence.

Looking at the charging system in the context of satisfaction, it is evident that chargers have not received much development attention, and the product has been created to fulfil the basic need of charging the bike. If the charging system is designed poorly the user will be dissatisfied, but if it is designed well the user's satisfaction level does not increase dramatically. This relationship can be portrayed by the Kano model which distinguishes between three categories of product specifications that when met, have varying effects on client satisfaction. This distinction is important because the charger falls within the 'Must-be' requirement (highlighted in blue in figure 42) [52]. The client will be very upset if these requirements are not met. However, meeting them will not make them feel more satisfied because the customer takes these demands for granted. Since the charger is a fundamental need for a product, fulfilling the requirement of a good charger will only lead to the user of feeling 'not dissatisfied'[52].

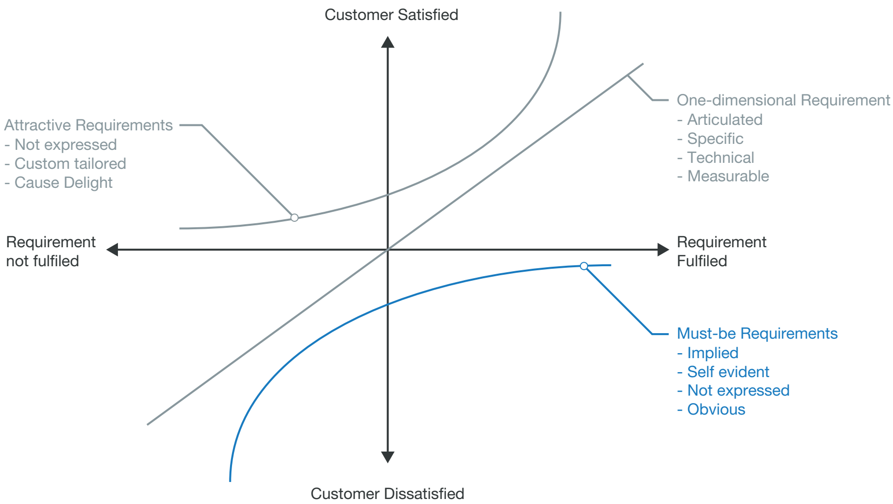


Figure 42: Kano model of customer satisfaction [52]

As a result, the charger will not be part of the marketing campaign or a unique selling point for Giant. Therefore, improving the user's experience of the charging system should be the focus even though it will not be the reason for a user to purchase a new bike. Elevating the user experience for the charging system will in turn improve the user's experience for the bike as a whole.

2.2 Measuring User Experience

To get an insight into the overall user experience and be able to evaluate the user, experience the aspects which contribute to the user experience needs to be quantified. (Figure 41) visualises the user experience as a continuous loop. As a result user experience is dependent on time. Therefore, it is important to determine the timespan user experience is evaluated and measured [53]. The ISO 9241-210 standard refers to this as use and/or anticipated use. However it can be broken down into more detail [46]. User experience can be experienced before, during and after use as well as over a long period of time [53].

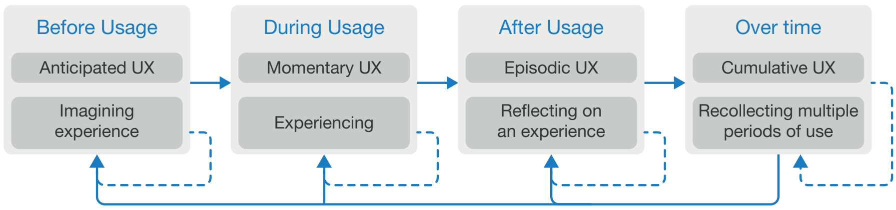


Figure 43: Time spans of user experience [53]

Before usage: (Anticipated UX): Involves anticipated expectations that have been formed for similar technologies, advertisements of the brand. Other people's opinion can affect and shape this perceived experience before interaction with the product has occurred. The anticipated use is important and studies have shown that it impacts on the consequent experiences, due to the reflection of similar usage situations or because the user's perspective has changed after use [53].

During usage: (Momentary UX): This refers to the experience of the user while interacting with the product. Assessing the experience while the user is experiencing the product is important because of the specific change in feeling during the interaction with the product [53].

After Usage: (Episodic UX): This involves the experience the user encounters with the product for a specific period. This is the continued use of the charger.

Overtime: (Cumulative UX): Over time the cumulative experience is a result of reported use and/or non-use of the product. This experience can take months-years [53]. It is viewing the experience of a system after it has been used for a while. The cumulative experience is more important than the temporary feeling when products are evaluated.

Based on these four usage states they will be applied within the user testing, since cumulative UX cannot be measured through a single usability study. The before, during and after UX will be accessed. The cumulative UX will be evaluated during a general study within Chapter 3 with users who have been using their Ebikes for a longer period of time.

2.2.1 Before Testing

Accessibility: Measuring accessibility is difficult to do directly as there are only tools available in the form of self-report questionnaires [47]. Unlike user experience and usability. To assess the level of accessibility of the design, the user capability and context can be changed to determine how this effects the overall usability of the design. This does not give quantifiable results and therefore accessibility usually relies on expert-based methods [47] such as check-lists to provide specific recommendations about how to support users with impairments, or cognitive walkthroughs to identify barriers by using severity rating and looking at how this affects the performance of a task. To assess the current accessibility the capability of the user will be determined, and the context will be changed.

Capability: To determine the user's capability, before the test the user's bike background and knowledge of Ebikes will be asked. As well as their age and gender.

Context: To measure the effect that context has on the user experience, the users will be asked to perform the task in two different scenarios: charging the bike and charging the battery. For a more in-depth analysis of how context affects accessibility, these tasks should also be performed in various conditions, such as a muddy bike, low light conditions, or rain. However, for the purpose of the initial testing, this was not conducted in order to reduce complexity. Any significant issues encountered by users in certain conditions are discussed in chapter 3 during the user survey.

Design: To measure the quality of the design the user will be asked "to comment on the products aesthetics?" Other measurable aspects with regards to the design are less obvious, however affordances built within the design can be observed: for example, does the user hold the plug in the same place or know how to remove the charging cover on the bike.

2.2.2 During Testing

Dependability: Dependability is strongly linked to the usability of the product, whether or not the product is predictable, it is trustworthy and reliable [47]. Therefore, the measurement of dependability will be based on how it performs during the usability component.

Usability:
Efficiency: To measure the efficiency of product usage, timing the user could be considered. However, this approach may introduce bias in how the task is performed, as it could cause testing anxiety or prevent the user from performing the task naturally. Therefore, observations will be recorded including the errors and sequence of steps. This documentation will help determine if the user consistently and logically performs the task.

Effectiveness: To measure the effectiveness observations will be made to see whether the user understands when a success has been made and how they interpret feedback. For example, do they keep pushing the plug in even if it has been pushed in far enough.

Workload: To measure the workload the amount of movement and effort will be documented through observations and discussions with the user.

2.2.3 Reflection

Emotions: Measuring emotion is a complex construct to study [54] there are two main ways to measure the users emotion. Verbal and nonverbal. Verbal measurements tend to be lengthy. Since emotions occur instantaneously, getting the user to verbally portray how they feel may distort the result. A self-report approach is widely used however this works best when the user is participating in the task passively [54]. The other challenge with verbal communication is the language barrier.

Non-verbal measurement tools include visual representations of emotions such as a happy face. To determine the nonverbal measurement common tools are self-assessment manikin or emo-cards [54]. To determine what emotions are felt during each usability test the user will be asked to reflect on what emotion they are feeling using the emo-cards developed Desmet, (2001) [55] . This is a fast and effective way for the user to determine how they felt during the process of using the charging system on a level of pleasantness and arousal.

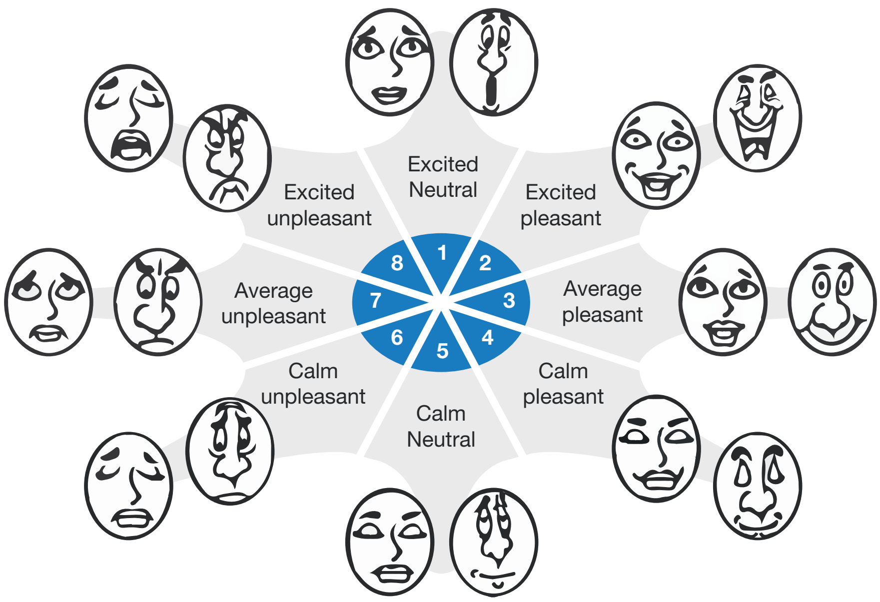


Figure 44: Emocards developed by Desmet, 2001 [55]

Satisfaction: To measure the overall satisfaction and usability the Usability Metric for User Experience (UMUX) will be used [56]. This metric is a four-item Likert scale (from 1-7) to evaluate the perceived usability [56]. It is designed to obtain similar results to the 10-item System Usability Scale (SUS) [57]. However the fewer questions align best with the ISO 9241-210 [56]. This satisfaction/reflection allows for a gut reaction from the user to see their episodic UX (after us-age) aligns with the observations which were made in the usability test.

Usability component	Candidate UMUX
1. Effectiveness	The charging system capabilities meet my requirements
2. Satisfaction	Using the charging system is a frustrating experience
3. Overall	The charging system is easy to use
4. Efficiency	I must spend too much time correcting things with the charging system

Figure 45: UMUX statements [56]

Based on the response, the score is calculated by [score -1] for statements 1 and 3 and [7-score] for statements 2 and 4. This is to remove the positive/negative keying of the items and allows for a minimum score of zero. From this the maximum score is out of 24.

$$Umux\ score = \frac{((1.E) - 1) + (7 - (2.S)) + ((3.O) - 1) + (7 - (4.E))}{24} \times 100$$

This result puts the UMUX score on the same scale as the SUS, and can be used to determine the system's usability and to act as a goal setting reference [56].

2.3 Testing User Experience of Components

Based on the recommended ways to measure the different aspects of user experience a usability study was conducted. During this study all aspects of the user experience were included and measured. By understanding the current user experience, bottlenecks and challenges within the current system were be highlighted.

The study will consist of 6 sections:

Section 1: Involves basic user questions such as their age, gender, as well as their level of experience with Ebikes and how many they own to understand their capability. Their first impressions of the charger was analysed. The emotion of the user was also taken before the start of the test to see whether their predicted emotion of the experience aligns with the emotion that they felt.

Section 2: Usability test 1A: Charging the bike: The user was asked to charge the bike directly

Section 3: Usability test 1B: Un-Charging the bike.: The user was asked to get the bike ready for a ride

Section 4: Usability test 2A: Charging the battery: The user was asked to charge the bike battery

Section 5: Usability test 2B: Un-Charging the battery: The user was asked to get the bike ready for a ride

During these four sections: Observations were made, the order in which the steps were performed, any errors/struggles the user had and the user was asked to reflect on the emotion they felt during performing the task based on the emo-cards [55].

Section 6: Reflection: In the final reflection phase the user was asked to reflect on their experience. They were asked to rank the ease of use of the product they used, comment on anything that surprised them and fill out the UMUX [56]. In addition they were also asked to suggest an alternative location for the bike charging port and comment on why they think it should be at this location. Based on this usability testing a good overview of the current user experience was obtained.

2.4 User Test – Explorer E+

For the user test 7 test subjects (user) from Giant were selected at random to interact with the Ebike in the steps mentioned above. The subjects had a range of knowledge and experience. With 4 users having no knowledge of Ebikes, and 3 users having lots of knowledge of Ebikes. None of the users owned an Ebike.

The test was performed on an Explorer E+ bike. While the design of the Ebikes vary greatly this bike is representative of Giant's portfolio as it contains popular features such as an integrated battery with a bottom release, a key and the charging port by the cranks.

Unlike the previous bikes that have been mentioned, the Giant Explorer E+ contains an additional plastic cover which has to be removed by a small screw before the battery can be removed, which indicated some usability challenges which will be discussed during the battery removal section. The testing highlighted several issues with the current design which are highlighted below.

Figure 46: Giant Explorer E+

2.4.1 Charger (6A smart charger)

Overall appearance: The main feedback regarding the charger is that users were surprised how big and heavy it was. It did not appear to be portable, and the cables were very long.

Charger Button: The button on the charger is used to switch it to 'storage mode' determining whether the battery will only be charged to 60%. Only one test subject (an expert) was able to identify correctly what the button on the charger does. The rest of the test subjects thought it was either to do with powering on, resetting, or causing the charger to display information.

LED charging feedback: The subjects were consistent with their expected LED feedback suggestion with

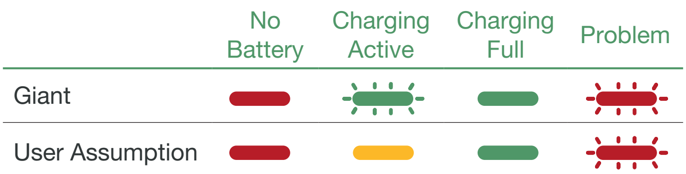


Figure 47: Actual and expected LED feedback

This expectation does not align with Giant's feedback colours, however during the test (when the charger was plugged in) the subjects were able to identify that a green flashing light must mean that the battery is being charged.

2.4.2 Charging Plug

Socket Cap: Before the user can access the socket, the cap needs to be removed. For this the cap is sprung loaded, pulled and rotated from the Ebike. 3 users were unable to figure out how to use this cap and one user rotated the cap anti-clockwise which partly obstructed the plug socket, preventing the plug from being able to be plugged. During the test 6 users failed to remember to users close the cap once the plug had been removed.

Pattern and orientation: To determine what orientation the plug should go the users looked at the pattern on the plug and the patten on the bike. 4 users could not figure out the plug orientation and expressed that it was not intuitive due to the similarities yet slight differences between the plug and the socket on the bike. It was noted that the plug cable hangs out at a 45°-degree angle whereas a traditional connection hangs vertically down (see figure 48). Once the user was shown the correct orientation they stated if they were to perform the task again, they would have no problem since they would remember how to orientate the cable.

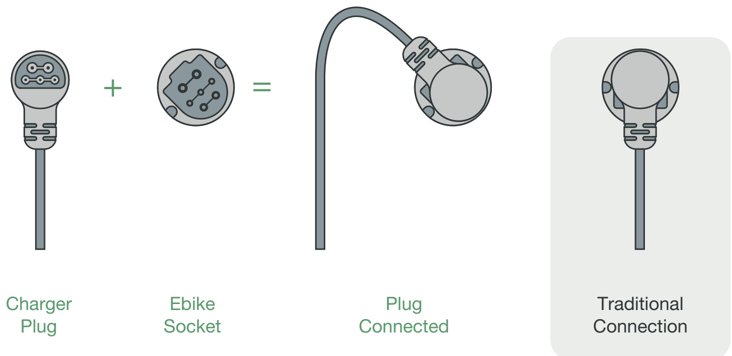


Figure 48: Current orientation of the plug on the Giant Explorer E+

Conclusion:

- Charger feedback should be intuitive for the user.
- If buttons or modes are used this needs to be communicated better to the user
- Distinction needs to be made between whether the charger is design to be portable or not and this decision should be reflected within the design (size and weight)
- A plug that is initially difficult to find is not a problem, but it must not hinder the usability. Since once the user is aware of its location it is no longer difficult to find.
- The socket cap should reduce the likelihood of it being left open
- The socket cap should be free to rotate in both directions, or only allow rotation in the direction which does not hinder the socket opening.
- The plug orientation should be in line with users' expectation
- Pattern on the plug sockets should match.

2.4.3 Battery

Overall appearance: 3 of the users were surprised by the weight of the battery and thought inserting the battery back into the bike was more challenging due to this weight and the awkward angle the battery is inserted to prevent it interfering with the front fender.

Battery Charging feedback: 6 users could not determine how much charge the battery had and did not realise that the battery first needed to be unplugged. Once shown they knew to press the button to see 2/5 dots and realised the battery was at 40%.

Figure 49: Display on the battery from the Giant Explorer E+

Conclusion:

- The battery feedback of the charging status should be easier for the user to obtain. They should not have to un-plug the battery to determine its status.

2.4.4 Frame

Plastic Guard: Before removing the battery, the plastic guard needed to be removed, this was removed by a small plastic screw. The additional plastic cover provided multiple usability challenges. There was no feedback whether the screw was fully undone or whether the plastic guard should be partly removed or completely removed. The same was true for putting the guard back on. The alignment of the screw with the frame was difficult and 6 of the users struggled to clip and align the guard correctly. They felt that the materials were cheap, and it felt like an afterthought. *"If I buy a Mercedes and get the interior of a Honda my experience will be unpleasant"* – quote from a user.

Key: This plastic guard and the key generated a lot of confusion since there was a "double lock" . They could not determine whether the key should be used first or second to remove the battery since the guard was already protecting the battery. When using the key there was no visible change since the guard obstructed the view of the battery being released as a result the need for a key was not obvious. For many users the key was not used correctly to secure the battery and remove it. During the experiment it was an obsolete feature.

Pattern and Orientation: When inserting the charger adaptor into the battery all users were able to figure out what to do since the adaptor pin pattern matched the battery pin pattern. However, when placing the battery back into the bike the orientation was not obvious and 4 users struggled with determining what it should be.

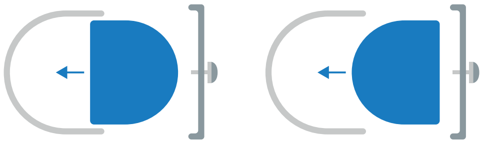


Figure 50: Battery orientation issues

Location: The location of the charging port was not obvious for 5 subjects, and they could not identify where to plug in the charger. However, this problem was only experienced by the non-experts. As soon as the plug location is known this is no longer a problem. The 4 of the users said they would not change the location of the plug, expressing that they did not want it to "dilute the beauty of the bike" whereas the remaining users who had less knowledge of the manufacturing challenges, suggested a location higher up on the bike around on the bike so it was closer to eye level.

Conclusion:

- Plastic cover should be completely removed and should be redesigned so that it is integrated within the battery, or easier for the user.
- The plastic screw should be redesigned so it is more durable and easier to use.
- The key should provide better feedback to the user, so they know whether the battery is locked and when it is released.
- The orientation the battery should go into the bike should be communicated better to the user.
- The location must not "dilute the beauty of the bike"
- The charger port must be located so that it is accessible to the user.

Figure 51: Port location on the Giant explorer E+

2.4.5 Overall Operating procedure

Looking at the procedure in which tasks were performed, some of the tasks led to much more variation in the operating procedure compared to others. For example, the tasks for inserting the battery are dependent on each other therefore the variation of steps is less. The sequence recommended by Giant's user manual was only performed by 1 user. For charging the battery the most popular sequence was either assembling the charger in a sequential man-ner from the bike to the mains or the other way around.

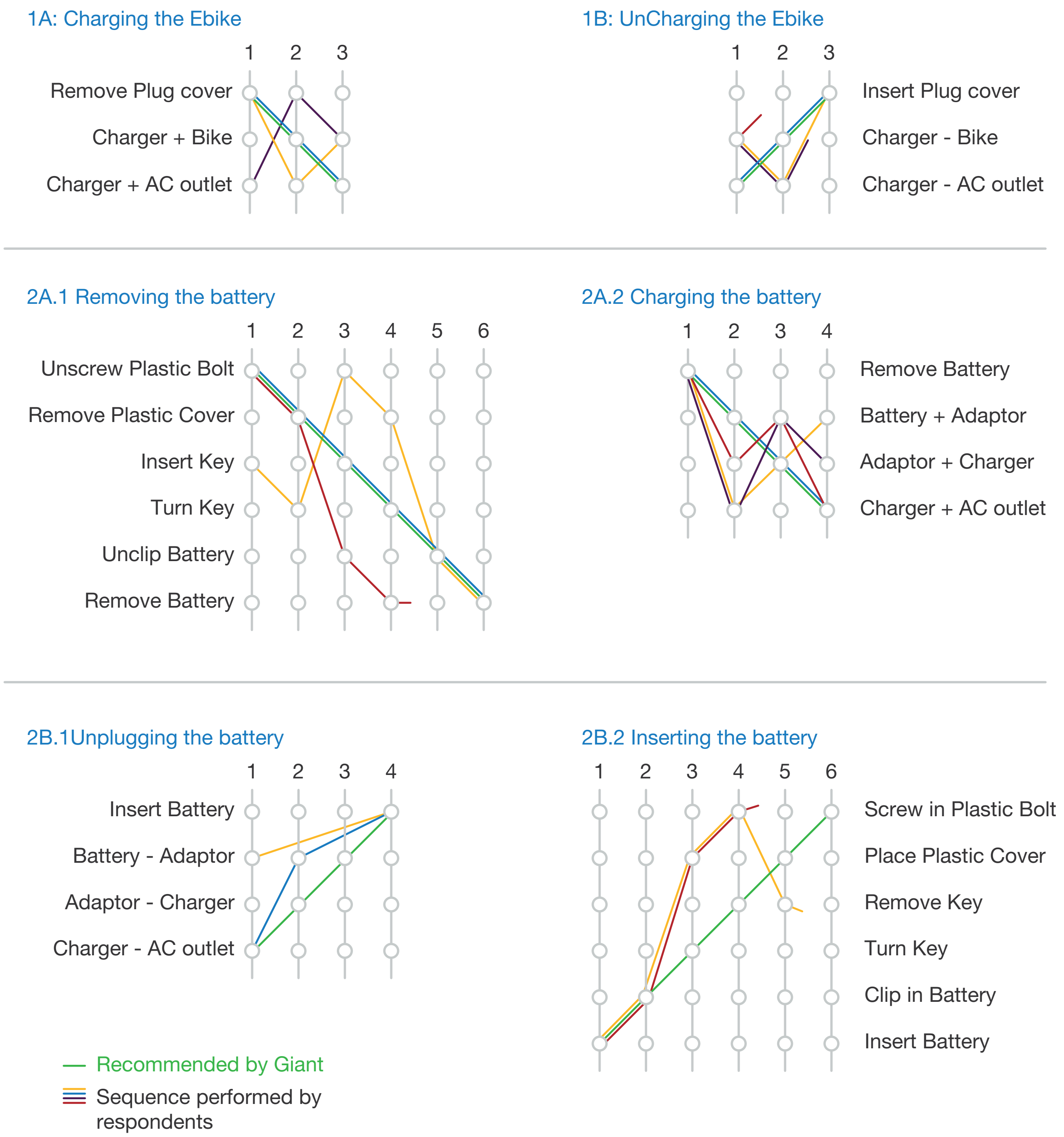


Figure 52: Sequence of stages carried out by the users during the test and that recommended by Giant

Conclusion:

- The design cannot be based on a set sequence the user must perform, it should be designed so it is safe to use regardless of the sequence
- Eliminating the adaptor would significantly reduce the sequence complexity.

2.4.6 Behaviour, Emotions, and Overall Usability

To calculate the user's emotions, the Emo-cards were used. If the average score of the emotions is taken based off figure 44, the average emotion score for the experienced users Vs the inexperienced users was 4.67 and 4.85 respectively. This tells us that both experiences were perceived as calm-pleasant, but the level of pleasantness and arousal cannot be based off these scores. To measure this data more accurately each of the components needs to be separated into level of arousal and level of pleasantness. With the average of the components calculated separately. To achieve this a graph plotted with arousal on the y axis and pleasant on the x axis was created. Depending on the emotion the user chose the score was selected shown in figure 53.

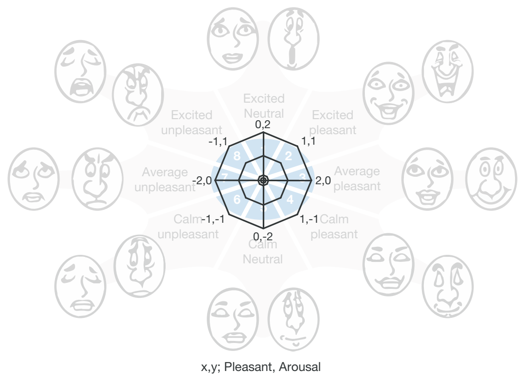


Figure 53: Plotting Pleasant Vs Arousal on a coordinate system

Emotions: Analysing the emotions of the user during the four tests, the average emotion score shifted depending on the task the user had to perform. The users found removing the battery to charge most unpleasant. While they found inserting the battery less unpleasant. This is likely because the users adjusted their expectation and only had to perform the tasks in reverse. Looking at the average emotion score plotted on the right diagram the average user's level of arousal and pleasantness dropped.

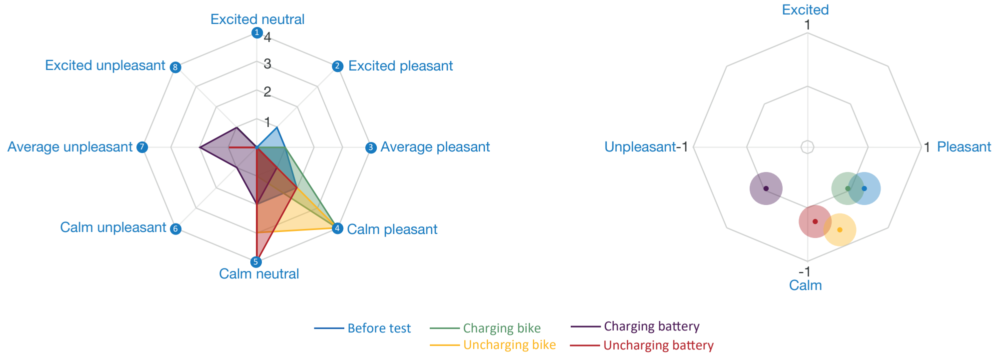


Figure 54: Users emotion after each of the 5 tests (based on the Emo-Cards)

The emotion score however was consistent with the reflection of ease of use of the four tasks, with the easiest task to hardest task being:

Figure 55: Four user test tasks ranked from easiest to hardest

The users determine this category based on the requirements of time to complete the task, number of steps required, and the amount of movement required.

Reflection on experience: using the four UMUX questions the user was asked to reflect on their overall experience. Based on the Final UMUX score out of 100 (the order of participants is in random for anonymity) these scores with the altered calculations of either 7-Score or Score-1:

	Inexperienced user				Experienced user		
Usability component	U1	U2	U3	U4	U5	U6	U7
1. Effectiveness	4	3	4	5	5	6	5
2. Satisfaction	5	1	5	2	5	5	6
3. Overall	5	5	6	5	4	5	5
4. Efficiency	6	4	5	2	5	6	6
Total /24	21	13	20	14	19	22	22
Total /100	**88**	**54**	**83**	**58**	**79**	**92**	**92**

Figure 56: UMUX score summary

Despite the large amounts of confusion or problems encountered during the tasks, most of the applicants scored the usability highly with an average score of 78, suggesting that the charging experience is not something the user critically analyses. The inexperienced users had a lower usability score with an average of 71 compared to the experienced users average score of 88, highlighting the usability challenges for first time users.

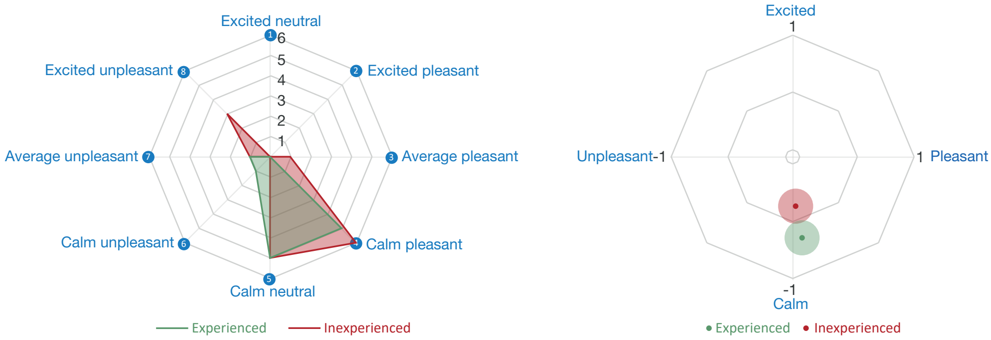


Figure 57: Users emotion based on whether they were experienced or inexperienced

This initial poor usability score aligns with a study by Moellendorff who explored the dynamic of user experience and how it changes over time [8]. The study found that the pragmatic goals improved over time whereas the hedonic goals deteriorated [8]. This was caused due to the increase in familiarity, as a result the usability increased leading to a better perceived usability. On the other hand, familiarity results in a lack of stimulation and excitement within the users, looking at the average scores from all usability tests by assigning a value to them. The inexperienced users experienced a higher level of stimulation (arousal) and a lower level of pleasantness. Whereas the experienced users experienced less stimulation and a higher level of pleasantness due to the familiarity of the bike.

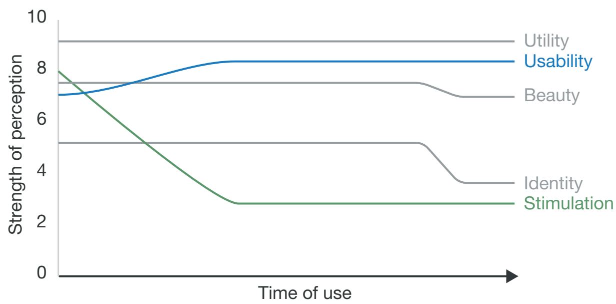


Figure 58: The typical trend and shapes of the five quality dimensions based on the mean elicited rating [54]

Conclusion: The first-time users experienced most of the problems and challenges. However, if they were to perform the task for a second time most of the problems encountered would be removed i.e. plug alignment, and knowing where the plug socket is. This was evident by the subject who was experienced with the Ebike as they could perform all the tasks nearly seamlessly.

2.5 Ebike Service support

To gather more insight into the current user experience at Giant an interview was conducted with the ESS (Electric Bike Service Support Team) see what problems the users encounter, but also from a service point of view of how to improve the serviceability of the charging system. Based on the discussion many points observed where consistent with previous observations such as the users struggling to know which sequence to plug in the charger, the users not understanding what the LEDs on the charger mean and providing better feedback to the user such as the charge status.

- Battery: If you press and hold the button for a long time there is a display which shows the last event code that was ran.
- Battery: Better linkage with the app. On the battery there should be a QR code that the user can scan to bring the user directly to the app where there are 30 second videos so the user does not have to read the manual.
- Battery: Should be engineered so it can be reused
- Charger: If the charger is fused, it no longer works, and the consumer needs to throw the whole thing away. The same is true for the battery. There should be a trip switch (magnetic fuse) that can be flicked for the user to see where the problem is.

2.6 Conclusion

Based on all the information gathered within this chapter, there are several ways in which the user experience can be improved. Looking at the user experience the testing so far has focused on usability, emotions and the resulting satisfaction level. With this distinction several improvement opportunities have been highlighted.

Accessibility:
For accessibility the size, weight and portability of the charger has been highlighted as important. Further insight into the accessibility is explored in the user survey section 3.1.

Performance:
Effectiveness: The charger feedback from the charger and battery needs to be improved.

- Charger: Understandable LED information
- Charger: Ensure charger modes are clear
- Battery: Feedback of the charging status

Efficiency: Reduce number of steps that are required by the user, reduce the likelihood of mistakes.

- Charger: Eliminate Need for an adaptor
- Frame: Eliminate need for additional plastic guard*
- Frame: Reduce likelihood plug cover is left open.

*(additional guard is not on every single Ebike)

Workload:
Physical: Reduce the amount of movement the user needs to do.

- Frame: Location of the charging port
- Battery: Integration of the battery with the bike

Mental: Reduce the amount the user must think.

- Charger & Frame: Make it easy for the user to know the plug orientation
- Charger & Frame: A Plug pattern that is rotationally unique
- Battery: Clear orientation for the battery to be inserted
- All: Sequence of connecting charging system steps should not matter

Emotion & Satisfaction:
The users are not critically analysing the charging system or reflecting on its performance, relating strongly to the Kano model with neutral experience or expectations. The achievement of positive emotion and satisfaction will be improved by optimising the previous steps mentioned above.

C3: USER BEHAVIOUR

The user testing has provided a good insight into how users interact with the system and the overall user experience however a bigger picture is needed to help further understand the extent in which the “consumers behaviour is being shaped by products or the product is shaped by the user’s behaviour” [58]. Therefore, it is important to understand whether the way people charge their Ebike is their choice or it is due to constraints such as living accommodation, power outlet, or how the battery is integrated on the bike. To help recognise these trends in user behaviour a survey was conducted.

3.1 User Survey

The survey conducted, combines the user experience and user behaviour to build up a bigger picture of how people interact with the charging system. In the survey there were 87 applicants, 84% were male, 14% female and 2% other. Out of the respondents there was a broad distribution of ages, Ebike types and living environments, resulting in a representative sample that provided a broad overview. The respondents were from all over the world with 47% of them being from the USA, 18% from the UK and 16% from the Netherlands.

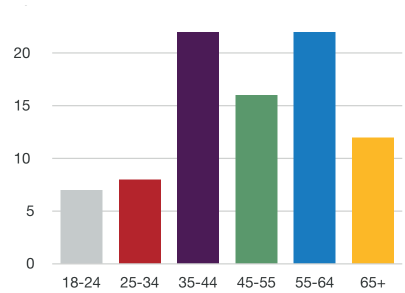


Figure 59: Age distribution of the respondents

User Profile:

To determine the user’s capability and some background of the applicants, a profile of their Ebike was made. For the survey 68 different bike models were analysed from more popular bikes such as the ‘Specialized Levo’, to ‘Radwagon 4’. The majority (57%) of the respondents owned one Ebike. The number of respondents who owned more Ebikes followed the relationship R=50/2^(n-1) , where n is the number of Ebikes owned. The respondents used their Ebike mainly for Mountain biking, leisure and commuting and are using their bikes frequently. With 90% of the respondents using their Ebike more than once a week, they will be charging their Ebike regularly.

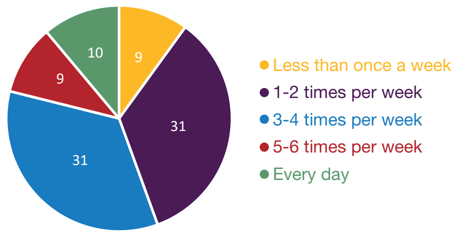


Figure 60: Usage of Ebikes

Living environment: To get an idea of the current context the Ebikes are used in, data was gathered on the living area, living accommodation and location that the Ebike is stored when not in use.

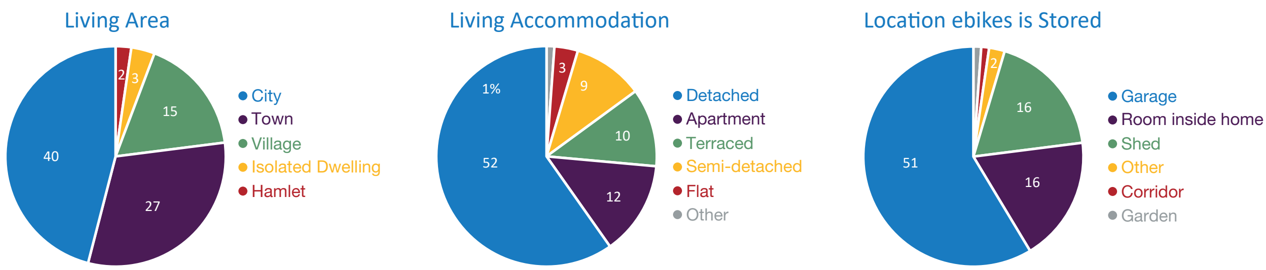


Figure 61: Pie charts comparing the users living condition to where their Ebike is stored

Most of the applicants live in a detached house and the bike is mainly stored in the garage, shed or a room inside the house. When comparing the data, based on the values of regression, there is no significant correlation between these three variables. Therefore the location or living area does not appear to have much significance on how the Ebike is stored.

3.1.1 Charger & Battery

Preferred choice of charging: The preferred choice of charging is charging through the bike (62%) rather than charging the battery (34%). The applicants where then asked how they charge the bike and the type of task the respondents performed. The results aligned with their preference and there was no difference. However, it is difficult to determine whether the preference is shaped due to current constraints within their context or because they altered their context to fulfil their preference.

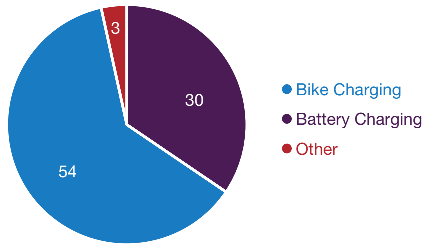


Figure 62: Preferred choice of charging

When asked to comment on the why the user charges the bike. The response varied significantly. The respondents who charge the bike, prioritise convenience, and efficiency. They stated it was easier because the "battery is within the bike" and because "the bike is stored on the wall".

Whereas the users who prioritise battery charging, prioritise the protection of their battery and safety over convenience. They do not want the battery to get cold and want it nearby so they can monitor the battery during charging to reduce the risk of a fire meaning that the user's charging system is not dependable. The second most popular response what that there was no power of accessible plug where the bike was stored, highlighting that context is the reason for their preference. If there was a socket or power in the garage, they would likely charge the bike directly.

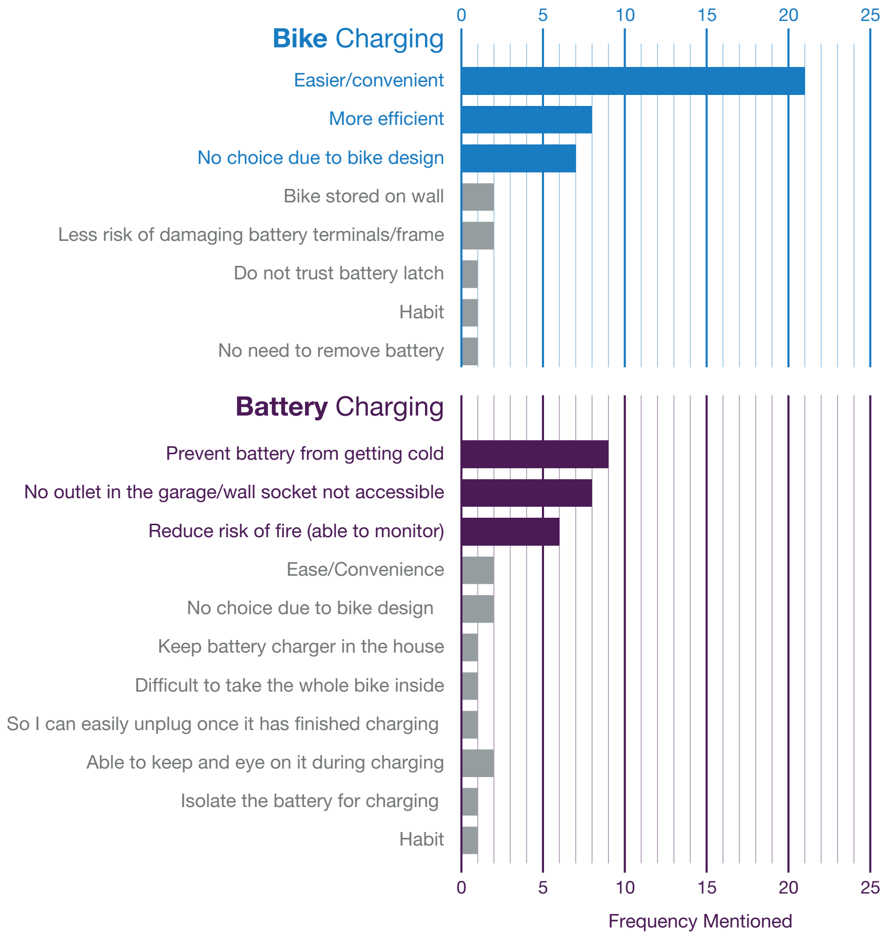


Figure 63: Reason for charging preference

Charging on the Go: 39% of the respondents never charge on the go, away from home, whereas the rest either sometimes or always charge away from home. Out of these respondents a larger proportion of respondents are removing their battery to charge their Ebike compared to their preferred method as stated before. This highlights that while charging the bike is the preferred method the flexibility of being able to charge the battery is important.

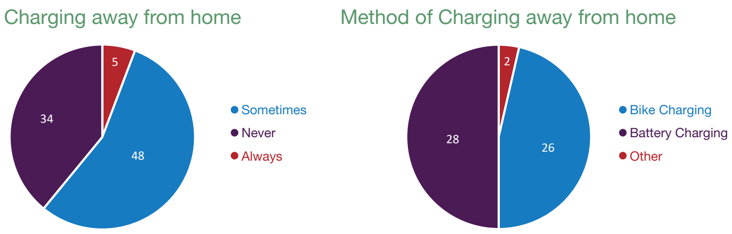


Figure 64: Charging away from home and method of charging

Charging system feedback: When charging the bike or battery the respondents want to receive feedback. With the respondents either using the bike display, the battery, or the charger to receive the information of the charging status. How the respondents receive feedback depended on whether they are charging the bike or the battery.

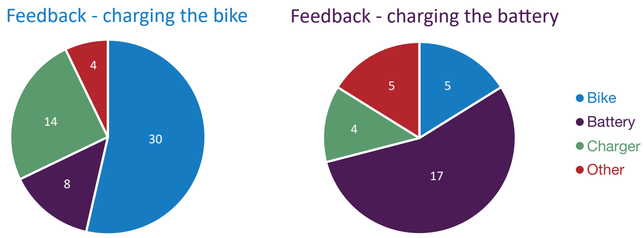


Figure 65: Where the respondents receive feedback when charging their bike

The feedback the majority of respondent are using is either on the bike's LCD/LED display when charging the bike and via the LED display on the battery when charging the battery. The use of the charger for gathering information is currently not in the majority. Others will obtain feedback through an application on the user's phone. The respondents were asked whether they thought the charger information was easy to interpret. The average score was 8.25 with a standard deviation of 2.17, suggesting that most of the respondents found it a very intuitive.

However, when asked whether they are thought the communication (effectiveness) could be improved, there was a large divide between respondents with an average score of 5.25 and a standard deviation of 3.70. So while they found it easy to interpret, they still felt the charger/ charging system lacked information.

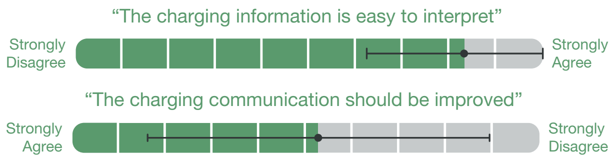


Figure 66: Effectiveness evaluation statements

To determine what charging feedback the user wanted, an open question was given, and the frequency of similar suggestions were recorded. Based on the responses, most of the respondents wanted to see a battery percentage rather than 4-5 flashing LEDs. They would also like to know how long it is predicted until the battery is fully charged. Other less commonly mentioned feedback suggestions which could be interesting to explore is information showing how far the bike could travel with the current level of charge and suggestions to increase the longevity of the battery through smart charging cycles.

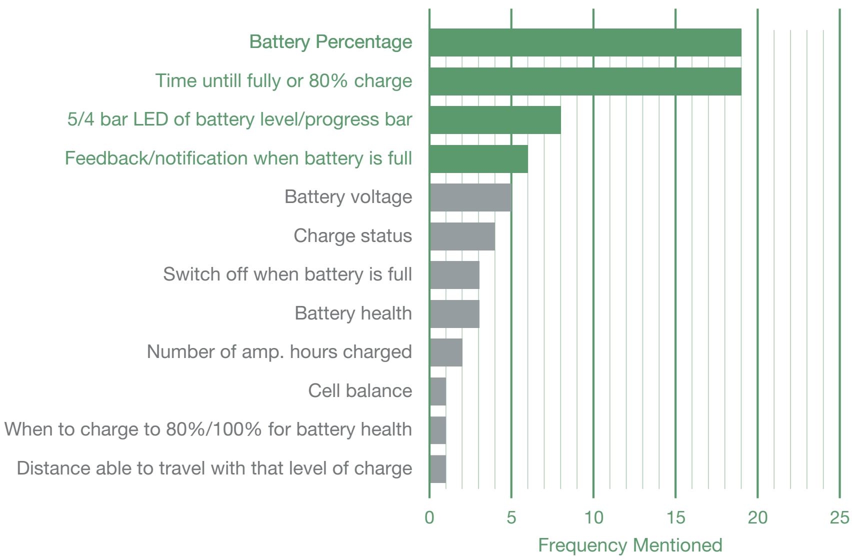


Figure 67: Charging feedback respondents wanted

Charger Plug:

Plug Types: To try to understand potential challenges the respondents are facing with certain plugs, the plug type used were analysed. Looking at the plug types, most of the bikes either used a Bosch fitting (20 respondents) or a barrel fitting (27 Respondents).

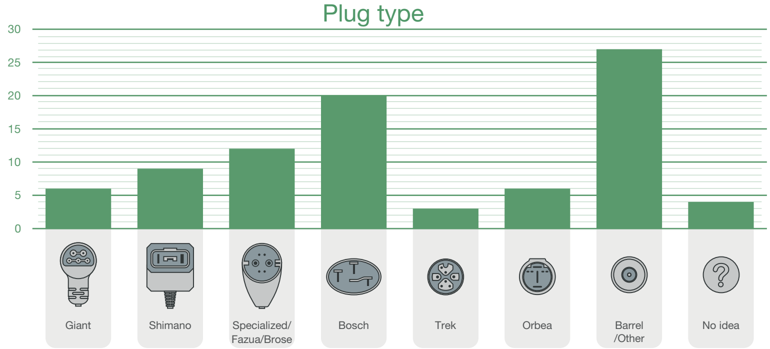


Figure 68: Plug type

The users were asked whether they found it easy to charge the bike, (1, Strongly disagree & 10, Strongly agree). The average score was 8.74 with a standard deviation of 1.78 suggesting this is not a procedure most people are struggling with.

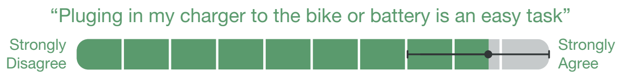


Figure 69: Ease of charging the bike statement

A separation of the average score was analysed to see if there was a significant difference between the plug type and port location against the ease of use. The location does not appear to have a significant influence on the ease of use of the plug. However, some plugs do score lower on average than others, but due to the sample size of each plug varying from 3-27, the small sample size of the trek plug is not representative. The results also show that the more expensive Rosenberger plug does not create significant benefits compared to the other plug type suggesting that the additional investment has not significant benefits.

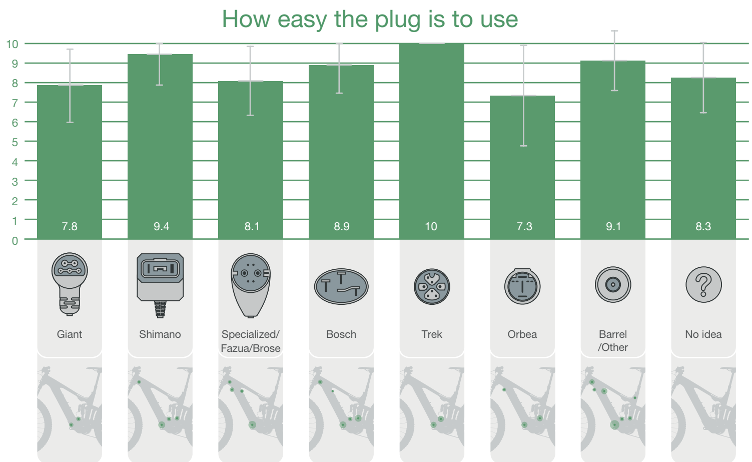


Figure 70: Plug ease of use in relation to the plug type and location

For those that encountered problems with their plug, these were mainly due to the orientation and the charging cover being poorly designed. However, the number of users which had problems with the plug was very low compared to the other tasks.

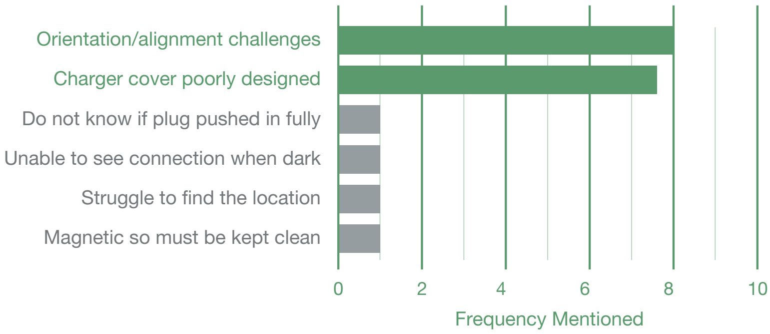


Figure 71: Problems encountered when using the plug

3.1.2 Frame

Inserting and removing the battery from the frame: To understand how the respondents interact with the battery and what context they remove the battery, a series of questions were asked. The main reason why respondents are removing the battery is for charging, followed by security. Based on the previous questions within the survey battery removal (charging) was only carried out by 34% of the respondents on a regular basis.

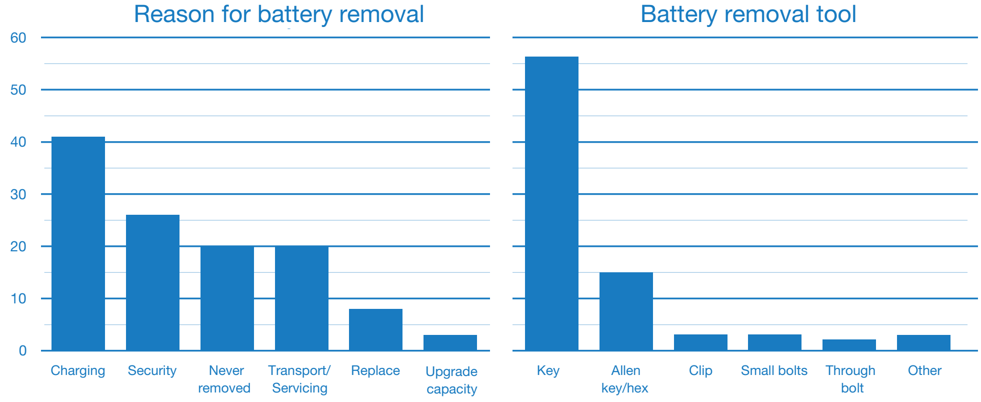


Figure 72 & 73: Battery removal and battery removal tool used

Of the respondents' bikes assessed the battery is most removed by a key and released by bottom pivot. While respondents like the Allen key they said sometimes it was difficult to align the Allen key with the bolt. The way which the battery is removed was also asked, with bottom pivot or top release being the most popular.

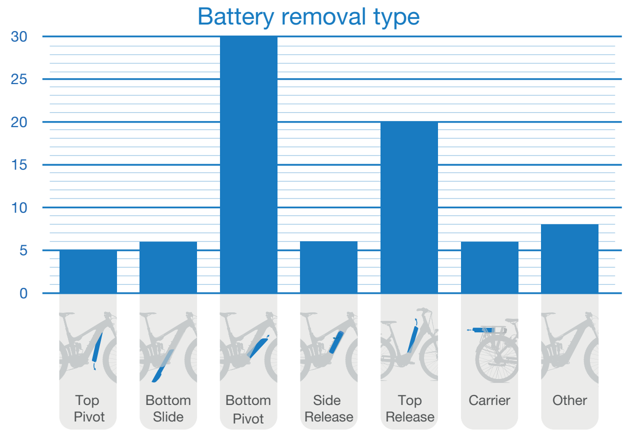


Figure 74: Battery removal type

The respondents were asked how easy they found it to remove their Ebike battery out of 10. The average score was 6.87 with a standard deviation of 2.67. Suggesting that there is some negative experience when removing the battery. This ties in with the reasons given why most people resort to charging the bike rather than the battery.

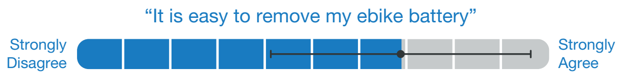


Figure 75: Ease of removing battery

Analysing what score out of ten was given for removing the battery based on the respondent's battery integration type there was a slight variation. The top pivot and top release scored slightly higher compared to the other removal methods. This could be due to less obstruction between the frame and the battery.

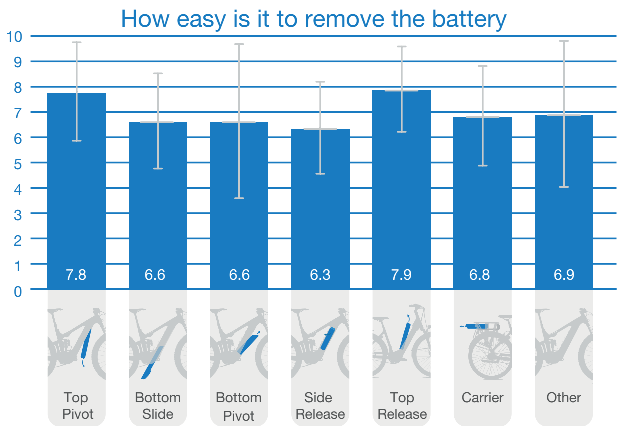


Figure 76: Ease of use for the battery removal in relation to the release type

For those who struggled there were a wide range of challenges. A common issue is that the battery is tight in the frame making it difficult to remove. However one user commented that this is a good thing because 'it means the battery is secure and will not rattle in the frame'.

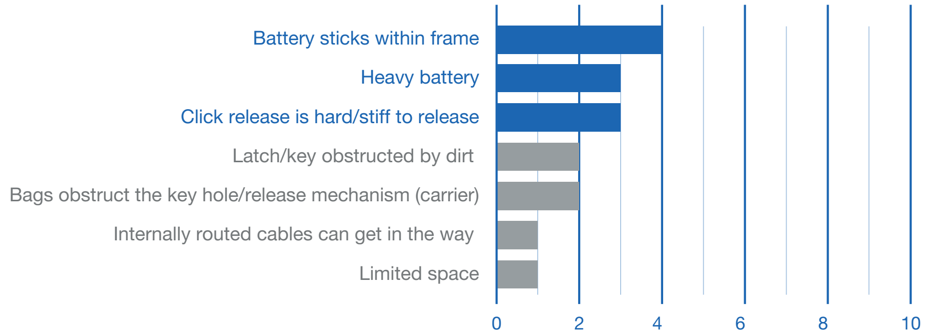


Figure 77: Common problems when removing the battery

Location: The most popular location of the charging port remained in the lower section of the bike, however the respondents were asked whether they preferred a location. The preferred location shifted higher up the bike. When commenting on their decision the users who preferred the charging port in the top region prioritised easy access, easiest to see when dark and less chance of contamination from water or mud. Whereas the users who selected the bottom region also prioritised ease of access, 'especially when the bike is hung on the wall' or stated that they liked where it was and had no preference.

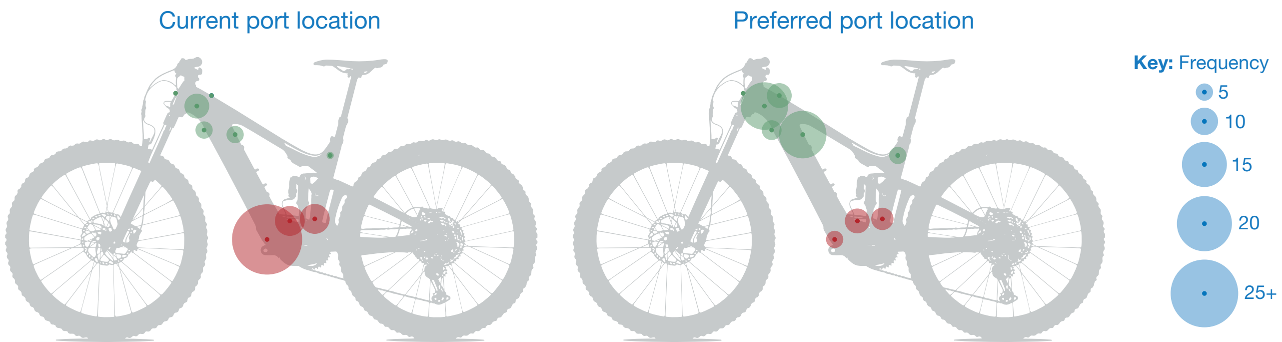


Figure 78: Port location Vs preferred port location

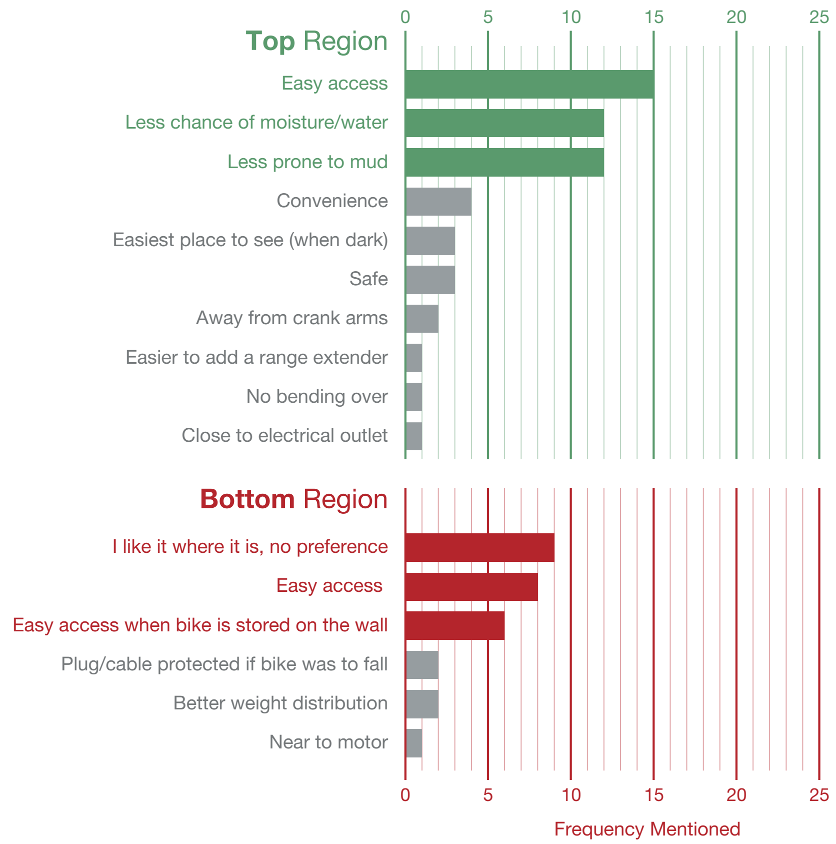


Figure 79: Reason for port location preference

3.1.3 Emotions, and overall usability

Emotions: Analysing the emotions of the overall charging experience, the average emotion was relatively neutral with a slight shift towards the calm pleasant region.

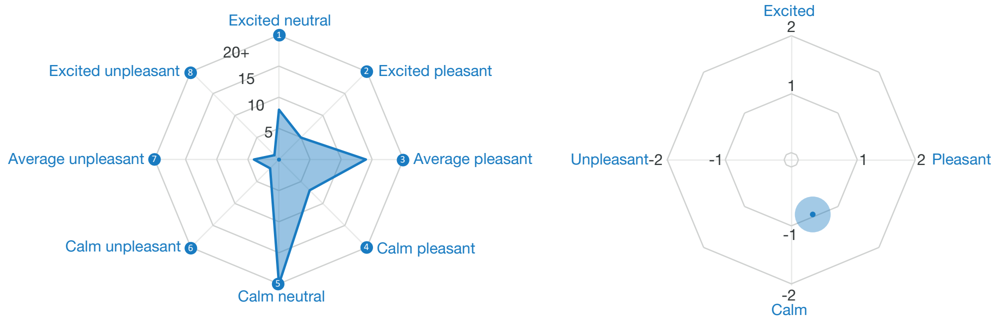


Figure 80: Frequency emotions were selected and average level of arousal/pleasantness

Reflection on experience: Using the four UMUX questions the user was asked to reflect on their overall experience. Based on the Final UMUX score out of 100, the average UMUX score was 82 with a standard deviation of 16.86 with a range of 13-100. While the majority find the experience positive there are a few respondents who have a very negative experience.

Usability component	Average Score /6
1. Effectiveness	4.70
2. Satisfaction	4.90
3. Overall	4.98
4. Efficiency	5.17

Figure 81: Average UMUX scores for each usability component

Based on the average from the four questions, effectiveness scores the most poorly highlighting potentially the lack of information or feedback within the charging system. The respondents perceive the current system to be efficient and have a relatively high level of satisfaction, however as seen within this survey there are still opportunities to im-prove the overall charging experience and elevate the overall satisfaction.

3.1.4 Survey Conclusion

Based on the survey conducted there are several aspects where the user's expectation does not align with the current system, and the user must adapt their behaviour to the current system. Breaking down the user experience components, each one is discussed based on the findings:

Accessibility:
- Charger: Easy to see in poorly lit conditions
- Frame: The location of the charging port plays an important role in determining where/how the bike is stored.

Performance:
Effectiveness: Provide clear feedback when a task has been fulfilled:
- Charger and/or bike display:
  - Time left to charge
  - When battery is fully charged
  - How far can be travelled on the charge level
  - Notify user through app
- Plug:
  - Feedback when plug is fully pushed in

Efficiency: Reduce number of steps that are required by the user, reduce the likelihood of mistakes

Workload:
Physical: Reduce the amount of movement the user needs to do.
- Battery: Easier removal and insertion of battery
- Charging: Easier for the charging port to be removed

Mental: Reduce the amount the user must think.
- Charger: Provide advice/guidance on how to increase the longevity of the battery.
- Charger: Switch off automatically when battery has reached desired charge level
- Charger: Make it easy for the user to know the plug orientation

Emotion & Satisfaction: The current charging system is perceived to be efficient and has a relatively high level of satisfaction. Based on the UMUX score the effectiveness of the system should be focused on the most.

3.2 Further Analysis

The survey highlighted several different aspects and decisions the users take to determine how they interact and respond to certain constraints when charging their Ebike. In addition to the survey an Ebike was used by the author for 2 months to test the charging experience as a first person to gather further insights into the stages required to charge an Ebike. To help separate the events of the user behaviour, four different stages will be discussed:

1. Ebike Usage
2. Preparation
3. Charging
4. Termination

3.2.1 Usage

Depending on the type of riding the user performs, the way they use their bike and when they charge their bike will vary. Four typical usage scenarios are mapped out and discussed to highlight different ways the user may use their bike and when they will be charging their bike during the day.

Adventure: This scenario depicts a user who is going out on a big adventure with a planned to set off at 7:00 in the morning, but realised they forgot to charge their Ebike. They charge their Ebike. Every 20 minutes they check the charge of the bike by switching it on, connecting it to the app and seeing the battery percentage to check the status of the charge because they want to go riding as soon as possible. When it reaches 100%, they drive to their starting location. They begin their large ride which they do regularly. At lunch time they lock their bike and charge their battery for an hour at the café. They then continue the second part of the ride where they end up where they started and will 're-member' to charge the bike next time they use it.

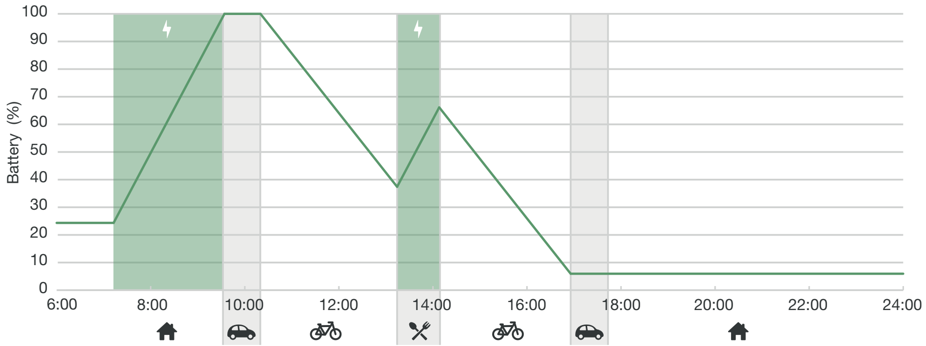


Figure 82: The timeline of an adventurer

Commuter: The user commute 20Km to work every day on their Ebike. Before they set off, they check their charge. With 60% battery they will have plenty of charge to make it to and from work. At work they remember they forgot lunch so make a short trip. On their commute home they nearly run out of charge. When they arrive home the commuter understands lots about battery retention and sets a time on his phone to remind him to charge his Ebike in an hour. When they then charge their Ebike they set a new timer to remind him to unplug the charger in 2.5 hours when it will be around 70% charged, they do not need much more capacity each day for his commute to work. After 2.5 hours they check the charge once to confirm the battery is at 70% then unplugs the bike.

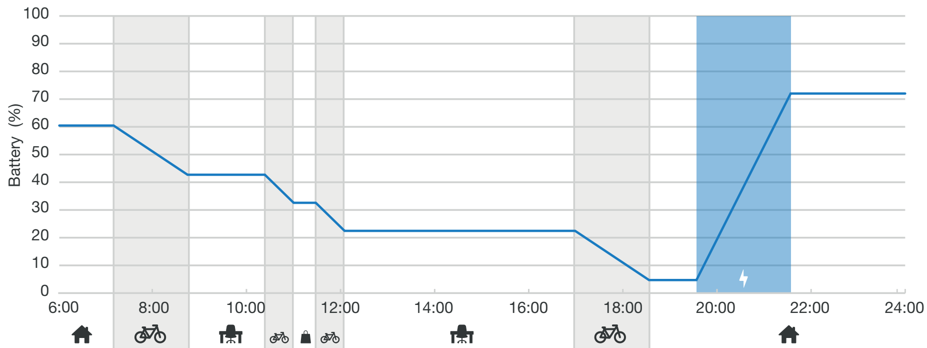


Figure 83: The timeline of a commuter

Leisure: The user only works 3 days a week and on the other days they try to go on a short road cycle on their electric road bike. They only use the road bike for assistance up the hills to allow them to get a good level of exercise and con-serve the battery. The battery is able to last the whole week and every Sunday, depending on the charge, they charge their Ebike in the morning or evening. Since they do not charge their bike frequently they sometimes struggle to remember what the lights mean on the charger and therefore have issues connecting the bike.

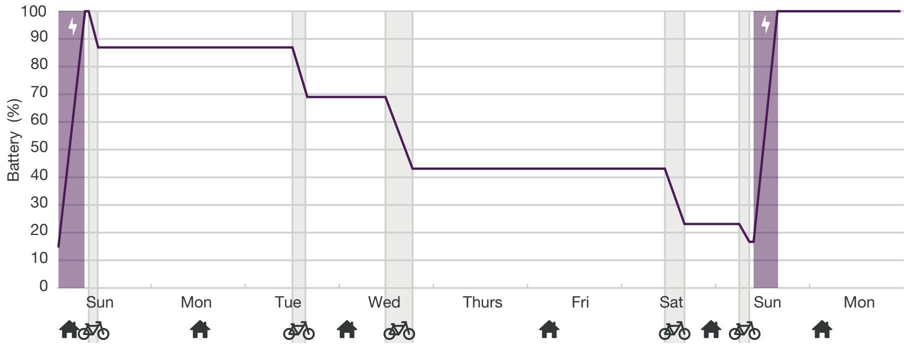


Figure 84: The timeline of a e-road bike user

Mountain: The mountain biker is going on a ride they do often. They know that they would have enough battery at 65% charge however they do not like going on a ride without the bike being fully charged. They charge the bike in the morning just after they wake and will unplug the bike as they use it. After their mountain bike ride they put their bike on to charge immediately since it is a habit. Just before bed they remember their bike is still charging and they unplug it.

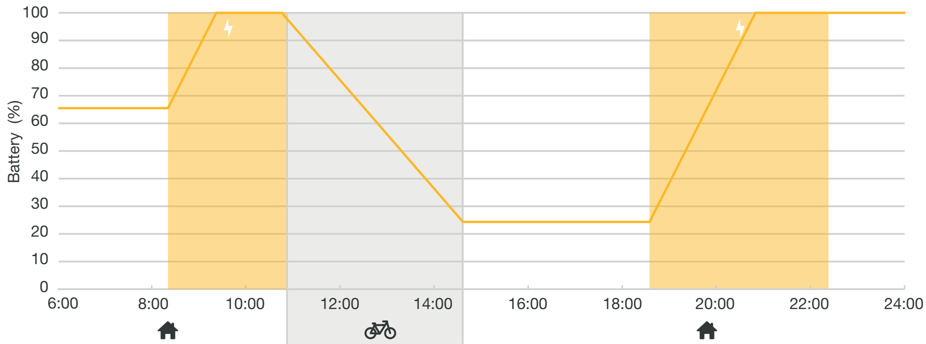


Figure 85: The timeline of a mountain bike user

While only a few scenarios have been discussed, there are a huge range of different usage scenarios and the way people use and charge their Ebike varies greatly. While there is no clear trend when the users are charging their Ebike, most of the users seem to charge their Ebike just before and/or just after a ride, whether this is every time the Ebike is used or on a weekly basis.

Figure 86: Electric Mountain bike user [1]

3.2.2 Preparation

Accessibility plays an important role in determining how the user prepares their bike for a specific operating procedure. This is whether the user charges the bike inside/outside or through the bike/battery. Based on the survey conducted there are several prominent decisions and constraints the user must undergo to determine how they will charge their bike in their home. The behaviour the user performs initially is based on Context, Dependability, user Capability (level of control) and Design. These constraints guide the user into performing a certain task.

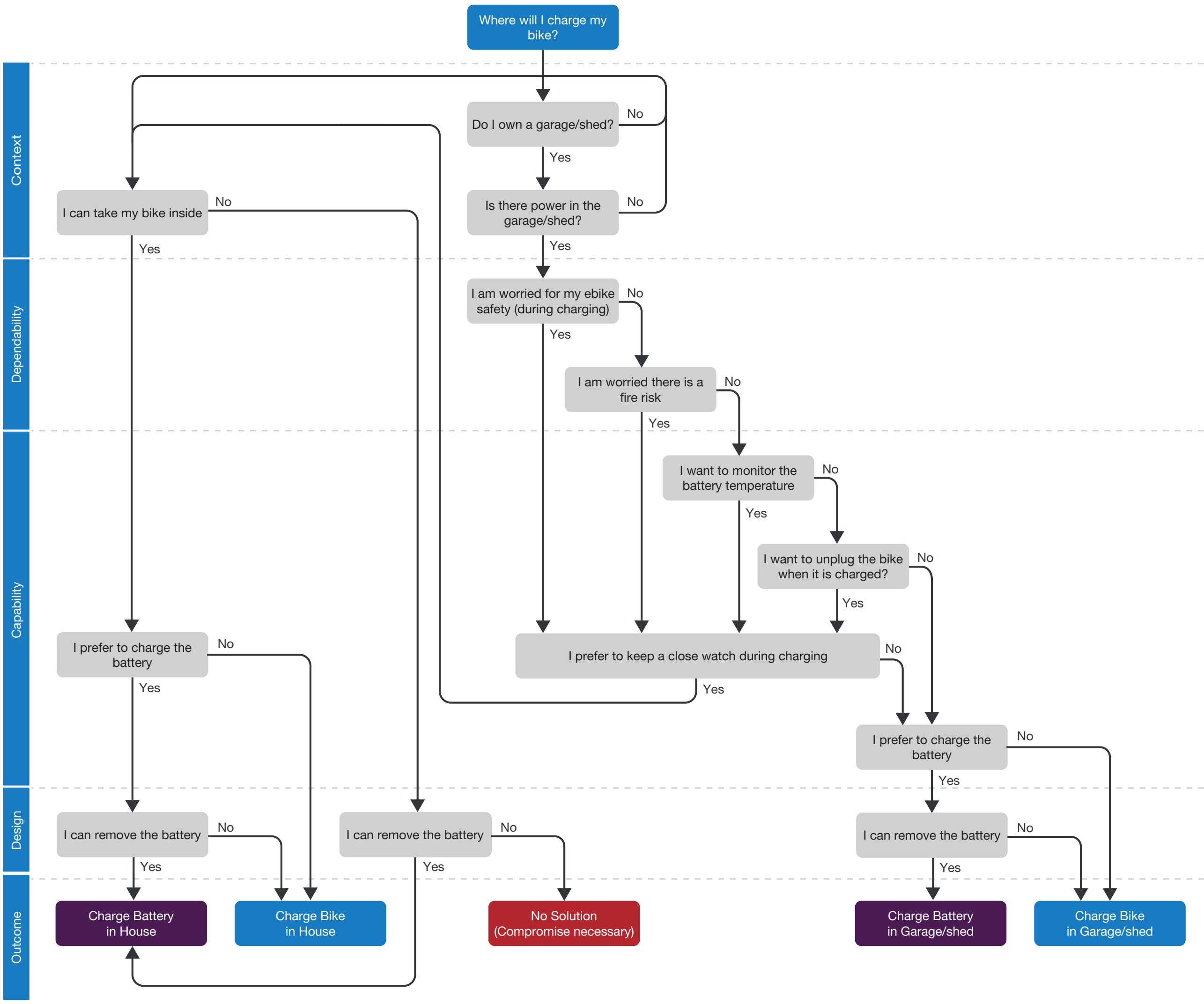


Figure 87: Constrains causing a certain user behaviour.

The figure above highlights the certain constraints which cause a user to choose a certain charging method. This diagram simplifies the problem and highlights the barriers the user must overcome if they want to charge their bike in a specific way. During the flow diagram if the contextual constraints are removed the decisive factor as to whether the user charges the bike in the house or not in the house (garage or shed) comes down to if they want to closely monitor the charging/bike based on the level of trust they have for the charging system.

Preparation procedure: Once the location of where the bike or battery is to be charged is decided upon, the charging preparation procedure can begin. The flow diagram below shows the procedure the user conducts to charge their Ebike or the battery.

The flow diagram (figure 89) highlights how fewer steps there are charging the Ebike compared to charging the battery, supporting the reason why the charging the Ebike directly is the preferred option. With the elimination of the adaptor the steps could be reduced. However, most people who charge the battery will leave the adaptor connected to the charger and therefore the step of connecting the charger to the adaptor is only carried out during the first use.

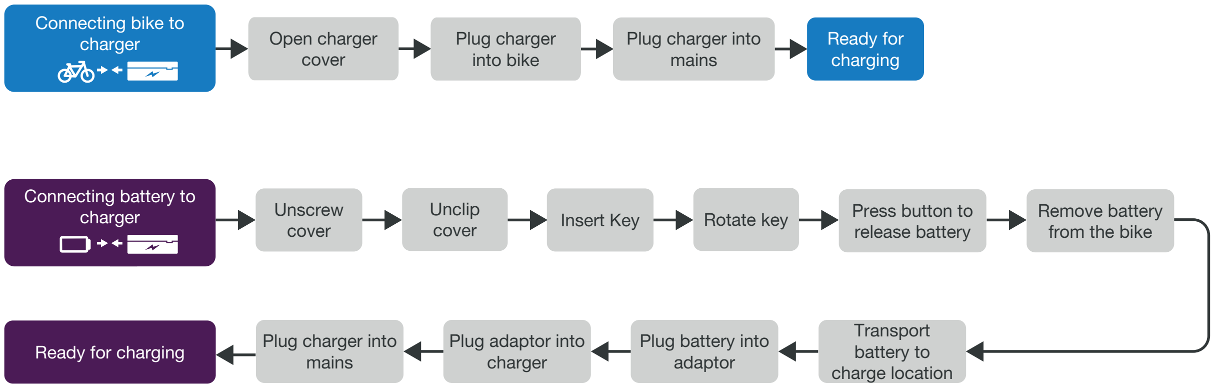


Figure 89: Stages to connect the bike or battery to the charger

Charging habits: The context in which the flow diagram is carried out varies depending on the location of the charging port and how the bike is stored. Six scenarios are outlined below.

Analysing the different scenarios, the location of the charging port (high or low) can be visualised. When the bike is hung on the wall a lower charging port is more accessible, however when it is stored on the ground a higher port is more accessible. The presence of a shelf helps lift the wires off the ground while supporting the weight of the transformer reducing the amount of strain on the plug connection. This is important to note especially in scenario number 2 the plug connection must be strong enough to support the weight of the transformer (charger box).
The scenarios with a shelf are ideal in a garage environment to protect the charger from dirt and grime on the ground.

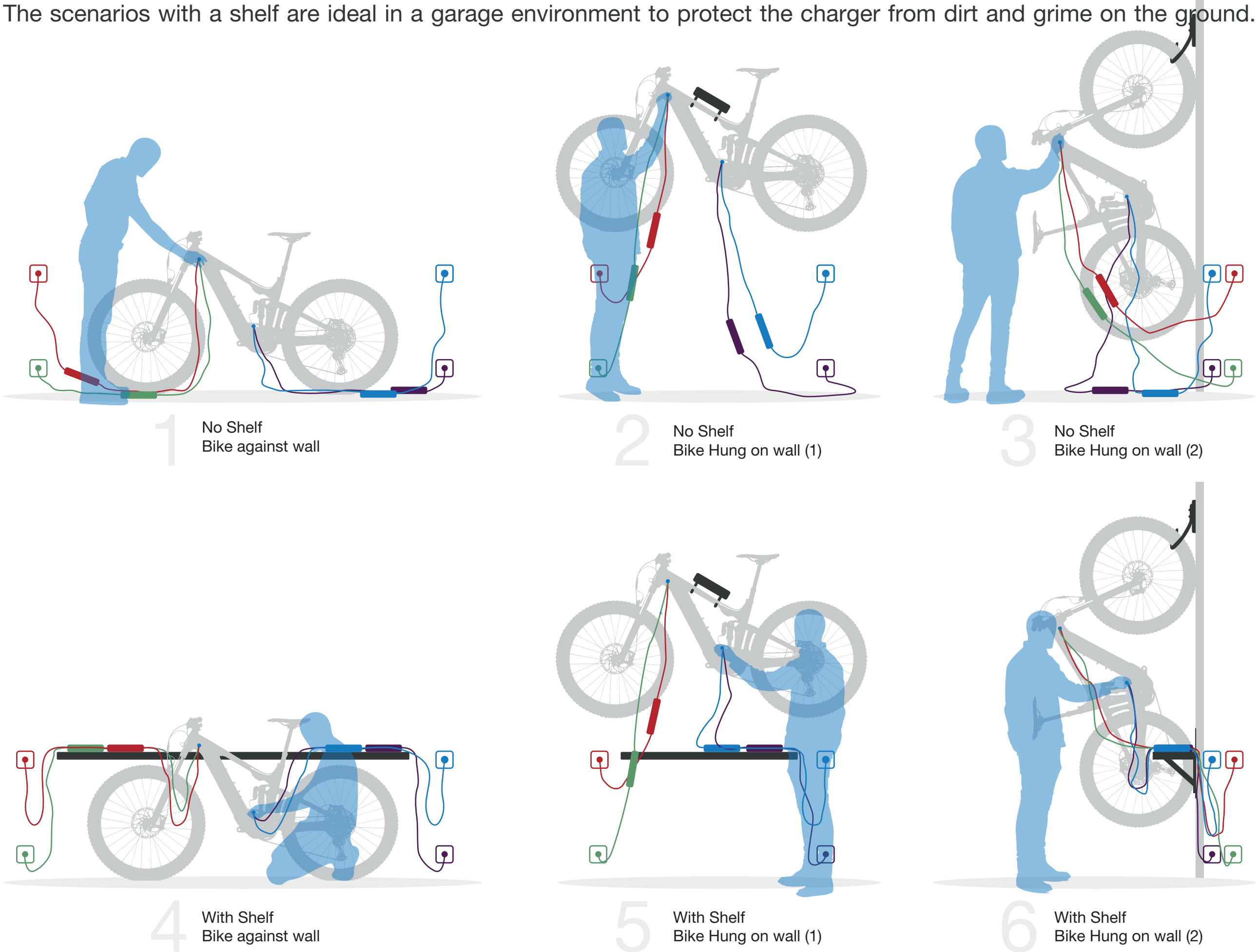


Figure 90: The different charging port locations and the effect of cable management and accessibility

However, for users with multiple bikes the bike that needs charging may not be close to a wall and therefore the charger cable must trail over the other bikes. This scenario is common with take-away or bike hire shops where they plug several chargers into an extension lead and run each charger their fleet of 10-15 bikes. This leads to a sea of cables, chargers and extension leads and as you imagine it can become a high fire risk.

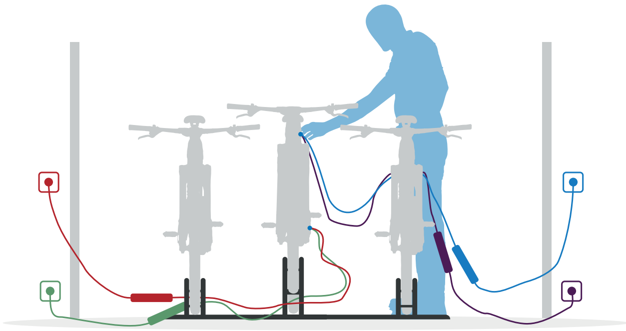


Figure 91: Charging scenarios of a user setting up the battery for charging

Looking at scenarios of charging the battery (below) there is less variation: either it is charged on the floor or on a shelf/ counter top. Despite the battery being heavy it is more manoeuvrable and therefore can be picked up and moved around much easier than a bike. Therefore, the user would either pick up the battery plug the charger in then place it back down on the surface or plug directly into the battery.

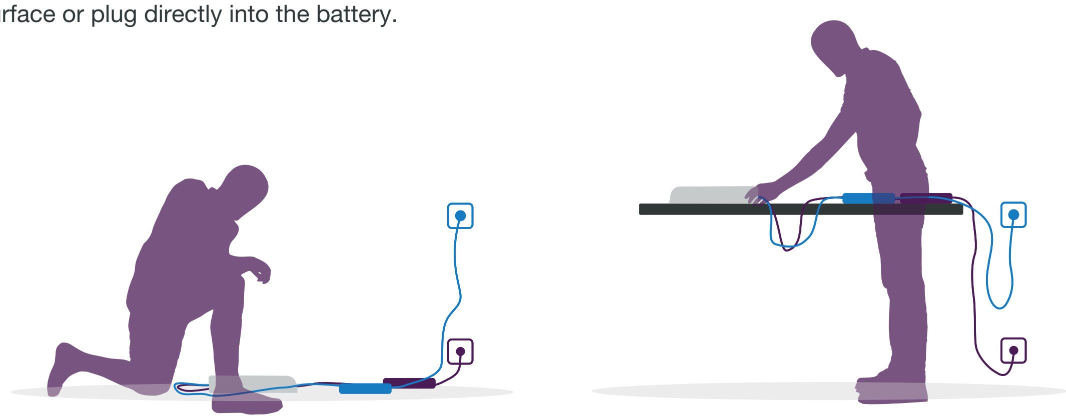


Figure 92: Charging scenario of user setting up the battery for charging

Once the user has determined the most convenient way of charging for them their charging setup will remain consistent. This means that they will likely not disconnect the cables initially and likely only unplug the charger from the bike or the battery, Leaving the charger still attached to the mains. For the users who charge the battery they will likely not notice the presence of the adaptor since most of the time it remains attached. That said, with the additional adaptor the issue come if the user changes their charging from bike to battery, for example they are going out on a long ride, or their contextual constraints have changed. Remembering to bring this adaptor, or even finding, it creates an unnecessary burden which could be mitigated through better design.

Feedback: When looking at the field of view of two scenarios, the location of the feedback (highlighted by circles) is not located within the field of view except for the battery LED's. In this situation the user must move to be able to see whether the bike/battery is charging. If it is not, they must move again and correct the problem. This unnecessary movement means that the feedback is not quickly obtained and will reduce the overall efficiency during the preparation. Similar situations occur for other scenarios, and whilst in some scenarios the bike display or charge is in the field of view, in the majority of the situations they are not since the focus is on plugging in the bike.

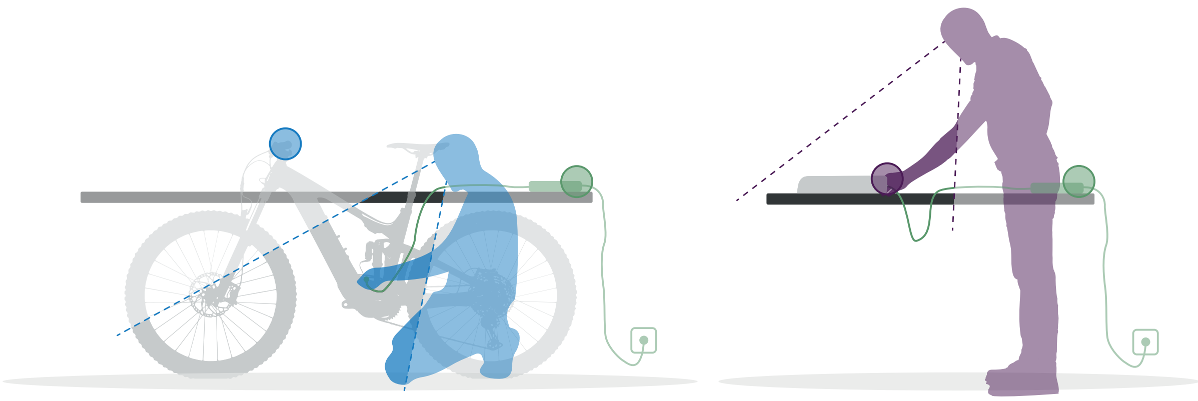


Figure 93: User field of view compared to the location of the feedback

3.2.3 Charging

During the charging process based on the survey conducted users charge their bikes in multiple different ways. These different ways will be explored through two flow diagrams based on Giants current Ebikes with (ergo 1-2 displays). Both diagrams are broken into two main phases:

1. Charge confirmation: which involves the user ensuring that their Ebike is charging
2. Monitoring: This involves the user checking the charging status to check the battery percentage.

*Note: To simplify the diagram the storage option to charge to 60% has not been included

Charging the bike: The first diagram (Figure 95: Page, 054) depicts the procedure steps the user can follow to charge their bike. The dashed boxes and lines represent components of the charging system that do not exist but could be incorporated to help improve the process.

Looking at the different procedures the user can take, they must first confirm that the Ebike is charging - this can be done through the feedback on the bike or the charger. If the charger is not charging alterations must be made. Currently there is no feedback as to where the fault could lie, therefore a trial-and-error approach by the user must be conducted to solve the problem. The correction task options listed involve ensuring the plugs are properly inserted. Poor connection could also be due to the presence of dirt.

Once the user has received feedback that charging has started, they can leave the charger and return in x number of hours when fully charged to 100%. However, if they want the charge to be less than 100% they must monitor the battery percentage during charging. To monitor the battery level, there are currently two ways this can be achieved either through the Bike display or via the app. Looking at the charge through the app will give the user an accurate display of the charge percentage however it requires more steps. Once the charger is at the desired percentage the user must unplug the charger if not the battery will still be charged until 100%.

Charging the Battery: The second diagram (Figure 96, Page, 055) depicts the procedure steps the user can follow to charge their battery. The dashed boxes and lines represent components of the charging system that do not exists but could be incorporated to help improve the process.

This flow diagram is very similar, however compared to the battery charging the main difference is that the user cannot use the application to see the exact percentage of the battery. To monitor the charge status of the battery currently the user only has the 5 LEDs on the battery so accurate control of the battery percentage in this scenario is limited.

Sequence of steps: The diagram below shows 4 different scenarios to charge the bike, looking at the steps the user takes. For the yellow user who just wanted their battery charged to 100% the charging experience was seamless with no repetitive steps. However, for the three other users they wanted their battery to be charged to less than 100% or did not want to overcharge their battery, therefore they were required to monitor their battery percentage and unplug the charger once it had reached that desired percentage.

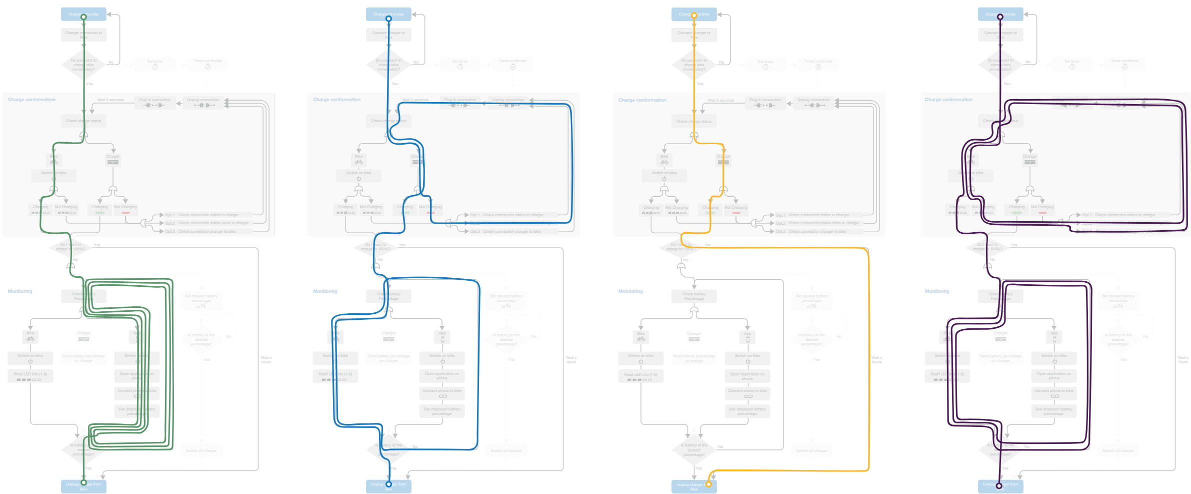


Figure 94: Example of different paths the user could make to charge their bike (colours relate to personas in 3.3.1).

For the blue and purple users, they did not get the charger to work first time and had to wiggle/adjust the cables to get the green light on the charge, or the flashing white light on the bike to provide feedback it was charging. Sometimes during this process there was a small delay between the charger from turning from a red light to a green flashing light which caused frustration. Based on these scenarios there is room for improvement, to make charging to a certain percentage more seamless, while ensuring that for the users who do not worry about their battery retention (yellow user) the design choices to make a more seamless experience for the other users does not hinder or extend their current charging approach.

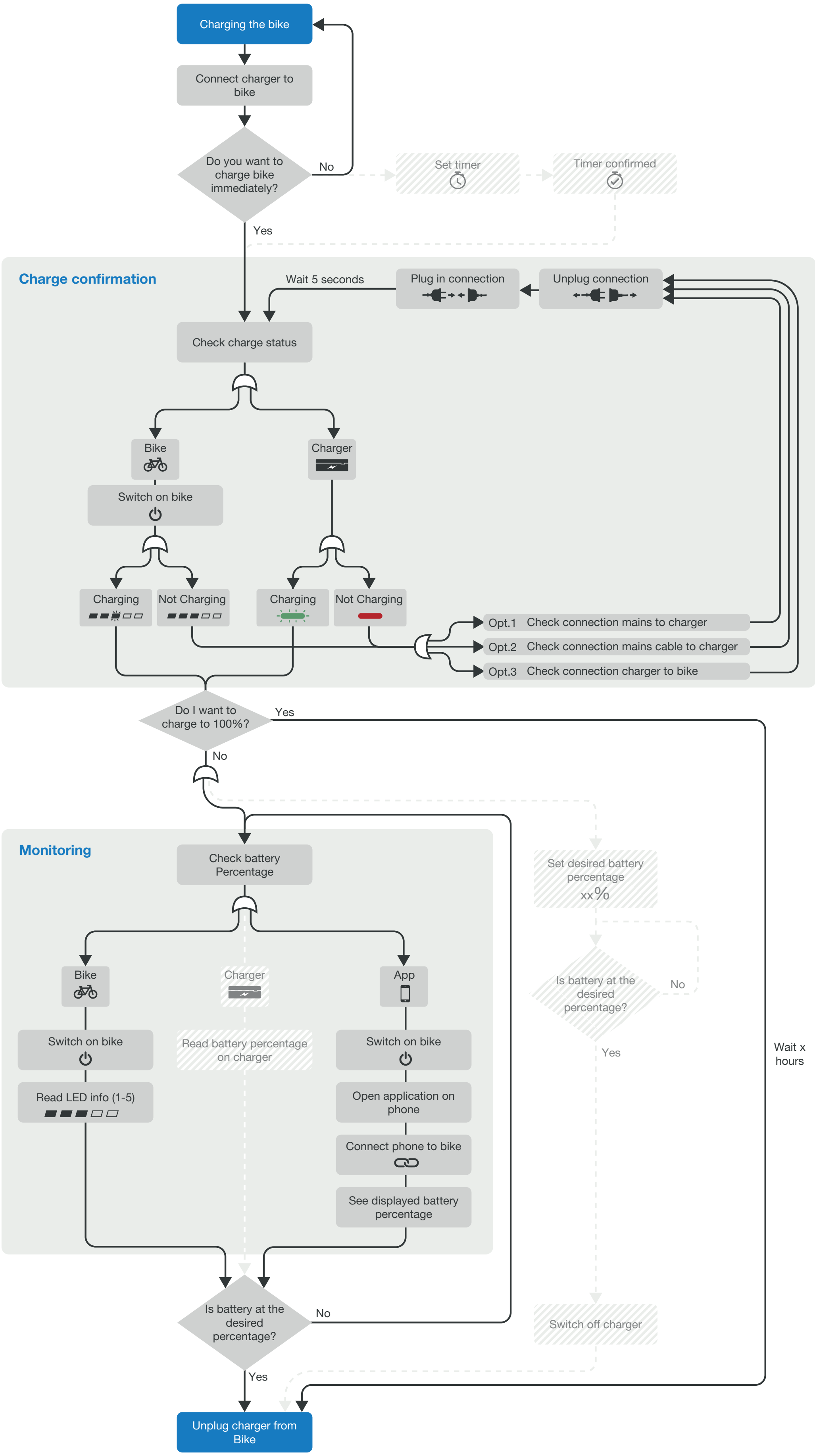


Figure 95: Flow diagram for the charging of the bike

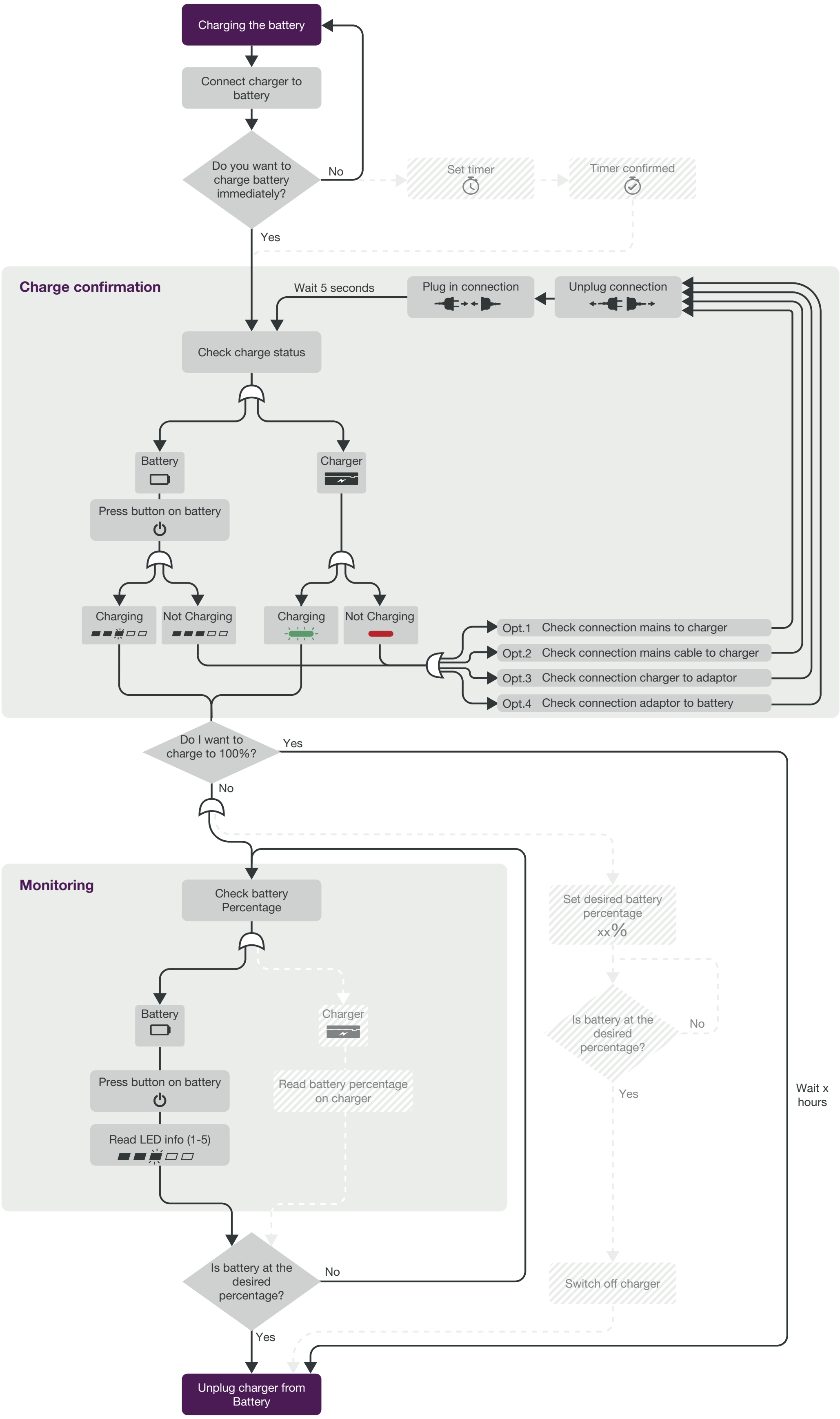


Figure 96: Flow diagram for the charging of the battery

3.2.4 Termination

Termination involves finishing charging and having the bike ready for a ride. For the process of charging the Ebike the termination steps are relatively straight forward, however, the steps for inserting the battery are more complicated with more steps. The steps for this are outlined below.

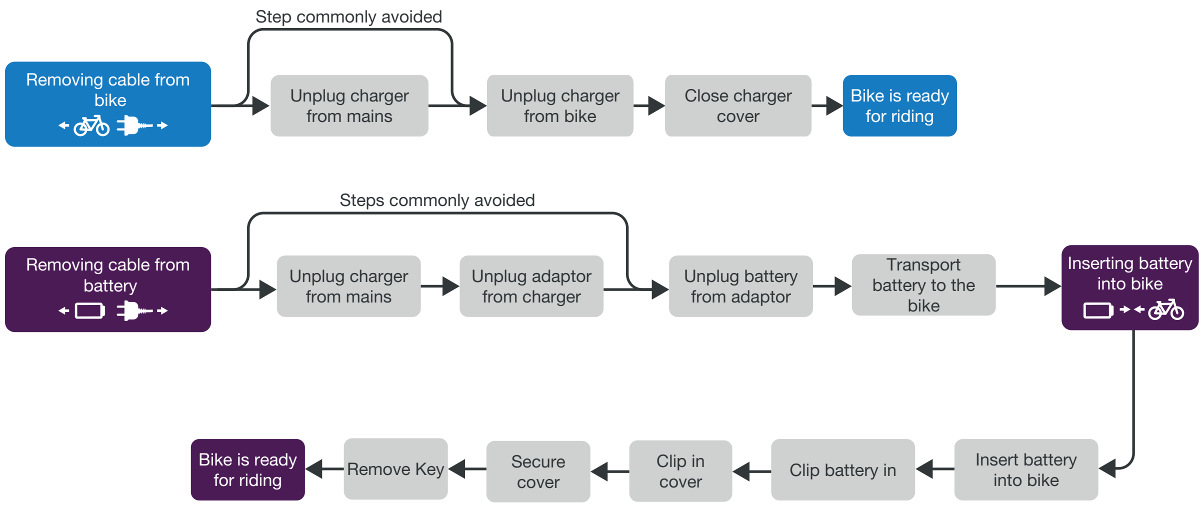


Figure 97: Stages to Get the bike ready for riding after it is charged

3.3 Conclusion

Analysing the use of behaviour, we have seen how the current charging systems are being used, the types of problems people encounter, why people are making certain decisions and how they are performing certain tasks. The survey and further analysis reinforced the data gathered from the user testing from in chapter 2. Highlighting different challenges that the user has encountered during different usage scenarios. Some notable elements which have been highlighted:

- Currently the battery removal is only performed due to contextual constraints or because the user is fearful of the safety when charging their bike.
- The battery removal/ charging the battery process is significantly more complicated than the bike charging. However with the battery removed the charging safety and ease of monitoring is improved since the battery is brought into the user's home.
- There are multiple unnecessary loops during charging the bike/battery for users who do not want to charge their battery to 100%.

The survey conducted within this chapter provided a better overview of the Ebikes. with the user's perception of plug type, battery removal procedures and charging habits highlighting areas to focus on, such as the charge feedback rather than the plug type which is used.

PHASE 1: CONCLUSION

During Phase 1 a large amount of information has been gathered and analysed. This information has provided an insight into the current charging system, how users experience charging and how they behave. Reflecting on Phase 1, areas have been highlighted that need addressing to ensure that the user experience of the charging system is improved. These areas have been broken down into 7 guidelines. To distinguish between the guidelines, they have been broken down into two categories each with a goal:

Preparation or Termination:

Goal: **To Improve the Efficiency to make charging the battery as convenient as charging the bike**

G1. Reduce the number of steps to charge the bike/battery
G2. Reduce the physical and mental workload when removing the battery
G3. Provide fast feedback that charger is setup correctly

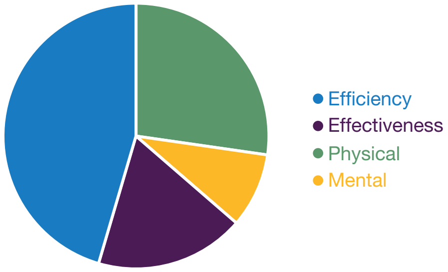


Figure 98: During the Perparation & termination phase the focus is on improving the efficiency

By improving the efficiency through reducing the number of steps and workload, the context will no longer become a determining factor as to whether the system is easy (bike charging) or a burden (battery charging). Improving this efficiency and workload will allow the users capability to increase too.

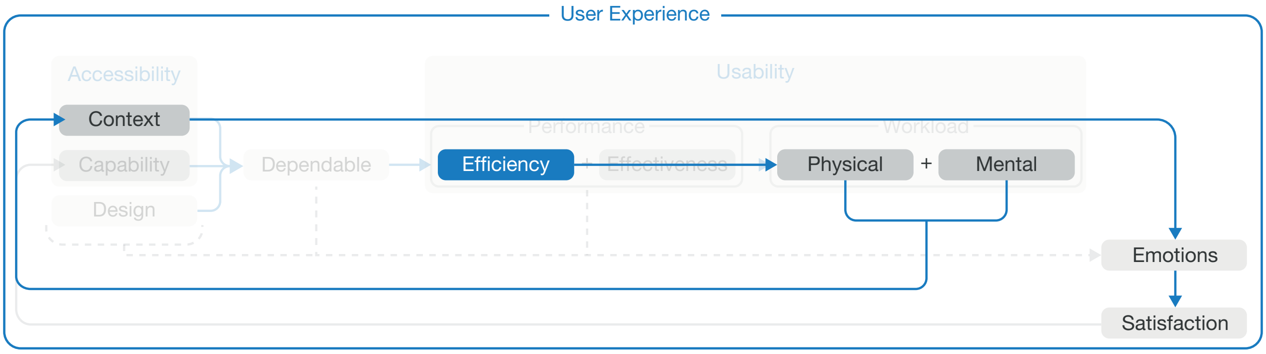


Figure 99: How focusing on the efficiency will affect the overall user experience

Charging:

Goal: **To Improve the Effectiveness during charging to improve the dependability and capability of the user.**

G4. Assist the user to better manage their battery health.
G5. Eliminate need to monitor the battery during charging when user does not want 100% charge.
G6. Provide better feedback on the battery charge status and other data when required.
G7. Ensure that feedback can quickly be obtained.

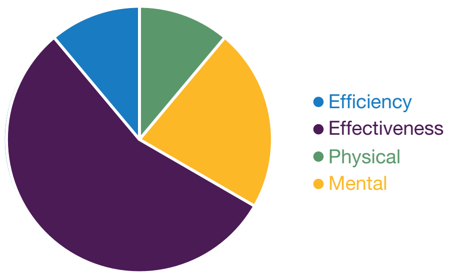


Figure 100: During the Charging phase the focus is on improving the Effectiveness and reducing physical work load.

By improving the effectiveness of the system and being more transparent with data from the battery. If the user can receive feedback quickly and easily their capability (knowledge) of the system will improve and therefore their dependability (trustworthiness) of the charging system will lead to a better overall user experience.

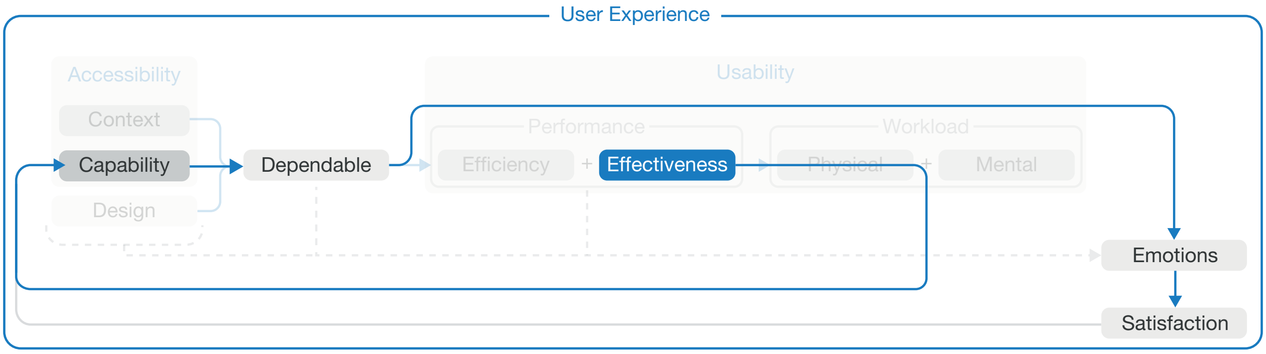


Figure 101: How focusing on the effectiveness will affect the overall user experience

These guidelines focus on effectiveness and efficiency to improve the overall user experience. Compared to the literature, the user experience could focus primarily on one of section such as addressing emotions or reducing mental workload. However, focusing on the efficiency and effectiveness in this case encompasses the majority of the problems encountered during the research.

Holistic Guidelines:

The final two guidelines are based on Context and Capability: as this determines greatly how the overall experience is perceived. This builds a level of trust of the system as soon as the user encounters charging for the first time.

G8. Ensure that the charging system usability is not hindered in different usage contexts.
G9. Design the system so that it can be performed by any user whatever on their experience

PHASE 2

TRANSLATION

C4: FURTHER RESEARCH AND ALTERNATIVE TECHNOLOGIES

In this chapter further research has been conducted based on the preliminary guidelines concluded in chapter 3. This will include understanding the battery and how to increase its longevity as well as looking at other established technologies in other markets such as; wireless charging in the phone industry and how the automotive industry assists the user with charging more sustainably. This further depth can provide greater depth of knowledge and act as a source of inspiration to address the guidelines.

4.1 Wireless charging

Wireless Power Transfer (WPT). Is the ability to transfer power without any physical contact [59]. There are three main types of WPT, Inductive power transfer (IPT), Capacitive Power Transfer (CPT) and Microwave. IPT will be focused on since it is most frequently used and well known [60]. It is achieved by taking advantage of magnetic flux distribution [60] between two mutually linked coils: one ‘primary’ connected to the grid and the ‘secondary’ connected to the battery [61].

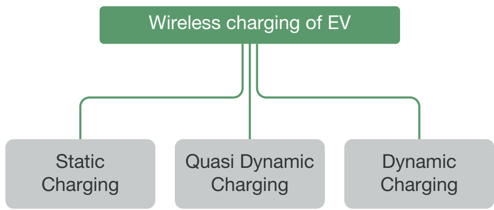


Figure 102: Three main ways WPT can be used [60]

There are three main types of WPT: static, quasi-dynamic and dynamic charging. Distinctions between charging types focus on electric vehicles, however they can also be applied to Ebikes [60]. Static charging would involve charging the Ebike while it is in a stationary position. Quasi-dynamic involves charging the Ebike while it is moving, such as charging pads implemented within the road at stationary sections such as junctions or traffic lights. Dynamic charging is when the primary coil is buried across the whole length of road allowing the Ebike to be charged during the whole journey. If WPT was to be deployed by Giant the most feasible and achievable option to focus on static charging. Large amounts of infrastructure is required to achieve Quasi-dynamic and Dynamic charging, and could be employed if every Ebike was fitted with a wireless charging module therefore creating a demand for these.

4.1.1 Benefits/Challenges

WPT of electric vehicles is increasing in popularity and there has already been a wide range of studies for electric cars. However to date there has been little adoption and experiments for Ebikes [62]. For the car industry wireless charging provides multiple benefits with regards to convenience, comfort and safety many of which are true with adopting this technology for Ebikes [63]. Some of these benefits are that the cables or a plug-in procedure is no longer required to begin the charging process [64]. This could improve the safety and increases the versatility where Ebikes can be charged such as in public spaces [62]. The connection also requires no physical contact so all the electronics can be isolated and protected. It results in a maintenance free connection that is unphased by water, ice, dirt and chemicals [59]. Since wireless charging can also go in two directions the WPT system would be able to facilitate the charging of the battery, but also the incorporation of the range extender to discharge its power through the same connection [61]. With these benefits the two guidelines could be addressed:

G1. Reduce the number of steps to charge the bike/battery
G2. Reduce the physical and mental workload

While these benefits hold true, the adoption of wireless charging from automotive or the phone industry for applying to Ebikes is not straightforward. The three main challenges include:

- **Weight/stability:** These are crucial in Ebikes [62]. Currently WPT systems are bulky and heavy components for cars is less critical, however much lighter would be needed for Ebikes.
- **Cost:** WPT systems for Ebikes must be significantly lower that cars [62].
- **Efficiency:** It goes without saying that inductive power transfer is less efficient than conventional wire-based power transformer, because of leakage within the magnetic flux due to the distance between both coils [61]. While the efficiency, as some research claims can reach values of around 86-95% [60, 65, 66]. In reality the efficiency values are typically much lower, around 50% due to coil misalignment and air gaps [67] and for wireless phone charges this efficiency varies from 25%-75%[68]. While lower efficiency is not necessarily a problem from mains power to charging the bike/battery (taking slightly longer), losing power between the battery-bike or the range extender-bike is not ideal and would significantly affect the overall range the bike is able to achieve.

4.1.2 How IPT type works

The basic IPT setup consists of the primary and the secondary coils (Lp and Ls). Which generates a mutual inductance (M). The compensation capacitors Cp and Cs. The Leakage flux for the primary and secondary sides (ϕl1 and ϕl2) [60].

IPT is usually broken down into two main groups of how far the distance is from the coils, this is either long or short [60]. A large distance between the coils, referred to as the coils being 'loosely coupled' and a short distance between the coils is referred to as a strong coupling. To calculate this coupling the coupling coefficient (K) is used. Typically, this value varies from 0.1-0.3 for loosely coupled. Where 1 is perfect coupling.

$$k = \frac{M}{\sqrt{L_p L_S}}$$

if the value of K is higher then the mutual inductance will be greater and is an important determinant in the power transfer efficiency [60].

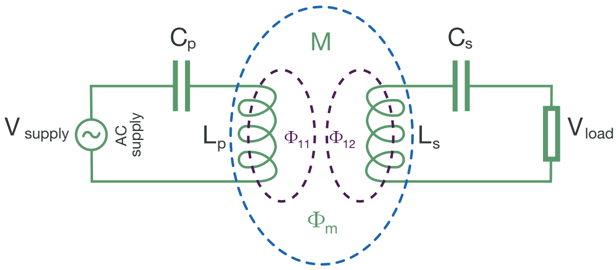


Figure 103: Fundamental structure of an IPT system [60].

4.1.3 Design Considerations

When designing a IPT systems there are several considerations which are necessary to ensure a good coupling between the coils and high efficiency.

Location: The location of the WPT system must avoid metallic structures or components to prevent them heating up, which could affect the overall safety and affect the users' health [62].

Distance: The coils of a typical transformer are highly linked because they are coiled around the same ferromagnetic core, and the airgap is not proportional to the core's diameters[63]. However for wireless charging when both coils become coupled the magnetic circuit is not coupled with a connecting ferromagnetic core and an airgap between the coils occurs. This distance can vary but is typically around 5mm (an order of magnitude smaller than the cross sectional area of the core). This gap leads to high inductance leakage and poor efficiency and is referred to as being loosely coupled[63]. Using a ferrous core on either coil helps improve the efficiency however, for higher performance Ebikes the overall weight of this (ferrous core) would add significant weight to the bike so is commonly avoided [64].

Compensation topology: Is the adding of compensation capacitors to the primary and secondary sides of the system to operate in resonance and reduce the total reactive power being created. These compensation structures vary however there are four basic structures: Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS) and Parallel-Parallel (PP). The SS configuration results in the capacitor values being independent from the resistive loads and mutual inductance. This configuration allows the system to remain in resonance and is less sensitive in the case of misalignment.

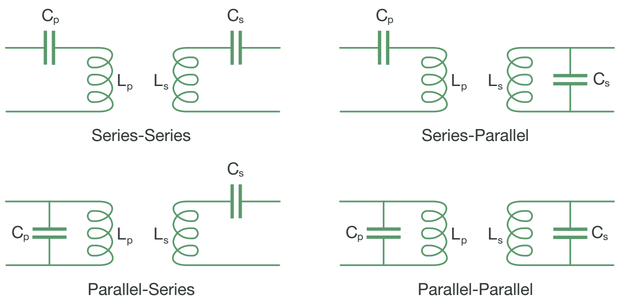


Figure 104: Basic WPT compensation topologies

Alignment: This involves the position of the two coils relative to each other. If misalignment occurs the resonant frequency of the system varies from the desired value. Therefore for WPT systems where misalignment could occur an inner control loop is required to track the natural resonant frequency of the system this is called auto-resonant frequency control [63]. For high misalignment tolerances, a series-series compensator is proved to be the best [69] because the circuit does not depend on a coupling coefficient. The coupling coefficient is the fraction of magnetic flux produced by the current in one coil that links with the other coil (K) [69].

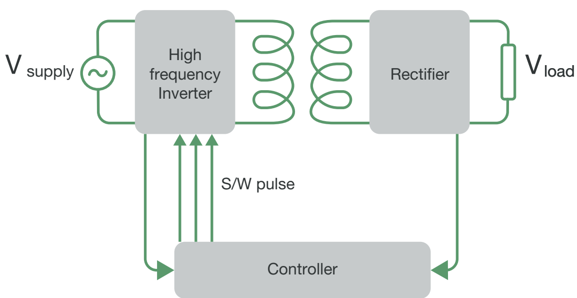


Figure 105: Closed loop control in conventional WPT charger [66]

The wireless power transformer's non-linear design makes charging control difficult. There must be several sensors on both the transmission side and the receiver side in order to implement the control technique of non-linear chargers. This results in a decrease in efficiency as well as a slower closed-loop reaction time in wireless charging for low power vehicles like Ebikes. [69] On the basis of this linearised area, simple closed-loop control is put into practice. During the closed-loop, an efficiency of 93% is attained at a coupling spacing of 200 mm, greatly beyond any existing topologies used for bicycle wireless charging [69]. The alignment has a significant impact on the efficiency. In a study by Mekhilef et al. an efficiency of 91.4% was achieved which decreases to 78% with 50% misalignment [70].

Operating Frequency: Choosing a high frequency will mean that the coil size can be reduced however the switching loss increases [60] this is because as the frequency increases the number of turns within the coils decreases. Within Electric vehicles the common resonant frequency used is 85KHz for standard power levels and has gradually become the standard for EVs [60] . For studies involving Ebikes the frequency varied from 38.4 kHz [59], 85 kHz [71] and 8.7-100Khz [63].

Health standard	Frequency Range
IEEE	3kHz- 3GHz
ICNIRP for LFA	1 Hz – 100 kHz
ICNIRP for HFA	100kHz – 300 GHz
ERHSD	3 kHz – 300 GHz
SAE	80 kHz – 90 kHz
Wireless forum of Japan	10 kHz – 10 MHz

Figure 106: Frequency ranges for different standards [60]

Foreign Material Detection: The wireless system should be able to detect and terminate the charging process if a foreign object is detected. This is because the magnetic field induces eddy currents which could heat up and lead to fire or injury [63].

Control system: This regulates the resonant frequency if the alignment changes, but the control system aims to monitor and regulate the battery during the Constant Current (CC) and Constant Voltage (CV) charging. Comparing the efficiency of the CC and CC/CV charging for WPT the CC charging has a slightly higher efficiency than the CC/CV method. The CV stage also takes slightly longer than the CC stage [60]. These control techniques consist of three different parts: dual-side control, primary-side control, and dual-sided control. Due to no physical connection wireless communication is required to transmit the State of Charge (SoC) data from the secondary side to the primary side. The location of the controller is very important because a sufficient amount of data is required from the Battery Management System (BMS) for safety and monitoring the battery [60].

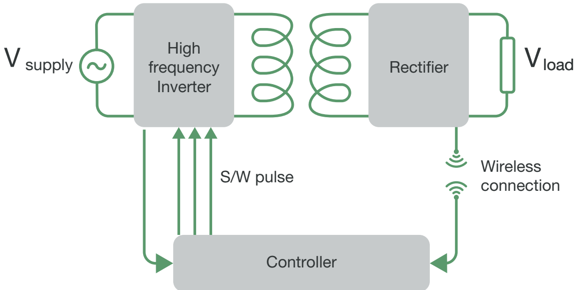
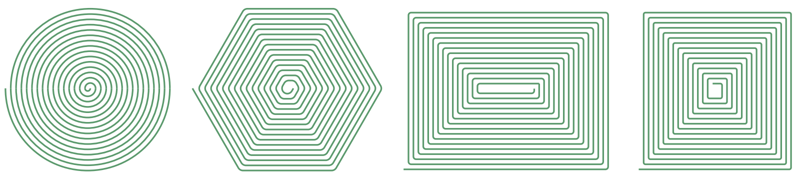


Figure 108: Wireless connection to the compensation controller [60]

Coil Geometry: There are generally no limitations to the shape and size of either coils, especially for the primary coil [60]. However, the geometry limitation in this case will be fitting the coil within the bike frame. Ideally this should be as compact as possible. There are four basic coil structures that can be found in literature: circular, rectangular, hexagonal, and square. In a study by [60] these shapes were compared in simulation using ANSYS Maxwell 3-D electromagnetic finite element modelling software. Using the same distance between the coils, coil area, cross sectional area and same copper mass. The circular pattern performed the highest value of K followed by the hexagon. The coupling factor is strongly related to the number of turns, however increasing the number of turns also increases the resistance of the coil, potentially leading to higher losses and an increased difficulty in controlling the system [71].



Coil Shape	Parameter	Dimension	Coupling Coefficient (k)
Circular	Radius	112	0.269
Hexagonal	Length of side	124	0.249
Rectangular	Length x Width	141 x 282	0.209
Square	Length of side	200	0.194

Figure 107: Different coil shapes and their associated Coupling coefficients [60]

4.1.4 Existing Solutions Proposed

Within research and on the market, there are several different wireless charging solutions that are proposed and tested. Currently all solutions have a stationary primary coil and the secondary coil attached within/on the bike is moved into contact with the primary coil. Below several are discussed:

Protruding pole: Genco, et al. proposes the secondary coil being placed in a pole [71]. The pole is inserted into a hole within the bike frame. By inserting one coil within another the coils have a close mechanical coupling, less misalignment issues and improved efficiency [71]. This design idea is very similar to how toothbrushes are charged with a small armature being inserted into the base of the toothbrush. The shape of the pole means that misalignment is nearly impossible to achieve. While this design has promising potential with the misalignment challenges, it is very similar to the properties of a normal plug.

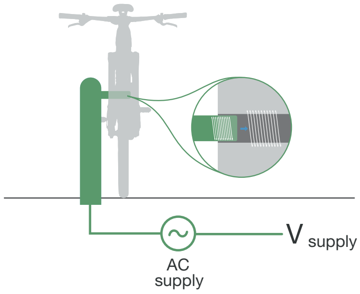


Figure 109: Protruding pole goes into bracket in the centre of the bike frame [71]

Kick Stand: The kickstand is used to support the bicycle and keep it upright when not in use for charging. It also allows the secondary coil, in this case mounted within the stand, to be in close contact with the primary coil stored underground. This wireless system has been proposed by many different companies such as Slew overdrive [72] and a dutch start up TILER [73] which can charge 80W-120W and 200W respectively.

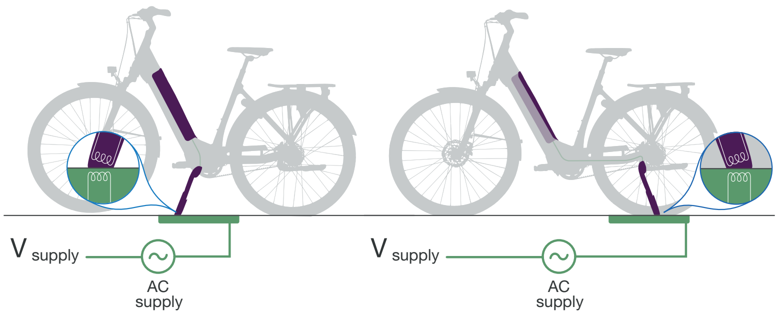


Figure 110: Two different types of kickstand positions. [63] [59]

While the majority of these WPT bike stands still being researched, there are several companies which have started to produce them. One recent start-up called TILER, established in 2019, has developed a wireless charger which will be brought to the market in the third quarter of 2023 [73].

Figure 111: Tiler kickstand product [73]

WPT Docking Station: This docking station provides a fixed place to charge your Ebike. These are commonly implemented within cities for Ebike hire. The benefit of wireless connection is that these docking stations are more resistant to vandalism and damage, as well as improving the convenience for the user. The current systems on the market consist of a large coil retrofitted to the exterior of the frame and are not well integrated.

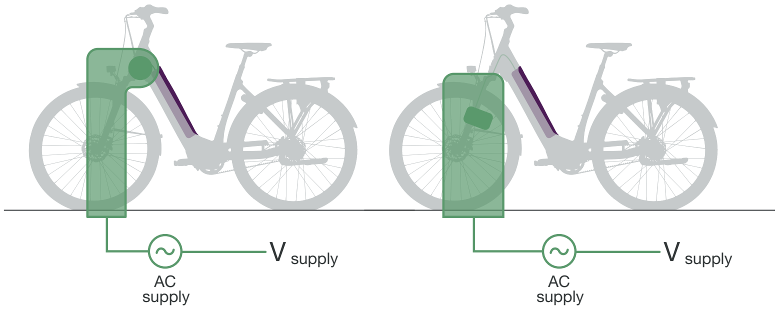


Figure 112: Left to right; Mobi dock and roll and Emoby wireless charging station [74, 75]

4.1.5 WPT Phones

Currently WPT for Ebikes and cars has been addressed however the phone industry is a market which has seen the recent adoption of wireless charging with big brands like Apple, Samsung and Huawei all selling phones with wireless charging capabilities. The chargers all comply to the Qi (pronounced 'chee') standard, designed for providing WPT to small electronics 5-15W [76]. With The operating frequency typically in the range of 87 to 205 kHz [77]. To date there are over 9000 certified products with the Qi standard. The standard ensures that different Qi certified devices are compatible regardless of the manufacturers and conform to the correct safety precautions such as heat shielding and foreign object detection.

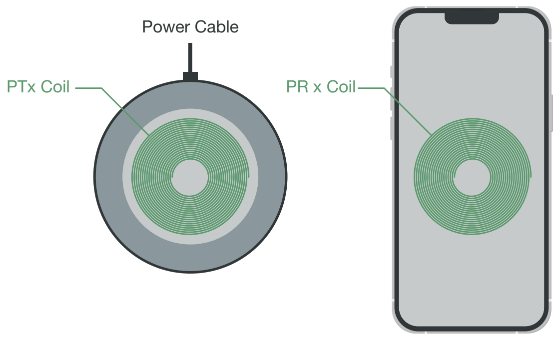


Figure 113: Phone with the power transfer (PTx) coil and power receiver coil (PRx) [77]

Compared to conventional WPT coils the Qi-based system is very different because it has a much lower magnetic coupling coefficient of around 0.5, whereas most systems strive to be close to 1.0 [77]. This suggests a low efficiency. Within Qi chargers the minimum efficiency varies from 25%- 65% for 5W chargers (depending on the power receiver) whereas for 15W chargers the efficiency ranges from 25-75% [68].

These wireless chargers come in two main forms, either as a small puck attached to a cable or in a docking station form where the phone is placed onto a stand. To help with alignment magnets are commonly used to 'snap' the phone into position. Another solution is to use multiple coils to prevent misalignment issues, such as in Zens Liberty Series wireless charger [78].

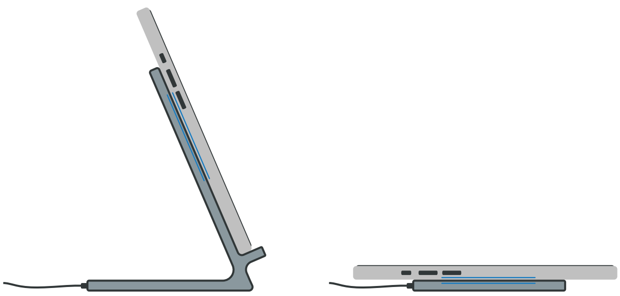


Figure 114: Phone Docking station and a puck

Comparing WPT of phones with Ebikes, we have seen that the power usage is significantly different. The power required for Ebikes is approximately 7 times greater than the power required for the phone. With the poor efficiency this would lead to significantly higher power losses as well as in increased safety risk. However, as seen, with new start-ups and the introduction of WPT for rental bikes it is achievable.

Another significant difference between Ebikes and phones is the user behaviour and the charging cycles. With a wireless connection the charging procedure is more convenient and more efficient. As a result, users charge their phones little and often, throughout the day. Whereas for Ebikes the charging cycle consists of much longer charging and discharging cycles as the bike is not used for short cycles like a phone is. However, before wireless charging a phone would typically follow a similar charging pattern to an Ebike of only being charged in the evening before bed. So, while the Ebike charging pattern may appear significantly different to a phone, the main cause could be due to the current inconvenience of charging. Urban mobility users and commuters, with short frequent journeys, and smaller charging cycles would benefit significantly more than say mountain bikers, having longer rides where there is a lack of infrastructure.

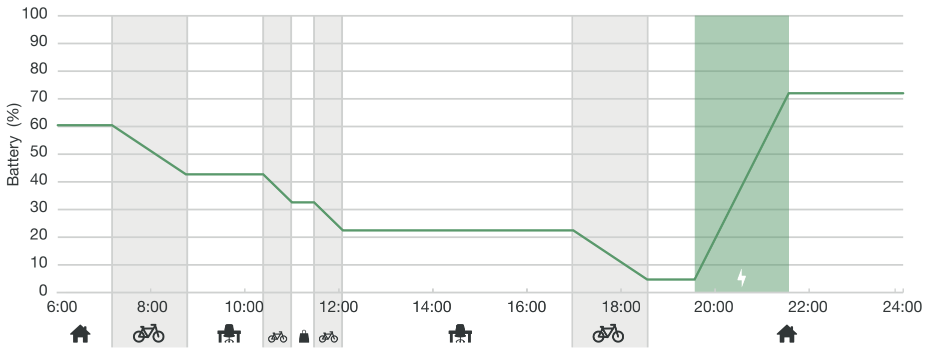


Figure 115: The typical charging cycle of a commuter

Figure 115 (above) depicts a typical daily use of a commute in an urban environment with a trip to the shops before lunch. Due to the large commute the battery level drops significantly

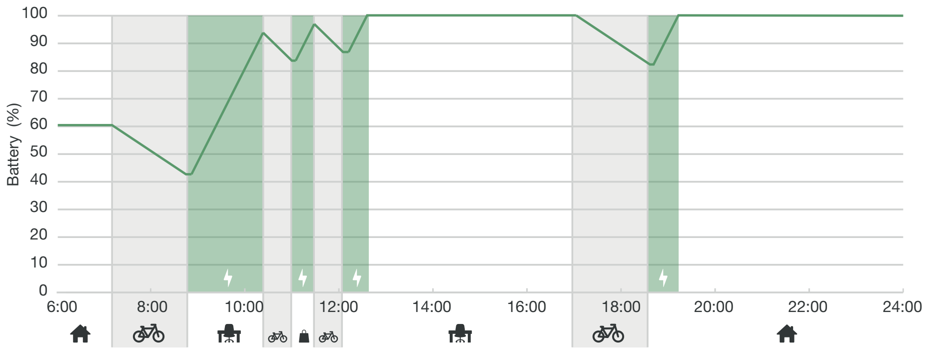


Figure 116: The potential charging cycle with the ability to conveniently charge with WPT

If wireless charging was available the user could charge their bike at every stop throughout the day, helping them maintain a greater battery percentage and allow them to use a larger level of assistance when riding since conserving the battery percentage is no longer as important. This potential charging cycle follows a similar pattern to a typical phone that uses wireless charging. Within the above diagram the battery level is constantly recharged to 100%. As discussed, this is not good for the battery therefore a cut off could potentially be used to ensure that the battery level is capped to around 80%.

4.1.6 Conclusion - Incorporating within Giant's Portfolio

Looking at these solutions from Giant's perspective, implementation of such a system within the user's home needs to be considered. Most of the existing Ebike solutions would be ideal for bike parks or within cities/public space where there are lots of the same/similar bikes being used at high frequency.

To create a WPT without a wire connection involves infrastructural challenges and would need significant benefits to outweigh the challenges to implement a design with WPT. However, an approach used with an adaptation of the Qi standards would be more feasible, portable and likely better align with Giant's Ebike portfolio and usage behaviour. During the conceptualisation phase wireless charging is something which should be explored, especially whether a "charging system be design that encompasses the convenience and benefits of WPT without hindering the efficiency (using a physical connection)."

4.2 Frame and Battery integration

These solutions discussed could also potentially contribute to tackling both the two guidelines:

G1. Reduce the number of steps to remove the battery
G2. Reduce the physical and mental workload

4.2.1 Gogoro

Gogoro is a Taiwanese company established in 2015. It has developed a battery-swapping network called the Gogogo Network for light EVs (electric scooters, mopeds and motorcycles) which is a modular battery swapping infrastructure deployed throughout cities[79]. Alongside this Gogoro has developed its own electric scooters compatible with these batteries and offers its own innovations to vehicle maker partners like Yamaha, PGO and eReady [80]. In 2021 Gogoro sold 55,000 vehicles and occupied 80% of the Taiwanese market share [81]. Since batteries are not included with the bike the user swaps the batteries when they run out of charge at one of the network's charging stations. What is useful to take way from Gogoro's system is that there is no on-board charging (a plug on the EV) this means that removing the battery to charge is the only option.

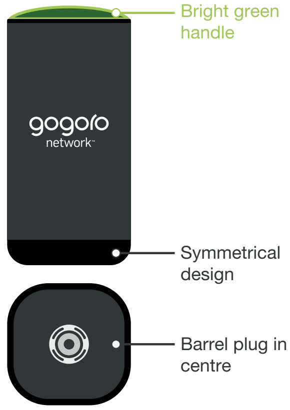


Figure 117: Gogoro battery with barrel plug in the centre and the rotational symmetric design [79].

To make this process as efficient as possible, the batteries contain a bright green handle on one end providing affordance to the user, showing where to hold the battery and aiding them when lowering the battery into the scooter. The batteries are also rotationally symmetric with a barrel plug connector at the base. This means that the battery can be placed into the EV or charging station in any orientation. The 1.3Kwh batteries are heavy weighing 9kg each. To overcome this Gogoro has cleverly designed the lifting of the battery vertically out of the bike and position movement into the charging station so the users' movements are kept to a minimum.

Gathering inspiration from a system like this is important because currently with Ebikes removing the battery is an inefficient, cumbersome process which is why most people decide to charge the bike directly. However, removing the battery provides benefits and more versatility as it is not as big, bulky, or heavy compared to the bike. If battery removal was easier, more users would be able to utilise these benefits.

Figure 118: Gogoro Network and scooter highlighting the ease of dropping the battery into the scooter

GOCharger: In 2016 Gogoro also introduced the GoCharger, a docking station for in the user's home, at restaurants or smaller scale locations. If you decide to make the Go Charger publicly accessible for more than 12 hours a day Gogoro will pay for it [82]. To charge the battery, the battery is placed into the charger the same way it is put into the scooter and charging station, by just sliding the battery into the square hole. The GoCharger is designed to be stored on the floor since the batteries are large and heavy this reduces the amount they have to be lifted. To provide user feedback there is a small LED on the right edge of the battery.

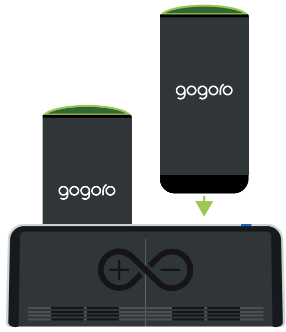


Figure 119: GoCharger by Gogoro [79]

4.2.2 Goshare

There are several EScooter and Ebike companies that rather than the user owning the bike or the battery they are providing a rental service. The bikes are scattered around cities and the user can rent one of the bikes through an app for a short period of time. The company is responsible for maintaining the bikes and as well as charging the batteries. To charge the batteries an employee goes around the city and swaps the batteries. Again this battery swapping process for the employee is incredibly seamless and the battery is placed in the top of the Ebike frame [83]. The same is true for the Emoped variant a car like Li-ion battery is clipped in underneath the seat like the Gogoro system.

While these systems are efficient, the battery is not integrated within the frame in an aesthetically pleasing way. For these rental companies, convenience and robustness are prioritised over aesthetics. The challenge comes with integrating the battery within the frame so that it cannot be seen, but is still quick and easy to remove.

Figure 83: Rental Ebike (Goshare/Bolt/dott/)

4.2.3 Docking Stations

Docking stations (DS) have already been mentioned briefly and are devices where a battery/product is placed for charging. Docking stations exist in all forms for all different markets, such as audio equipment, power tools and laptops. These are all essentially a stationary charger which the device is attached too/in the docking station.

Bike charger DS: Currently on the market docking stations are not common, with few companies offering a docking station. These include Qwic charging station [84] and Pendix charger [85].

		Pendix		Qwic
Input	Volts	200-240	200-240	200-240
Output	Amp	1.25	3.3	6
	Volts	48	48	36
	Pins	6	6	6
Weight	-	0.4 Kg	0.6 Kg	2.8 Kg
Cost	-	110€	150€	299€

Figure 121: Comparison between Pendix and Qwic charger [80, 81]

Figure 122: Qwic charger, Pendix charger [84, 85]

Comparing the two docking stations, the Qwic charger has a higher amperage and is therefore significantly heavier. Compared to Giant's chargers' weight of 1.4kg and 0.8 kg, the Qwic charger is significantly heavier. This is likely to ensure that it is stable during charging and does not tip over when holding the battery. The Pendix docking station, contains a form like that of a kettle charger. The battery can be just dropped onto the top and the charger does not hug the battery, due to a cylindrical battery the alignment with the Rosenberger plug is more difficult however there are three pins on the base to help with alignment. While this battery does not hug the battery compared to the Qwic (which hugs the battery) if the diameter of the battery e.g. the width was to change the charger would still be compatible with the new battery whether as the Qwic charger would not.

Power Tool DS: Power tool docking stations, while similar to the Ebike battery DS, are more compact and have a slightly different form. Nearly all power tool batteries, slide into the base of the drill and charger and then click into place. The sliding means that the battery connection easily aligns and the clicking mechanism ensure that the connection between the battery and charger/drill is secure. It also provides the user with feedback to inform them that the battery is in the correct position.

Figure 123: Ryobi battery docking station [86]

4.3 Li-ion battery

The Li-ion battery is an essential part of the charging ecosystem. While there has been technological advancements in batteries over the few decades, the reduction in battery capacity over time is a prominent issue, together with having a limited cycle life, poor performance in hot and cold environments [87]. In addition, batteries are resourceful and expensive to produce, which is why it is important that the consumer looks after their battery to reduce potential risks and increase the life of the battery as much as possible. To ensure that Giant can aid the user in maintaining their battery and extending its life an understanding of the basics of how Giants batteries work and the conditions which cause the battery to degrade have been researched. With this further knowledge Guideline 4 can be better understood:

G4. Assist the user to better manage their battery health

4.3.1 How it works

The main components of a Li-ion battery are the cathode, anode, electrolyte, and separator [87]. The Cathode's and Anode's active materials are metal oxides and different forms of carbons respectively. With both purposes to store the Lithium for long periods of time safely [87]. When there is a difference in chemical potential the Li-ions undergo intercalation and de-intercalation as they move back and forth between the cathode and anode during battery operation. The separator is an inactive component and prevents physical contact between the two electrodes [87]. The Electrolyte allows the Li-ions to diffuse between the electrodes during charging and discharging. Once the circuit is connected the during charging electrons are transferred from the anode to the cathode.

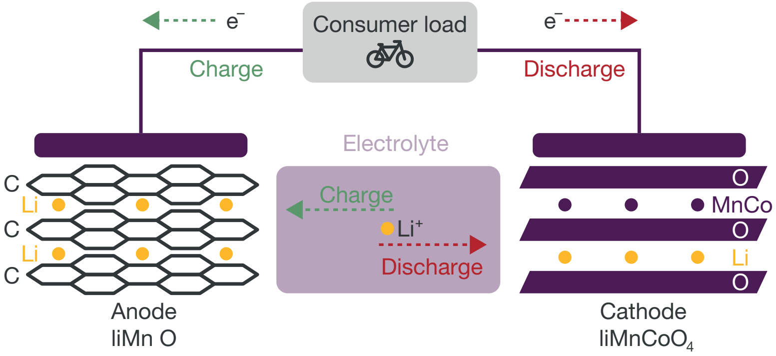


Figure 124: Basic structure of a lithium-ion cell

Cathode: There is a large variety of metal oxides that are used for the cathode (positive electrode) and all offer slightly different properties such as: cost, lifespan, specific power, specific energy, and safety. Giant's batteries are made in partnership with Panasonic [1]. Their batteries are made from Lithium Cobalt Manganese, which uses Li-ion cells with Lithium Manganese Oxide as the cathode [1]. Lithium Manganese Cobalt Oxide (LiMnCoO4) is used as the cathode. The Manganese creates a three-dimensional structure that improves the ion flow [88]. This results in a lower internal resistance which in turn increases the current handling, improves the thermal stability and overall safety, and allows for a high discharge rate. However, the drawback to Manganese is that it has a relatively limited life and poorer lower energy density (110-120 Wh/kg) compared to other compounds [87].

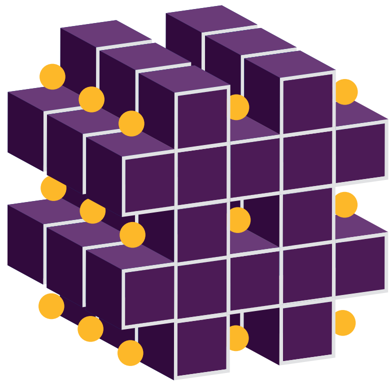


Figure 125: Lithium ions within manganese 3D structure

Cobalt has one of the highest energy densities (110-190Wh/kg) and has low discharge rates. It ensures that the cathode does not easily overheat or catch fire and overall helps extend the life of batteries [87]. However, Cobalt is scarce and expensive so it cannot be used in large quantities. Combining both the Manganese and Cobalt, their beneficial properties can be utilised resulting in a battery that Giant claims has the lowest discharge rate of all Ebike batteries [1].

Anode: This (negative electrode) comprises of Li intercalation compound built up of thin layers. The compound and the way it is manufactured is important because it can have a large impact on the discharge rate capacity and the cell aging behaviour [87]. Generally, the anode is made from a carbonaceous material like graphite in powder form as it exhibits a good rate if lithium insertion/removal. However, the cell performance is limited due to solid electrolyte interphase (SEI) which is the formation of a film due to the a reaction between the anode and the electrolyte that occurs during cell cycling [87].

4.3.2 The Battery Management System (BMS)

Within the battery pack there is a battery management system (BMS). The BMS is designed to ensure the battery is ready to use, extends the battery life and protect the battery from damage [89]. Therefore, some of the information which could be useful to the user is already collected and monitored within the BMS, such at the battery temperature, charge battery level and battery health. As seen with the competitor's applications some of them convey this information through their app.

Within Giant's battery, the battery is broken up into 40-50 cells separated in a series of 10. Each of these series is measured and the temperature and stress that is put on the cells is measured. The BMS controls how much stress is put on each of the series, allowing to better maintain the longevity of the battery, safety, and performance [1].

Figure 126: Internal structure of one of Giant's Batteries [1]

4.3.3 Effect of Charge Rate and Cycle Number

The Charge Rate (C-rate) is the rate at which a battery charges or discharges in relation to its rated capacity. For instance, a battery may be fully charged or discharged in 1 hour at a 1C rate. A battery will be completely drained in 2 hours at a discharge rate of 0.5C. Ageing or the degradation of the battery is accelerated by faster cycling rate (C-rate) resulting in more capacity fade (reduction in battery capacity). Slower C-rates result in a higher retention of battery capacity and a lower battery fade [87].

As a result of cycle ageing, the maximum storage capacity also steadily decreases, the more cycles, the lower the battery capacity. The cycle ageing-related irreversible capacity loss can be linked to any one or more of the following:

- Electrolyte decomposition
- SEI layer formation on electrode and current collector surfaces
- Dissolution of active materials
- Phase transitions in the insertion electrode
- Electrode structural changes

The battery is charged in two phases. In the initial phase the battery is charged at a Constant Current (CC) until it reaches a certain voltage level. In the second phase the battery is charged with the reached/constant voltage (CV) level until the current falls below a specified threshold [62].

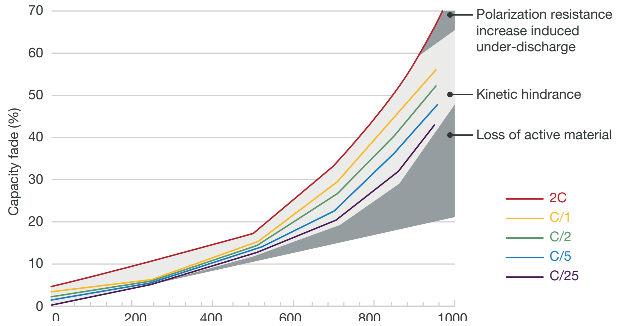


Figure 127: The cell capacity loss map under room temperature as a function of cycle aging at various C-rates [87]

4.3.4 Temperature

The temperature of the Ebike battery, strongly influences the discharge voltage and therefore the discharge capacity [90]. In studies with different EVs the range is reduced by 20% when travelling at outdoor temperatures of -7°C instead of 20°C. Compared to the battery capacity at 20°C, with temperatures of -20°C the capacity is reduced by 9%. Most EV contain battery heating and cooling to avoid these extreme temperatures however this too results in a reduction in performance [90].

There is also evidence that when the battery is discharged and charged at low or high temperatures its life is reduced [90]. Battery life degradation is a gradual process. The classification of the ideal temperature range varies slightly but the ideal temperature is generally around 10°C-60°C[87].

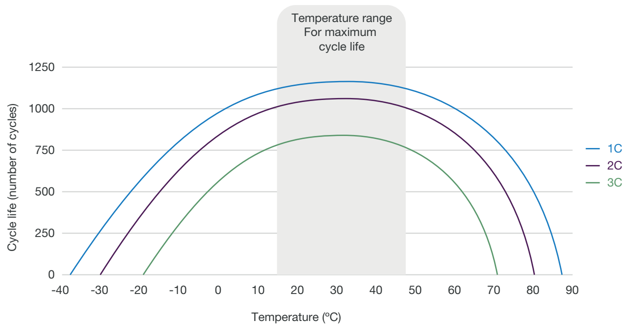


Figure 128: Total number of charge cycles based on the temperature range. C is the charge rate: higher charge rate over time will also hinder the life of the battery. [90]

Low temperature operation: The Arrhenius law states that chemical reactions proceed at a rate that is proportional to temperature:

$$k = Ae^{\frac{E_A}{RT}}$$

Where T=temperature.

This means that as temperature rises, the rate of chemical reactions increases exponentially. For instance, the rate of cell deterioration might double with a 10°C increase in temperature. In contrast, a drop in operating temperature results in a slower rate of reaction of the active elements in the cell, which suggests a reduction in the ability of the cell to handle power during charge and discharge [90]. On the other hand, low temperatures reduce reaction rate and cause electrode materials to shrink, limiting the intercalation gaps needed for Li-ions insertion. This might result in anode lithium plating and subsequent capacity fading [87]. The intercalation process is where the guest molecule (lithium ions) move onto the activate material.

High temperature operations: The greater the operating temperature the greater the battery's discharge capacity. As shown in figure 129 (below). This temporarily improves the performance of the Li-ion battery due to the increased reaction rate. The effect of operating temperature at a moderate discharge rate of 1C [83] (voltage also same as SOC).

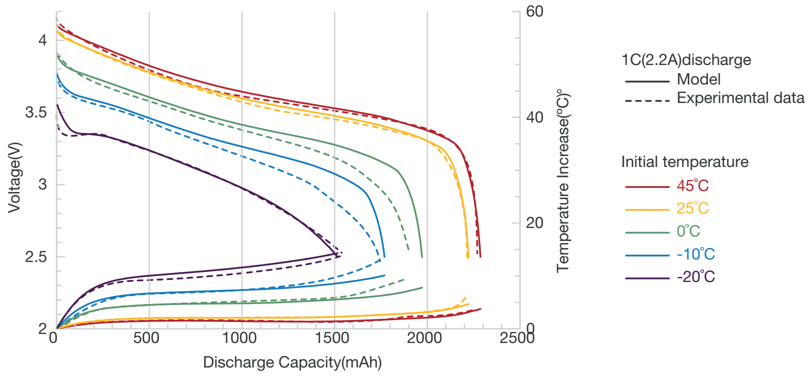


Figure 129: Discharge capacity in relation to the temperature [91]

The effect of operating temperature at a moderate discharge rate of 1C [87] (voltage also same as SOC) However, this also enhances the cell degradation rate due to the larger currents causing a larger dissipation of heat. Resulting in higher temperatures, Additionally, the Solid Electrolyte interphase (SEI) film growth is increased at elevated temperatures leading to layer evolution (discussed in the cycle number) leading to capacity loss [87].

4.3.5 Effect of state of charge (SOC)

High and low states of charge can enhance the aging of the battery due to either capacity fade and/or power fade. Voltage limiting is important to prevent over-charging/discharging of the battery as well as high depths of discharge (DOD).

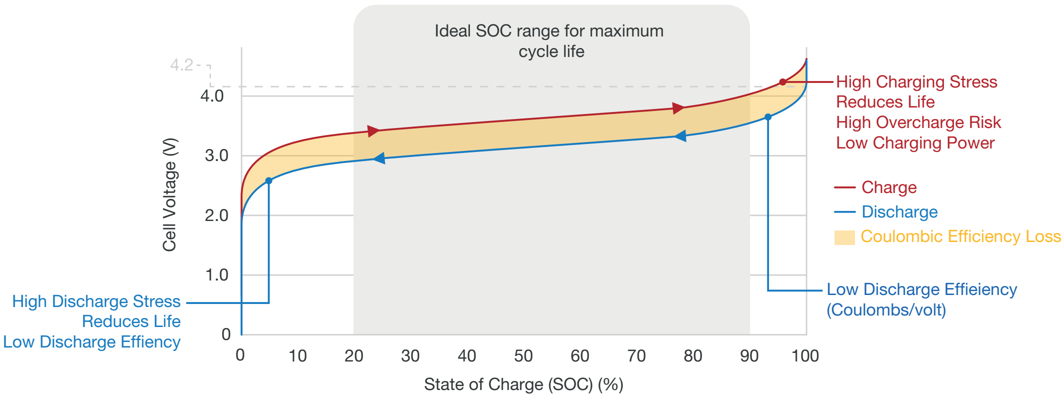


Figure 130: : The SOC operating window for a typical Li-ion battery[87].

4.3.6 Moisture

It has been demonstrated that contaminants, particularly water or moisture, are to blame for cell deterioration. LiPF6, the salt that is most frequently used as the electrolyte in Li-ion batteries, is very moisture sensitive[87]. When exposed to moisture, LiPF6 salt will break down into hydrofluoric acid (HF), which has a very high level of reactivity and degrades both the electrolyte and the electrodes [87].

4.3.7 Giant's User Manual

Within Giant's user manual they offer advice about maintaining the battery and increasing the longevity in several different scenarios: Charging, Storage and Cleaning/maintenance. The following points are taken directly from the user manual [14]:

Charging:
- Charge the EnergyPak battery at room temperature (±20°C/68°F).
- Charging below 0°C or above 40°C (32°F~104 °F) can lead to insufficient charging and can have a negative impact on the battery life cycle.
- CAUTION: Avoid contact with battery and charger during charging operation. The charger can become hot during charging

Storage:
- Store the EnergyPak in a dry, safe location.
- Store the EnergyPak at a temperature between -20°C and 20°C (-4°F ~ 68°F).
- Storage at temperatures above 20°C (68°F) can decrease battery health and overall service life.
- Store the EnergyPak at about 60% charge level.
- Check the EnergyPak charge level monthly during longer storage periods.
- Recharge the Energypak when charge level has dropped below 60%.
- Charge the EnergyPak to 60% at least once in every 3 months.
- Improper storage and/or long-term neglect of the EnergyPak can cause decreased capacity and defects, and may void the factory warranty.

Cleaning and maintenance:
- High speeds combined with wind and rain could cause moisture to be pressured into the electronic parts, which can lead to temporary malfunctions or permanent defects.

Despite the advice Giant offers many of the points could be difficult for the user to interpret, remember and develop into a habit. There are lots of references to monitoring the temperature. However, without the user receiving feedback of the temperature of the battery they cannot know when the battery is 'too hot' or 'too cold'. In addition the user is advised to check the charge level on their battery every month and recharge it when it drops below 60% - something very few users will remember to do.

4.3.8 Conclusion

To reduce the rate of battery deterioration there are many tasks that the user must do frequently. These could be included/ incorporated within the app to help the user increase the longevity of their battery. In summary these include:

Temperature/environment:
- Do not immediately charge your electric battery after a ride (let cool down before use)
- Warm battery up to room temperature before charging.
- Minimise exposure to extreme temperatures.
- Keep your battery dry and clean.

Use:
- Avoid quick discharging – that is quick spurts of battery use.
- Avoid deep discharges from 100% to 0%. Shallow discharges and recharges are better as they do not stress the battery.

Storage & charging:
- Avoid long periods at 100% charge.
- Keep your battery around 80% charge .
- Store battery in a cool dry place.
- Give the battery short charges every 90 days if not in use.
- Avoid fast charging frequently.

4.5 Effective Charging systems

4.5.1 Automotive industry

Compared to Ebike charging automotive charging is now a relatively mature technology. With more legislation on the charging system. This is mainly to ensure compatibility with public charging infrastructure, which is not established within the Ebike market. The European Commission has decided that all electric vehicles must be installed with a “type 2” connector to ensure that all vehicles can be charged at EV charging stations. [92].

A type 2 connector has 7 contacts in total and can be used with a three-phase (400 V) power supply. It can reach up to 43 kW with a fixed cable (63A/400V) and up to 22 kW with a detachable cable (32A/400V) [92]. This power consumption is significantly higher than that of an Ebike charging system. What is interesting with this technology is how the home chargers are used to help the user with battery management.

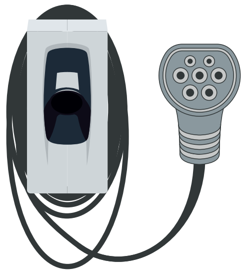


Figure 131: Type 2 connector.

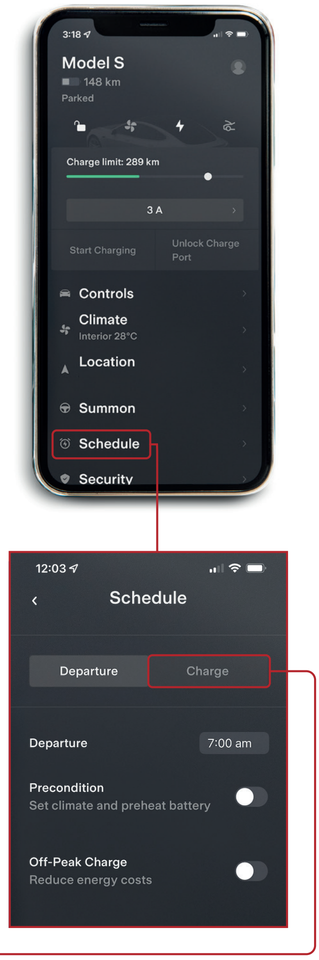
Taking the Tesla app as an example, the app allows the user to schedule when they plan to next use the car e.g. driving to work the next morning and they can schedule what time to begin the charging. The app will then ensure that the charging begins at that time and the car will be at the desired charge level by the scheduled time an approach which aligns with the guideline:

G5. Eliminate need to monitor the battery during charging when user does not want it to be 100%

It is also interesting to note that is rather than displaying the battery percentage the total driving distance available is shown [93]. This is more tangible to the user than a percentage which could be a solution to address the guideline:

G6. Provide better feedback on the battery charge status and other data when required

Transferring this pre-set charge technology across to Ebike users would be useful for those who use their Ebike for commuting with a consistent. However, users such as mountain bikers who may use their bike in more of a random pattern, the schedule this would likely need to be altered every time they begin charging since the time and day, they will be using their Ebike may change. This is likely to be the reason schedule charging has not become integrated within phone charging, however, to help extend the batteries life the iPhone has an ‘optimised charging’ feature. This feature prevents the phone from being charged over 80% to reduce stress on the battery. The iPhone learns the users usage pattern and delays the charging to 100% moments until the user wakes up in the morning, to preventing the battery from being at 100% for the majority of the night.



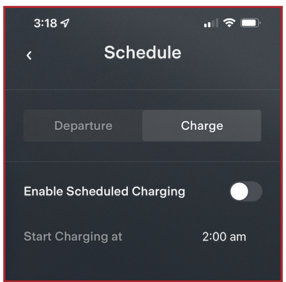


Figure 132: Tesla charge planning incorporated within their app [84]

4.6 Providing fast feedback

Providing the user with feedback that is easy to understand is important, however it is just as important that this feedback is displayed as soon as the user requires it. If the feedback is too early, before the user has completed the task, they will be confused and if it is too late the user will get frustrated and is likely to perform an additional action before the feedback is loaded.

This case is true with the current smart charger. As seen in Chapter 3, the delay of the charger going from red (unplugged) to green flashing (Charging) take several seconds. The time for this feedback to be displayed is slightly too long so the user begins to unplug and re-plug in the connecter to address the problem. Had they waited a few more seconds they would realise that the plug was already connected properly and they just had to wait, amending this addresses for the perpetration/termination (G3) and the Charging (G7):

G3. Provide fast feedback that charger is setup correctly
G7. Ensure that feedback can quickly be obtained

4.6.1 Automotive industry

Looking at Tesla's charging their preparation step has an additional feature that allows for better user feedback.

Preparation:

1. Charging port can be open from a button on the tesla charge or from the touch-screen within the car, phone key or by pressing on the port door. This means that opening the charging cover can be easily done from any user context.
2. With the cap open a Tesla 'T' is shown in white to show the car is ready to be charged.
3. As soon as the plug is inserted the 'T' goes blue showing that it is waiting or preparing to charge.
4. A green pulse indicates that it is charging. This green pulse slows as the Tesla approaches completion.

Termination:

5. To unplug the user presses and holds the button. The T will turn blue then white. Once white the user can remove the plug

Make	No Battery/waiting to charge	Plug connected	Charging Active	Charging Full	Plug not connected	Problem (see touch screen display)
Tesla						

Figure 133: Tesla charge feedback

What is important here is the intermediate step of the blue light. This stage helps overcome the small delay between plugging in the charger and for charging to commence. The change in colour provides the user with fast feedback to inform them that something has happened and that the task has been carried out correctly. If not, the 'T' goes red.

What is also interesting is the incorporation of the app/display in the car. The LED provides minimal feedback, to prevent 'overloading' the user with information. The time when the user requires more information, i.e when there is a problem, the information will be displayed on the display within the car.

Feedback in field of view:

What Tesla has designed well is, that compared to the current Ebike systems, their feedback information is next to the plug, perfectly in the field of view. There is no feedback on Tesla's charger itself and all the information is received through either the phone app or through display/ LED on the car. This highlights the structure and design of the system; it would have been a conscious decision to make the charger a passive device which maybe to ensure the user experience is centred around the car rather than the charger. For the Ebike a similar charging setup could be obtained, however, unlike the Tesla, battery removal is required which means there is a separation from the user and their Ebike , within different contexts, making the decision of where to place feedback more challenging.

Figure 134: The feedback light when the tesla is charging [95]

Another example of applying feedback within the field of view is the Kia E-Niro. This EV has its charging port at the front right corner of the car; to inform the user of the charge status 3 LEDs are displayed at the top of the dash board and can be clearly seen when connecting the charger [96].

4.6.2 Phone feedback

Within the current Ebike system the user must unlock their phone, open the ride control application, switch on their Ebike and connect their phone to the bike. The iPhone on the other hand provides the user with nearly instant feedback. With a clear overview of the charge status for all compatible devices that are connected. This feedback is displayed through a widget on the home screen and is obtained simply by unlocking the phone [97]. If something similar was implemented within the Ebike the feedback loop to determine the charge status of the bike would be significantly reduced.

Figure 135: iphone Widget displaying Charge status feedback [97]

4.7 Conclusion

The implementation of the preliminary guidelines within existing technology has been explored, as well as alternative, relatively novel, technologies such as wireless charging. This information has provided interesting insights that can be used as a source of inspiration during the ideation phase. Currently little additional research has been conducted into the context and capability guidelines as these heavily rely on the overall system and the user behaviour.

C5: MEASURABLE GUIDELINES

To evaluate the suggested design concepts, the designs need to be compared and evaluated against the guidelines. To achieve this the guidelines, need to be quantifiable and measurable. While this will allow the concepts to be compared, it will also allow for evaluation of the final concept/prototype against the design. The assessment method for each guideline varies as some guidelines are more ambiguous compared to others. To help create a distinction between the guidelines have been grouped within preparation/termination and charging.

5.1 Preparation & Termination

These guidelines focus primarily on the physical design, rather than digital interfaces therefore the measurement approach used represents this.

5.1.1 G1. Reduce the number of steps to remove the battery

To measure the guideline ‘G1’ the number of steps which the user must perform to charge the bike/ battery will be obtained through a flow diagram describing each task that has to be performed for that concept. However, the flaw with this measuring method is that some steps take longer than others. Therefore, a concept with fewer steps could take just as long as a concept with more steps. As a result, ideally the total time to perform the task should be measured. However, during concept selection this time cannot be directly measured and only predicted, therefore it is not an ideal way to compare the concepts. For better comparison the physical and mental workload of each concept will be used to evaluate the overall workload with the time taken being one component of the workload.

5.1.2 G2. Reduce the Physical and mental workload when removing the battery

An analogy is often made between physical and mental load to stress (mental load i.e. task demands) and strain (Physical load i.e the impact on the human) [95][98]. Stress is comprised of multiple features, such as time pressure and task complexity and strain shows multiple variations depending on the type of job the user must complete.

Quantifying the physical and mental workload is challenging as there are multiple components which contribute to a high workload. There are many ways to describe workload with different approaches such as information processing, task load, and self-regulation [99]. Combining these approaches, the following diagram is generated which highlights workload as a contribution from task load, processing, performance and (self-regulation). These are generated from stimulus, input/output, response, and evaluation respectively [99]:

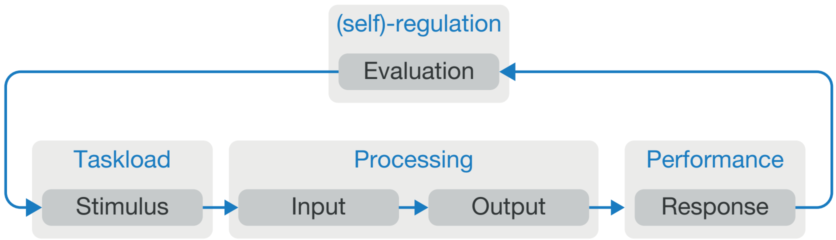


Figure 136: Overview of workload based of stimulus, input, output, response and evaluation [99].

Stimulus: This represents the external stimuli, which physical work environment, such as the displays and controls informing the user what task should be performed.

Input: This represents the user's 'sensory reception': their eyes, ears and other sensory organs which influence the quality and quantity of information flow.

Output: Perceived information is filtered and processed. This involves the decision making before behavioural changes and responses have occurred. The output involves both mental and physical state changes such as anxiety or fatigue.

Response: This involves the user's behaviour based on the how they have processed and actioned the information.

Evaluation: The evaluation action process may be long term or after several cycles. The user experience is a major factor which affects this box. This is usually measured by the effectiveness.

This diagram (Figure 136) and its elements highlight the continuous cycle and how, for every task, the workload increases. The measurement of both the physical and mental workload must take the working method (number of tasks) into account as this results in an increase in workload. Firstly, physical workload is explored.

Physical workload:
To measure the physical workload typically tests are conducted in real life using different devices such as posture monitoring instruments, heart rate measurements, blood pressure, and triaxle accelerometers (which measure the joint angle, range of motion, angular velocity, and angular acceleration). This data can then be combined to determine the overall physical workload [100]. However, within literature no research has been conducted on predicting the physical workload and evaluating design concepts before a physical prototype is produced. Therefore, an evaluation framework must be created to help determine the 'ideal' concept direction. To help determine the ideal concept to develop an assessment criterion for the physical workload based on scenarios should be created, based on the research by van der Beek and Westgaard [101, 102]. The physical workload is comprised of two elements: External exposure (based on the environment (context)) and internal exposure (based on the individual's capability).

To predict the user's physical workload based on the proposed concepts, the only variable which can be altered through the design is the external exposure. While the internal exposure (capability) is just as important, this element is uncontrollable since the user's capability and environment varies greatly. To quantify the external exposure, there are several influencing factors which can be quantified and used to evaluate the concepts.

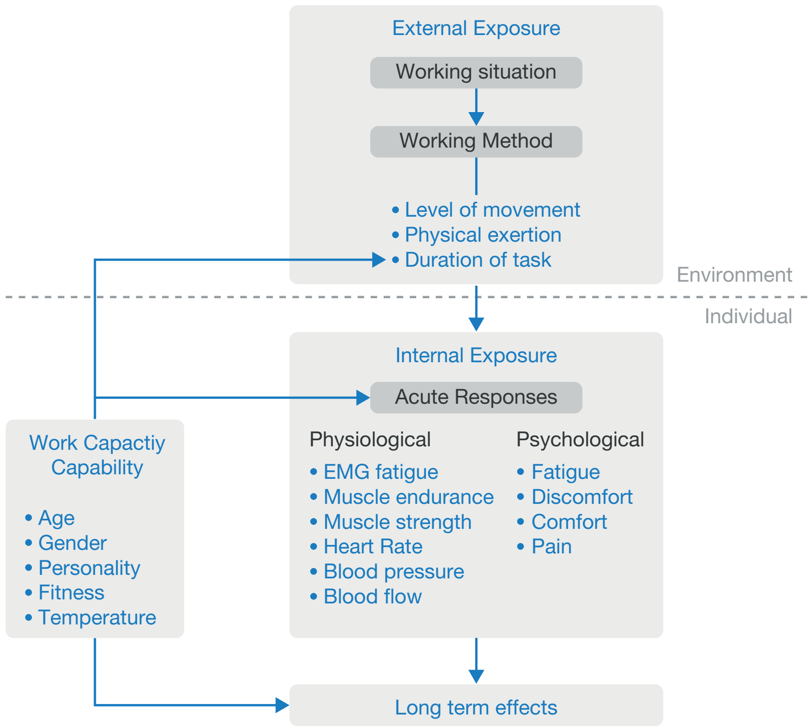


Figure 137: Model to indicate relationship between physical workload, specified as work demands independently of the worker (external exposure), and musculoskeletal health [101, 102].

Working situation: This involves the demands, and level of decision freedom. With the opportunity for the user to develop and improve their situation [102]. This element is based primarily on the user and therefore will not be used in the assessment analysis.

Working method (T): This involves the number of tasks the user must perform. Between concepts the distinction of the tasks will be consistent. For some scenarios/concepts the number of tasks will be higher compared to others.

Level of movement (M): This is how much the user would likely have to move to perform each task and their working height. This will be evaluated on a score from 1-10. 1 = No movement. 10 = High level of movement.

Physical exertion (P): This is primarily the weight of the objects the user must move and therefore how much muscle strength and endurance is required to carry out the task. This will be evaluated on a score from 1-10. 1 = No physical exertion. 10 = High level of physical exertion.

Duration of task (D): This involves a prediction of how long the task will take to perform. This is measured in seconds. While it is difficult to determine the exact time, since it is a comparison, the consistency between design concepts is important. e.g. if in multiple concepts the user must transport their battery into the house this task should be considered to take the same time.

Measuring the Overall Physical workload: To calculate the physical workload the following formula is derived, based on the elements which together create the external exposure:

$$PWV = \sum_{n=1}^{T} (M_n \cdot P_n \cdot \frac{D_n}{10})$$

Looking at an example of this calculation the current flow chart to prepare charging the battery is depicted below:

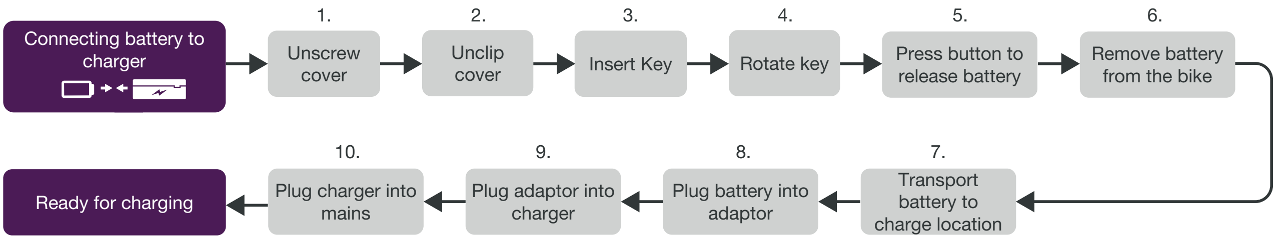


Figure 138: Flow diagram to charge the battery

Note: The figure above does not include decisions the user must make. It is assumed that after every task there will be processing required and a decision that the user must make. For each of the tasks four assessment scores are made. The sum of these values provides the final Physical Workload Value (PWV).

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Level of movement	3	4	2	2	4	6	6	2	2	3	
Physical exertion	2	2	2	2	4	6	4	1	1	2	
Duration of task (sec)/10	2	1.3	0.5	0.3	1.2	2	3	0.3	1	0.4	
Physical Workload	12	10.4	2	1.2	19.2	72	72	0.6	2	2.4	**193.8**

Figure 139: Physical workload value

This PWV will act as a reference number to compare the concepts with the current system to determine whether there is any significant improvement with the new concept. The PWV has also been calculated for the preparation/termination sequences.

These PWV's calculated align with what users stated (as an easier task) during the usability testing of the Giant Explore E+ (figure 55, page 038). Therefore, the calculation approach appears to provide a consistent representation on the user's physical workload. These scores act as a basis to see whether there are any significant improvements between the concepts.

	Procedure	PWV
Preparation	Charging Bike	9.3
	Charging Battery	193.8
Termination	Un-charging bike	7.8
	Un-charging Battery	156.4

Figure 140: Current system PWV scores

Mental Workload value:
Mental workload or cognitive load represents how much of the user's working memory is occupied. The common way to measure the mental workloads is by measuring methods involving eye tracking, blink rate, heart rate, speech activity, brain activity and Electroencephalogram (EOG) to name a few [51].

Looking at the mental workload against the user's performance, if the workload is not optimal the user's performance will be reduced. This suboptimal workload in literature is either due to a mental overload or underload. Overload is when the operator is faced with more stimuli than they can cope with based on their capabilities. Underload results from too little stimuli as the user's resources are allocated elsewhere or are demised due to underuse [98]. However, with chargers the task the usage profile is rather different from tasks where this model can be applied, such as, the riding of a bike or working on a PowerPoint presentation. The difficulty with chargers is that this time is only for a very short period. We have seen, based on the emo-cards and user testing, that under stimulation is occurring with a low level of arousal. This case is acceptable for the charging system however over-stimulation must not occur [98].

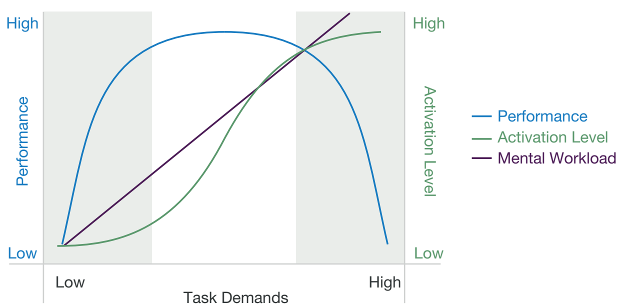


Figure 141: The relationship between activation level, workload (task demands) and performance [98]

To quantify mental workload and level of stimulation, like the physical workload, these measures also involve physical testing which cannot be used to analyse the concepts. That said, by looking at the elements which impact on mental workload, there is possibility that these can be measured and quantified for concept comparison. According to cognitive load theory (CLT) there are two types of cognitive load: Intrinsic load and Extraneous load [103].

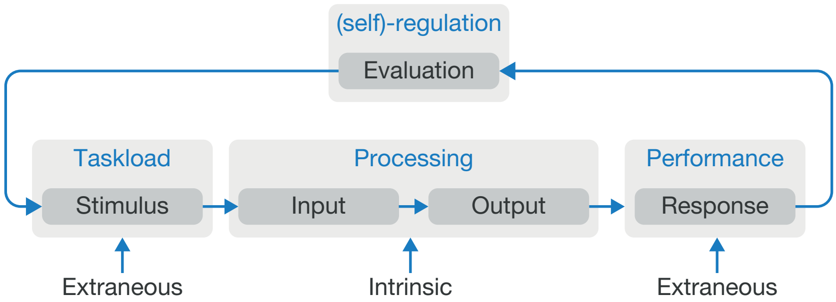


Figure 142: Overview of workload based of stimulus, input, output, response and evaluation [99].

Intrinsic load refers to the user's working memory. The Working memory resources are allocated to process information intended on learning a task. The task complexity and amount of learning that is required based on the user's expertise (capability), which must be used, simultaneously results in a greater intrinsic load [104].

Extraneous load involves the way in which the task is presented, external factors such as the physical environment, and/or internal factors such as the emotional state of the user [104].

Based on the intrinsic and extraneous loads, the user's capability is independent of the concept. However the task complexity/decision is dependent, which mean these can be quantified. Additionally, as seen, the (mental) workload present during each task, to quantify workload four variables will be measured.

Working method (T): This involves the number of decisions the user must perform (usually the same number as the number of tasks since during all task decisions need to be made).

Decision Complexity (C): This is how complex the decision is the user must make, based on the number of elements the user must think of and tasks they must perform. Increasing the difficulty (complexity) of the task can also increase the task demands, resulting in an increase in mental workload [98]. This will be evaluated on a score from 1-10. 1 = No complexity. 10 = High level of complexity.

Decision Severity (S): Within the extraneous load internal factors are the user's emotion. If the decision is going to result in a more severe outcome, this may result in an increase in negative emotions such as stress or anxiety. Therefore, the severity of the decision will also contribute to the overall workload. This will be evaluated on a score from 1-10. 1 = No severity. 10 = High level of severity.

Decision Feedback (F): Based on the evaluation the user makes to determine whether they have completed their task/the response of their decision has been confirmed. This involves the effectiveness. If feedback is clear the user will know they have completed the task correctly and their working memory can be reduced, as they are certain they can progress to the next task. This is evaluated on a score from 1-10. 1 = Certain the task is complete. 10 = High level of uncertainty that the task is complete.

Measuring the Overall Mental workload: To calculate the mental workload the following formula is derived, based on the elements which together contribute to both the intrinsic and extraneous loads:

$$MWV = \sum_{n=1}^{T} (M_n \cdot P_n \cdot \frac{D_n}{10})$$

Looking at an example of this calculation the current flow chart to prepare charging the battery is depicted below:

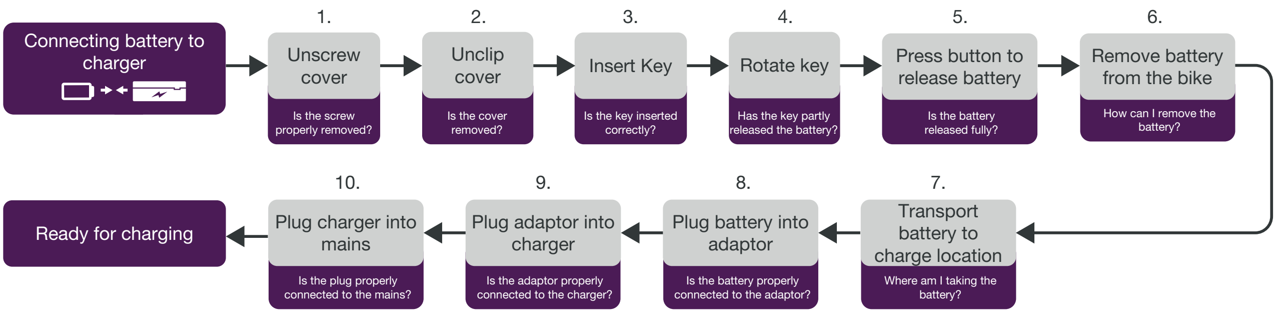


Figure 143: Flow diagram depicting the mental workload

Note: In the figure above all the decisions occur after each of the elements (1-8) in the diagram. e.g decision 1 will be "is the key inserted correctly?"

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Decision complexity	3	3	3	3	4	2	1	3	1	1	
Decision severity	1	1	1	2	2	3	1	2	3	2	
Decision Feedback	3	4	2	6	2	2	1	4	4	3	
Mental Workload	9	12	6	36	16	12	1	24	12	6	**134**

Figure 144: Mental workload value

This MWV acts as a reference number to compare the concepts. The current Mental Workload Value (MWV) for the preparation/termination options are shown opposite.

	Procedure	MWV
Preparation	Charging Bike	88
	Charging Battery	134
Termination	Un-charging bike	11
	Un-charging Battery	62

Figure 145: Current system MWV scores

These scores will act as a basis to see whether there are any significant improvements between the concepts. Looking at these scores the difference between the physical and mental workload is highlighted as the value orientation varies. In this case un-charging the battery has a lower mental workload than charging the bike. This is primarily due to the lack of feedback during charging the bike as the user cannot see whether the plug is fully inserted and orientated correctly. In contrast un-charging the battery simply involves pulling out cables and clipping in the battery, which needs physical effort however the feedback and decisions required are very low.

5.1.3 G3. Provide fast feedback that charger is setup correctly

This guideline falls in the preparation phase and charging phase. It involves feedback, which is informing the user that the charger is correctly setup to eliminate the 'trial and error loops' discussed in section 3.2.3. The measurement of this guideline will be incorporated within guideline 7 (5.2.3).

5.2 Charging

Goal: To Improve the Effectiveness during charging to improve the dependability and capability of the user

This goal primarily focuses on providing the user feedback during the preparation and monitoring phase during charging, allowing them to reduce the likelihood of errors such as leaving the bike charging above their desired percentage. Based on literature, the common way to measure effectiveness is the quantity of errors a user makes [105] or how many answers the user is able to get correct [106]. Learnability also plays an important role in overall effectiveness. If the user can operate the charging system to a certain level of competence in a short amount of time the system is effective [105]. In a study by FrØkjaer et al, effectiveness was measured on a scale from 0-5 based on the quality of the user's answer e.g the user performed the task correctly and explained why this is the best way [107]. Again, like the physical and mental workload assessments the effectiveness is evaluated with a real prototype to determine. Since this type of assessment is not present in literature an assessment method is created derived from the guidelines.

5.2.1 G4. Assist the user to better manage their battery health

Establishing the level of assistance required is challenging as a high level of assistance e.g multiple warning messages, reminders and notification could lead to further frustration. It is important to have the correct balance of assistance. To evaluate this score there is an optimum value. This assistance should be present and will be accessed within the whole feedback evaluation.

5.2.2 G5. Eliminate need to monitor the battery during charging when user does not want it to be 100%

To analyse whether the user will need to monitor their battery/bike during the charging process. The best solution to evaluate the concepts will be involving the number of steps required to set up the charging system as well as the mental workload discussed in section 5.1.2.

5.2.3 G6. Provide better feedback on the battery charge status and other data when required

To evaluate/measure whether a design has improved feedback on the charging status will be based on the outcome of guideline 4, 5 and 7. This guideline will be embedded within the charger requirements to ensure that the battery charge status is fully incorporated within the design.

5.2.4 G7. Ensure that feedback/assistance can quickly be obtained

This guideline could be measured in a similar way to the PWV & MWV, however feedback is not appropriate/available for every task. This results in difficulty in producing a quantifiable measure to evaluate and compare the concepts. Accordingly, this guideline will be applied within the development phase of the charger to improve the feedback and make it quickly accessible. Those feedback features that are measurable (eg. to determine how easy it is for the user to receive information of the charge status (retrieved from the BMS)), can be evaluated by:

Number of steps (N): This is the number of steps the user must take to receive the information they require. Keeping the number of steps to a minimum decreases the time it takes for the feedback to be obtained.

Delay (D): This is the duration of time the user must wait, or the additional tasks required, before they can receive the feedback. For example, once the user has plugged in the charger there is a time delay before the user received information that their Ebike is being charged.

Movement (M): For some tasks the user must move to see the feedback, e.g. to determine the battery percentage from the bike the user must move to switch on the bike. For each task that occurs the movement should be kept as low as possible. To measure this a scale of 1-10. Where 1= No movement and 10 = High movement.

Clarity (C): Another important component of feedback is clarity, the information within the feedback should be clear so that the user knows exactly what to do next and whether they have achieved what the task. A scale of 1-10. Where 1= Very clear and 10 = Very unclear was rated for each feedback task.

By multiplying all four scores together a feedback value for each of the charging features can be calculated. Based on these scores the charger lacks clarity on informing the user what to do if there is a problem. The large number of steps required to see the battery % means that this feedback score is also high, suggesting that there is significant room for improvement. Since some feedback elements are not present a summation of this calculation, similar to the PWV and MWV is not possible.

Feedback	Confirmation			Monitoring		
Feedback required by the user	Plug is inserted correctly	Charging has begun	If a problem user knows what to do	%	°C	Range
Is this feature Present (Y/N)	N	Y	Y	Y	N	Y
Number of steps to obtain feedback		1	1	4		2
Amount of Physical Workload (focus on level of movement)		3	4	2		2
Time to obtain feedback (seconds)		5	5	25		15
Clarity of feedback		6	10	1		3
Feedback score		90	200	200		180
						180

Figure 146: Feedback score for confirming charging and monitoring

When evaluating these different feedback scores, they are relatively high. However, with the current charging system, there is a high level of physical work required because the user has to move to see the feedback. Additionally, the clarity of the feedback is poor, resulting in a high score. For instance, interpreting the LED on the charger is difficult, and the user does not know what to do if the charger is not charging. These feedback scores will not be applied to each concept individually, as they will be incorporated into the charger requirements and used to evaluate whether the feedback has been improved during the reflection in section 16.1.2.

5.3 Holistic Guidelines

Measuring quantitatively holistic guidelines is difficult to quantify; however it will be embedded within the requirements for each of the components.

5.3.5 G8. Ensure that the charging system usability is not hindered in different usage contexts:

The different contexts which the charging system(s) must be suitable for are:

- Charging the bike directly
- Charging the battery directly
- Transportable
- Use indoors, garage &/or outdoors.
- Compatible with the range extender and bikes.
- Wifi & Bluetooth connectivity

5.3.6 G9. Design the system so that it can be performed by any user whatever their experience.

This guideline focuses on the performance and will be based on the overall design of the bike. To reduce the physical and mental workload and improve the performance (efficiency and effectiveness) of the charging system is to reduce the number of errors a user can make through influencing their behaviour [108]. This approach is referred to as the Design intent [108]. In the case of the charging system, the design will reduce the likelihood of the user performing tasks in the wrong way i.e. Such as the orientation of the plug or the battery.

In research by Lockton et al. the method suggest that there are 6 different lenses, While these lenses have different focuses, depending on what industry, they will be explained in the context of the charging system [108]:

Architectural: This involves the structure of the system to influence behaviour. For example, the current bike is designed in a way that the battery cannot be released until the key is turned thus causing the user to perform the sequence in a certain way. For other elements there is more freedom, and the architecture is less constrained [108].

Error proofing: Considers variations from the intended behaviour as “errors”. The design can help prevent these errors by either allowing the user to work without making a mistake or by preventing the mistakes from occurring in the first place [109]. An example could be the plug hole allows the charging plug to be inserted into the bike in only one orientation to prevent misalignment or connecting the wrong pins. In this case it reduces errors but can still lead to frustration from the user as they need to alter their behaviour and align the plug correctly.

Persuasive: Represents the persuasive technology primarily focused, in this case, on the application, how the interface can be used to persuade the user to change the attitudes, behaviour and habits through contextual advice and guidance [108]. This primarily will involve how the app can help persuade and assist the user to take better care of their battery.

Visual: Involves the visual language based on ecological psychology and Gestalt psychology that involves [110] how the user interprets meanings and patterns as they interact with the charging system.

Cognitive: Draws on behavioural ergonomics and looks at how people make decisions [103]. How it is affected by heuristics and biases. Understanding how users make decisions will allow the design to address this.

Security: This represents that undesired user behaviour is something to prevent or deter from occurring through the design of countermeasures [108].

It is important to note that designing to guide the user or create intended use should be assistive and help the user with performing the task, with the intent to reduce as much frustration as possible. This will ensure that any user based on their capability is able to use the charging system.

PHASE 2: CONCLUSION

Multiple technologies have been explored which could be incorporated within the charging system to address the 9 different guidelines. Some technologies had more potential to be incorporated compared to others, such as gathering inspiration from electric vehicle chargers ie. Tesla. This research provided a useful source of knowledge to take into the next ideation phase. This phase also resulted in the creation of methods to quantify the guidelines, which were be used to refine and select concepts to best fulfil these guidelines.

PHASE 3

IDEATION & CONCEPT CREATION

C6: OPTIMUM SYSTEM

To establish a focus for the ideation phase different user scenarios are explored and evaluated against the PWV and MWV, to ascertain whether there is a significant benefit to improve and eliminate steps. To determine these optimised steps the distinction is made between preparation, charging and termination. At this stage there are still a lot of unknowns, the values of the metal and physical workload will vary slightly once the design has been refined, however they will act as a ballpark.

6.1 PREPARATION & TERMINATION

Looking at the preparation and termination, these phases are very similar. The termination path is slightly simpler since it involves disconnecting plugs rather than connecting chargers. Looking at the flow diagrams for the preparation they can be simplified by incorporating/removing certain elements within the current design.

6.1.1 Bike Charging:

The existing Ebike charging preparation contains very few steps. To improve the physical and mental workload the following alterations should be incorporated within the new design.

1. This includes removing the need for the user to open & close the cover.
2. Ensure that the charger is always plugged into the mains.
3. Plug port location higher up on the bike.

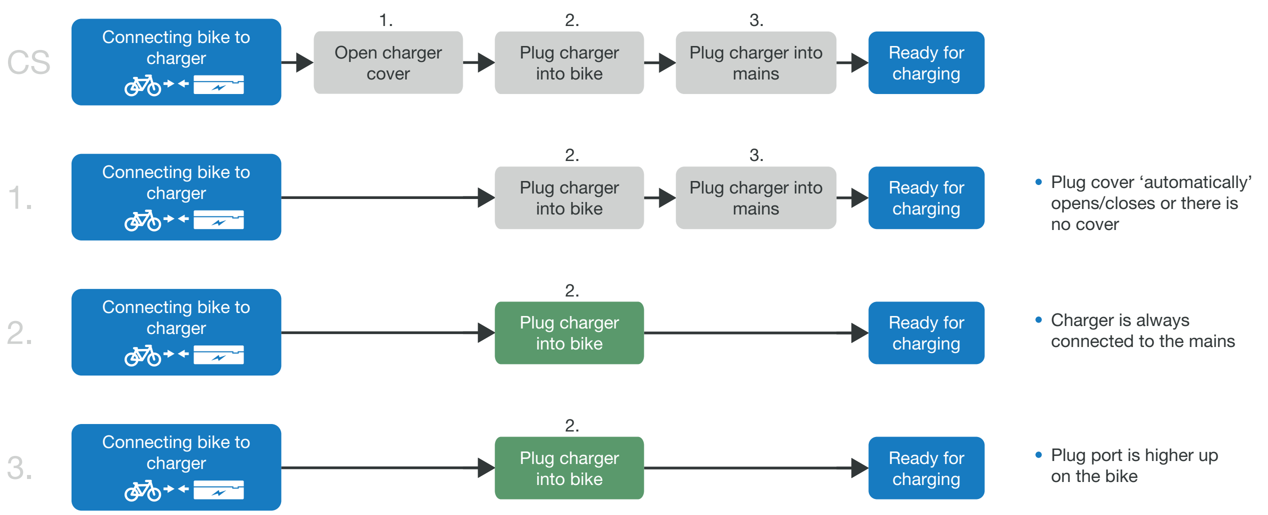


Figure 147: Optimising bike charging scenario. To see the optimisation of the flow diagrams for Uncharging the Bike refer to Appendix B.

6.1.2 Battery Charging:

For the battery charging preparation there is a less direct design optimisation approach. A more detailed concept on how the battery is released, removed, and connects to the charger needs to be evaluated, before the total physical and mental workload values can be determined. Eliminating the need for adaptors, and combining the battery release and removal into one smooth motion will reduce physical and mental workload slightly, as the user would not need to find a small button under the bike to release the battery further.

For the termination phase the same is performed but in reverse. Looking at the new physical and mental workload values we can see that there is significant improvement by eliminating steps. For the charging of the bike there is only a small improvement, but for the battery charging there is opportunity for greater improvement and will be key in the design development.

		Current System (CS)	1	2	3
Bike charging	PWV	9.3	6.9	4.5	3
	MWV	88	76	64	64
Bike Uncharging	PWV	7.8	5.4	3	1.5
	MWV	11	9	3	3
Battery charging	PWV	193.8	171.4	167	129.8
	MWV	134	113	95	83
Battery Uncharging	PWV	156.4	123	120.2	112.8
	MWV	62	34	32	22

Figure 148: Reduction in PWV and MWV scores due to flow chart optimisation. To see raw data used to calculate the PWV & MWV refer to Appendix C.

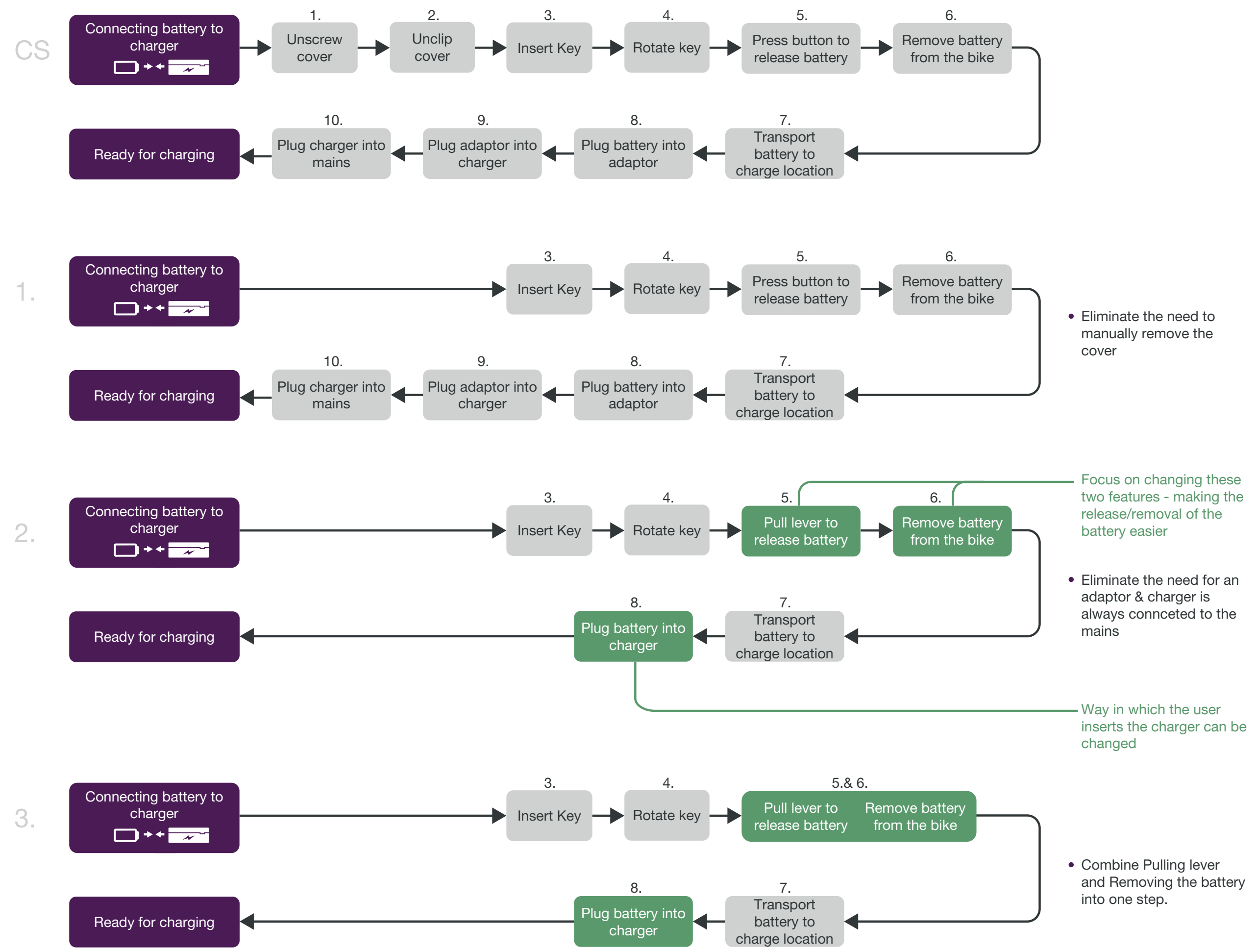


Figure 149: Optimising battery charging scenario. To see the optimisation of the flow diagrams for Uncharging Battery refer to Appendix B.

6.2 Charging

For the charging system the improvements primarily focus on how to provide the user with feedback and battery assistance. The location of the feedback still needs to be determined i.e. whether it is on the bike, battery, or charger.

The new alterations and flow diagram involves:

- Informing the user of the Charger status
- Inform the user if there is a problem and what the problem is
- Allow them to set their desired charge percentage
- Display the desired charge percentage, charge time and battery percentage.

The way this feedback is to be presented needs to be determined. During the ideation of this feedback the three criteria need to be focused on:

- Reduce the number of steps to obtain the feedback.
- Reduce the amount of physical workload (movement) to obtain the feedback
- Improve the feedback clarity

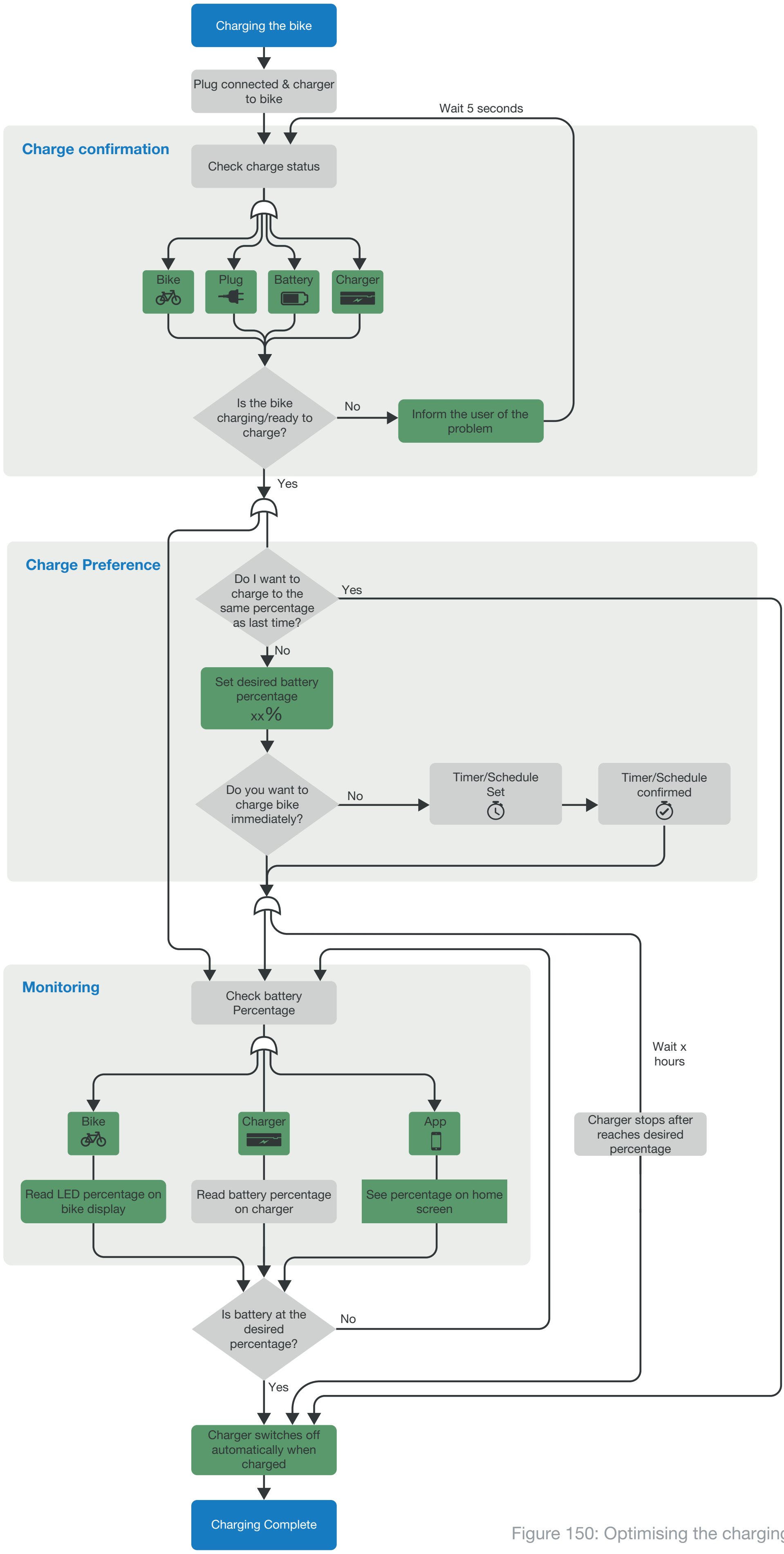


Figure 150: Optimising the charging sequence

C7: IDEATION

Since the charging of an ebike involves a whole system, it is not just dependent on one product, therefore, to aid the design process the design will be broken down into different sections. Looking at the guidelines we can see a clear distinction: guidelines 1, 2, and 3 focus primarily on the physical interface whereas guidelines 4, 5, 6 and 7 focus on the software and displays to convey feedback to the user.

Based on this distinction the Design phase will be broken up into 4 categories:

1. Charger
2. Communication between the charger and the bike
3. Integration of the battery within the bike (battery & plug)
4. The whole system

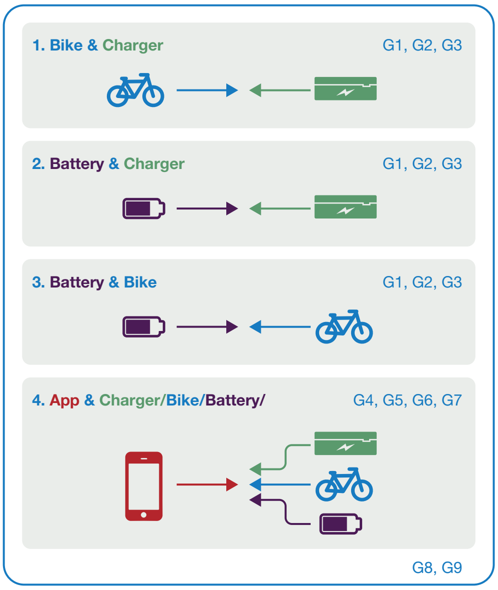


Figure 151: Distinction of 9 guidelines

7.1 Charger Configurations

There are multiple possible charger configurations which accommodate different user groups. The connection types between the bike, battery, charger etc. need to have compatible male and female connectors and eliminate the need for adaptors. In the figure below 8 different configurations, including Giant's charging system is depicted below.

Compact Charger: Has little difference from the current charging system. Some of the adaptors have been eliminated, however an adaptor is needed for the children's EnergyPak and the EnergyPak Plus but this could be masked in the form of a bottle cage or something similar, so it does not pose too many challenges. In all these cases the charger cable is brought to the bike/ batteries.

Docking Station + Bike cable: The docking station involves a stationary charger (with the transformer incorporated into the docking station base) where the user can drop/place the EnergyPaks into the docking station then move the cable to the battery. In scenario 4 the connecting cable between the bike and the adaptor could be removed if the user only chargers the battery, creating a clean docking station without additional cables. The problem with this configuration is that users who want to charge their bike on the go must carry the docking station with them, which would be bulkier and potentially slightly heavier than the current configuration.

This configuration highlights the importance of male and female configurations. Looking at scenarios 4 and 5. S4 does not need adaptors for the range extender and child energy pack, however the charging port would need to be located in close range for this to be an option. The S5 configuration means that the male connectors are on the cables and the female connectors are on the batteries/bike preventing the plug protruding from the bike/battery and being an eyesore.

Docking Station: Just a docking station would be suitable for the users who just want to charge their batteries and not their bike.

Charging Hub: This type of charger would be designed to be mounted on a wall. The hub would house the transformer then a series of different length cables could be purchased to charge the users ebike. This charging hub would be less compact and therefore less portable for the users who want to charge on the go. With the charging hub there would be the option to charge the batteries through a cable via a docking station. Since the docking station does not contain the transformer, it can be made much lighter.

Charging Hub +: This is the larger charging hub which would allow multiple plugs to be inserted and multiple bike/ batteries to be charged at the same time. It would be similar in design to the charging hub but would be larger with feedback for each of the connections.

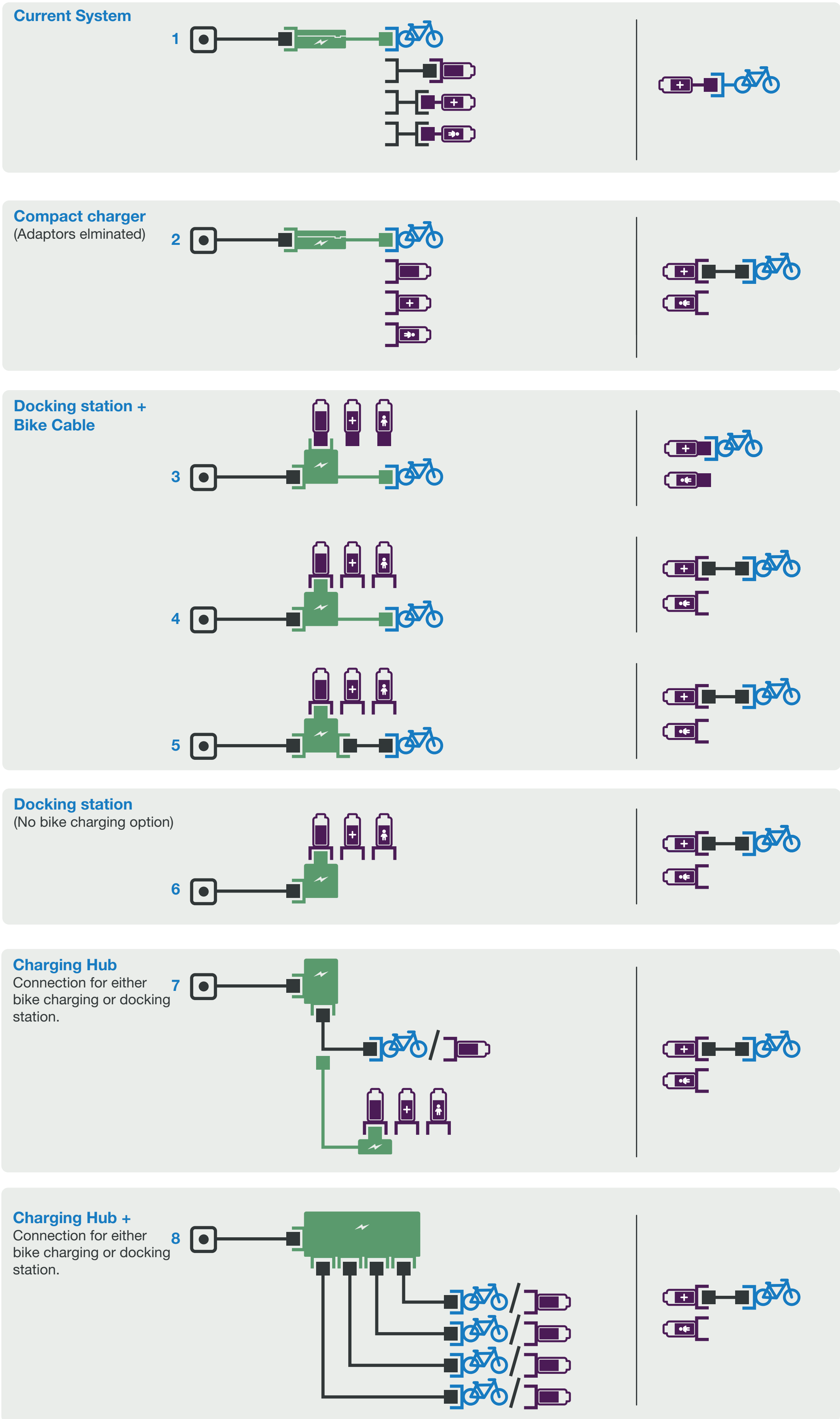


Figure 152: Different charger configurations

7.1.1 Selecting configurations

These different configurations are best suited depending on the usage scenario. Based on the usage research there are four different types of usage scenarios to charge the bike: at home (inside), in a garage, outside/on the go and a company who charges multiple bikes at the same time. Which configurations are best suited for certain scenarios are compared below, they are scored on a series:

	Configuration	Home (Inside)	Garage	Outside	Company
Current System	1	*	**	*	*
Compact charger	2	*	**	***	*
Docking station + Cable	3	**	**	-	-
	4	**	**	-	-
	5	***	**	*	*
Docking Station	6	***	*	*	*
Hub	7	**	***	-	*
Hub +	8	*	**	-	***

Figure 153: Ranking the different charger configurations

Looking at the table above there is not one configuration which fulfils the need of every user group, therefore, a selection/ focus needs to be decided. To achieve this a standard charger which comes with the purchased bike will be either configuration 5 or 7. As additional extras; a portable compact charger (configuration 2) and a larger charger Hub + for multiple bikes could be purchased (configuration 7). The compact charger will not contain smart features to help retain battery health since the charger is only designed for charging on the go and it will not be designed to use as a frequent charger -this will keep the charger simpler and keep the cost down.

7.1.2 Charger Requirements

Based on the research undertake these chargers will have different requirements.

Category	Ref No.	Requirements	Charger Type		
			Go Charger	Home Charger	Company Charger
Form	Ch1.1	Align with Giant, Liv & Momentum's identity	Yes	Yes	Yes
Purpose	Ch2.1	Charge battery/ Bike:	Away from home	Home/Garage	Corporate facility
	Ch2.2	Compatible with Range extender	Yes	Yes	Yes
Performance	Ch3.1	Amp:	2-4	4-8	6+
	Ch3.2	Weight:	<1Kg	<2Kg	<5Kg
Connection/ data transfer	Ch4.1	Wifi	No	Yes	Yes
	Ch4.2	Bluetooth	Yes	Yes	Yes
User Input	Ch5.1	Provide option to charge to X%	No	Yes	Yes
	Ch5.2	Schedule charging	No	Yes	Yes
Display	Ch6.1	Battery %	Yes	Yes	Yes
	Ch6.2	Charge time	Yes	Yes	Yes
	Ch6.3	Charge schedule	No	Yes	Yes
	Ch6.4	Feedback on how to solve a problem if it occurs	Yes	Yes	Yes
User Requirement	Ch7.1	As small as possible	Yes	No	No
	Ch7.2	Able to manage cables	Yes	Yes	Yes
	ch7.3	Elevate charger off the ground	Yes	Yes	Yes
	Ch7.4	Charge multiple Bikes/batteries at once	No	No	Yes
	Ch7.5	Transportable	Yes	Maybe	No
	Ch7.6	Versatile	Yes	Yes	No

Figure 154: Charger Requirements

7.1.3 Charger Ideation

Mood board: Mood boards were created for Giant, Momentum, and electronic products, to help determine the design language of the brands as well as electronic products. One of the major challenges for the charger(s) design is that they must be suitable for all three brands and therefore must not conflict with the different design styles of the other brands. This is the main reason why the current charger is a black cuboid shape that has no design language or personality.

Figure 155: 1 of 2 Giant's product moodboard

Figure 156: 1 of 2 electronic products moodboard

Based on these mood boards we can see several features have been highlighted, these have been summarised in the table below. To see the remaining 3 mood boards, refer to the Appendix E.

Category	Giant	Momentum	Electronic products
Form	Twisted lines. Continuity between surfaces Long curves/ flowing lines	Cylindrical Straight tubes, combined with one curve. Utilitarian	Bulbous Rounded edges. Concave & convex transitions High contrast Symmetry
Materials	Painted aluminium Painted Carbon	Painted aluminium Painted Carbon	Matt Plastic with brushed 'metal'
Details	Smooth surfaces Non textured	Smooth surface Matt sandblasted surface.	Dots, ribs, and lines Minimal displays/buttons
Colours	Metallic Gradient Earthy	Bold Earthy Playful	Neutral: white, black grey Small neon details/accents.

Figure 157: Summary of the moodboards

Go charger: Two different ideations have been conducted for the portable charger. These are a general form study and possible ways the charger could be attached to the bike. This is an important aspect to ensure that the charger is easily portable.

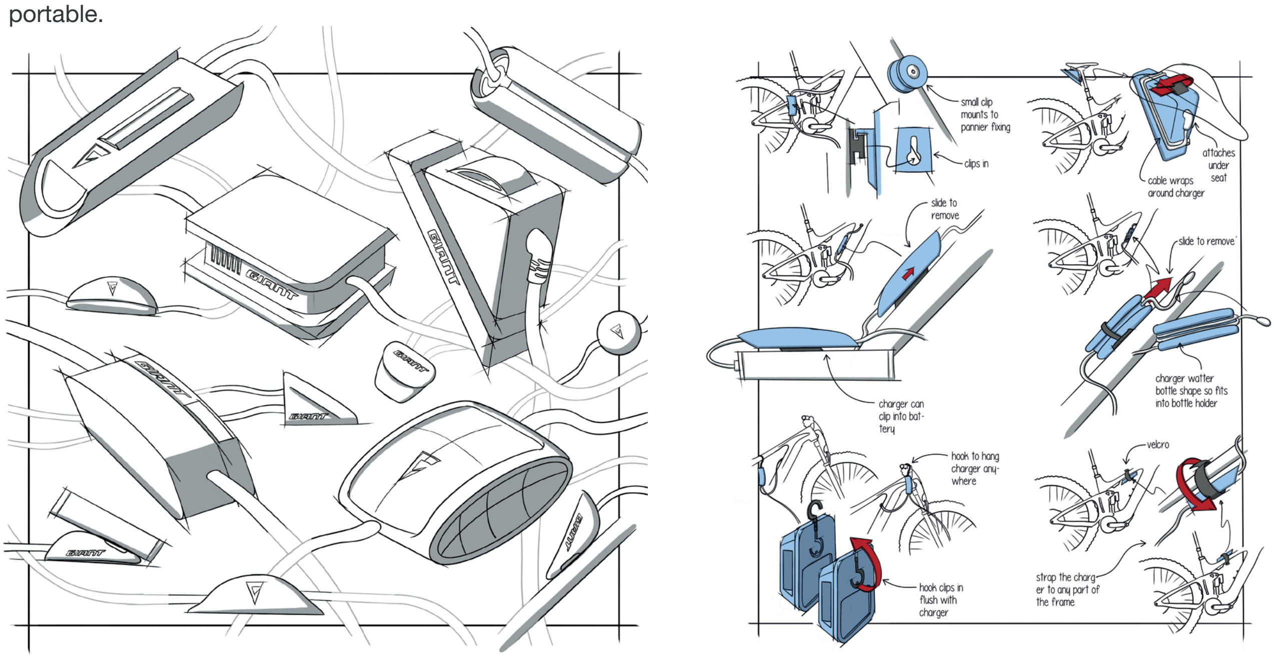


Figure 158: Go charger ideation

Charging Hub & Hub+: Since the charging hub+ is an extension of the charging hub the ideation has been undertaken collectively. Against two forms of ideation have been conducted; looking at a general form as well as ways in which the cables of the charger could be organised.

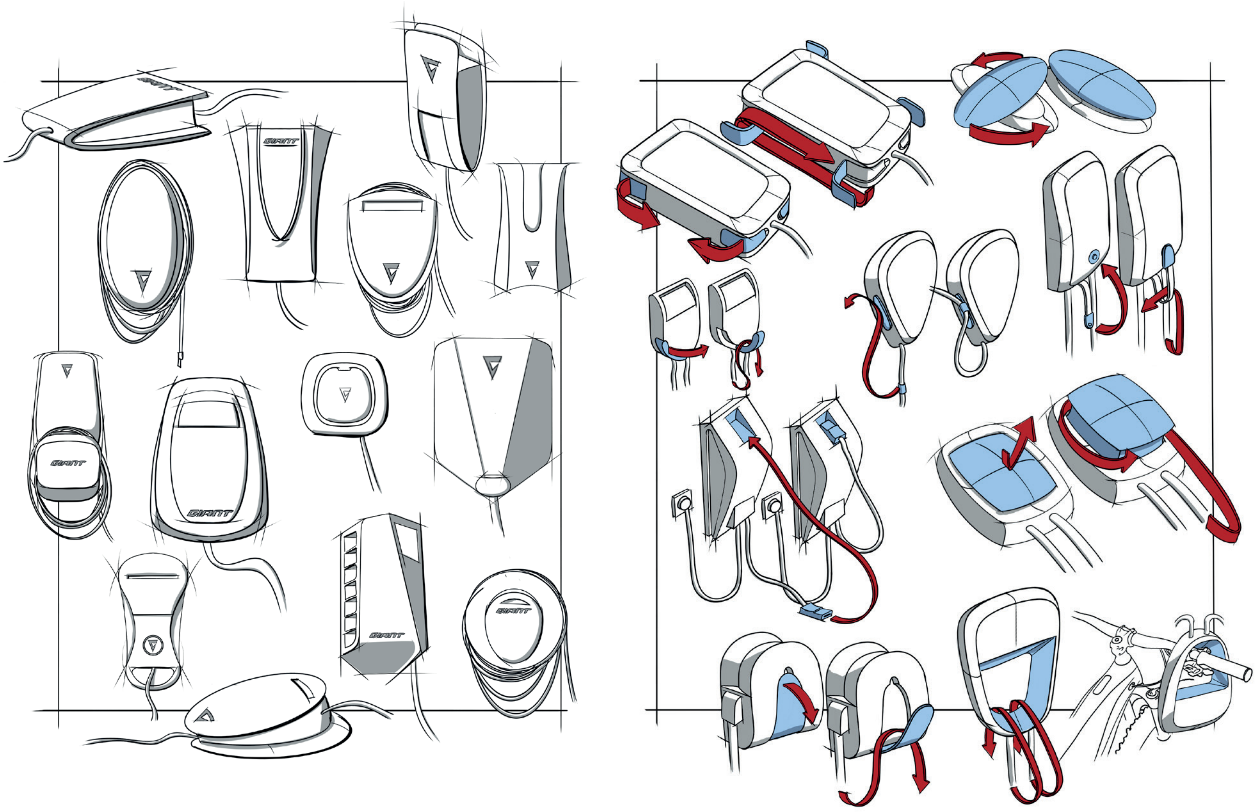


Figure 159: Charging Hub ideation

7.2 App and System structure

Within the configuration of the charger types, how these chargers will communicate between the Ebike, battery, Ride control app and charger is explored, together with what device could be conveying feedback back to the user. To help differentiate when and how the user could receive feedback the same stages as used in user behaviour (C3) is used. The ideal scenario involving all the relevant information of the Charging System is shown in the figure 160, page 094.

7.2.1 Users with an App

1A Usage: During usage the Ebike is switched on. Feedback of the remaining Range (Km) and battery percentage is shown on the bike display. This information, along with the battery cell temperature, is also uploaded to the app via Bluetooth Low Energy (BLE).

1B Not in use: When the Ebike is not in use the bike is switched off and therefore communication between the Ebike and the app cannot be made. However, the phone has stored the information the bike sent just before it was switched off. This allows the user to refer to the range, battery percentage and last temperature without any connectivity to the bike.

2A Preparation: This preparation stage can occur at any point, either after or before the user rides their Ebike. In this preparation phase the user can input the range/battery percentage (e.g. 80%) that they would like their Ebike to charge to. They can set the time to begin charging and how long they want the bike to charge, for example, if they charge their bike overnight the charging process can be much slower, helping increase the battery longevity. Once this data has been inputted into the app, the app will remember this until it is connected with the charger. The inputted information will remain the same until the user update changes the settings within the app.

2B Preparation: When the charger is connected to the mains/switched on, the charger can communicate with the phone via Wi-Fi and therefore is able to determine the user's charge preference set within the app. This information is then stored within the charger. There is opportunity for the charger to also convey feedback to the user. This will assure the user that their input from the app has been successfully sent to the charger.

3.Charging: Once the charger is connected to the bike or battery, the bike/battery will communicate the information from the BMS back to the charger via the physical data cable connection. The charger will then update the user's app of the current temperature, battery percentage etc. through wireless connection, and display the information on the charger's interface. With this approach the user can see the information/charge status from anywhere in the 'house'. If the bike is stored somewhere where the charger does not have Wi-Fi connectivity, the user can use Bluetooth to upload the information from the app when they are in close proximity, or they can see the live updates on the charger's display.

4.Termination: When the charger switches off (because it has reached the desired percentage charge set by the user initially) or it has been disconnected from the power supply, the phone will store the information uploaded on the charger just before it was switched off and notify the user of completion. This again, allows the user to know the battery percentage, range temperature etc. from anywhere with or without Wi-Fi. If Wi-Fi is not available data stored on the phone will remain the same as the last time it was connected to the charger via Bluetooth.

Charger feedback option: As seen with the Tesla charging, there is option to eliminate the feedback on the charger and obtain it all through the application, however, this penalises the users who do not own a smart phone or have Wi-Fi signal where their charger is located. Looking at this scenario further, the user would likely require more feedback on the bike or on the battery, however this involves the increase in complexity of both the battery interface and the bike interface to display more information about the charging status.

User with more than 1 bike/battery: If the user has more than one Giant Ebike the communication approach does not change. Within the application there needs to be an option for the user to toggle/flick between their bikes, therefore they choose their charging preference for a specific battery/ bike. However, the issue is that the batteries could be used in different bikes. If they are the same size battery the user cannot determine which one is which. To help with the distinction the user can colour code their battery and choose a name for their battery within the app.

7.2.2 Users without access to the App:

If the user does not have an application the process is similar and the charger is able to have similar functionality. In this case the user can adjust their charging preference through the Ride Dash display on the bike. This information is stored in the bike & also sent/ stored in the battery. When either the bike or battery is connected to the charger the information is transferred to the charger. If the user is using both the Ride dash and the app the charger will select whichever information was updated closest to the time of charging.

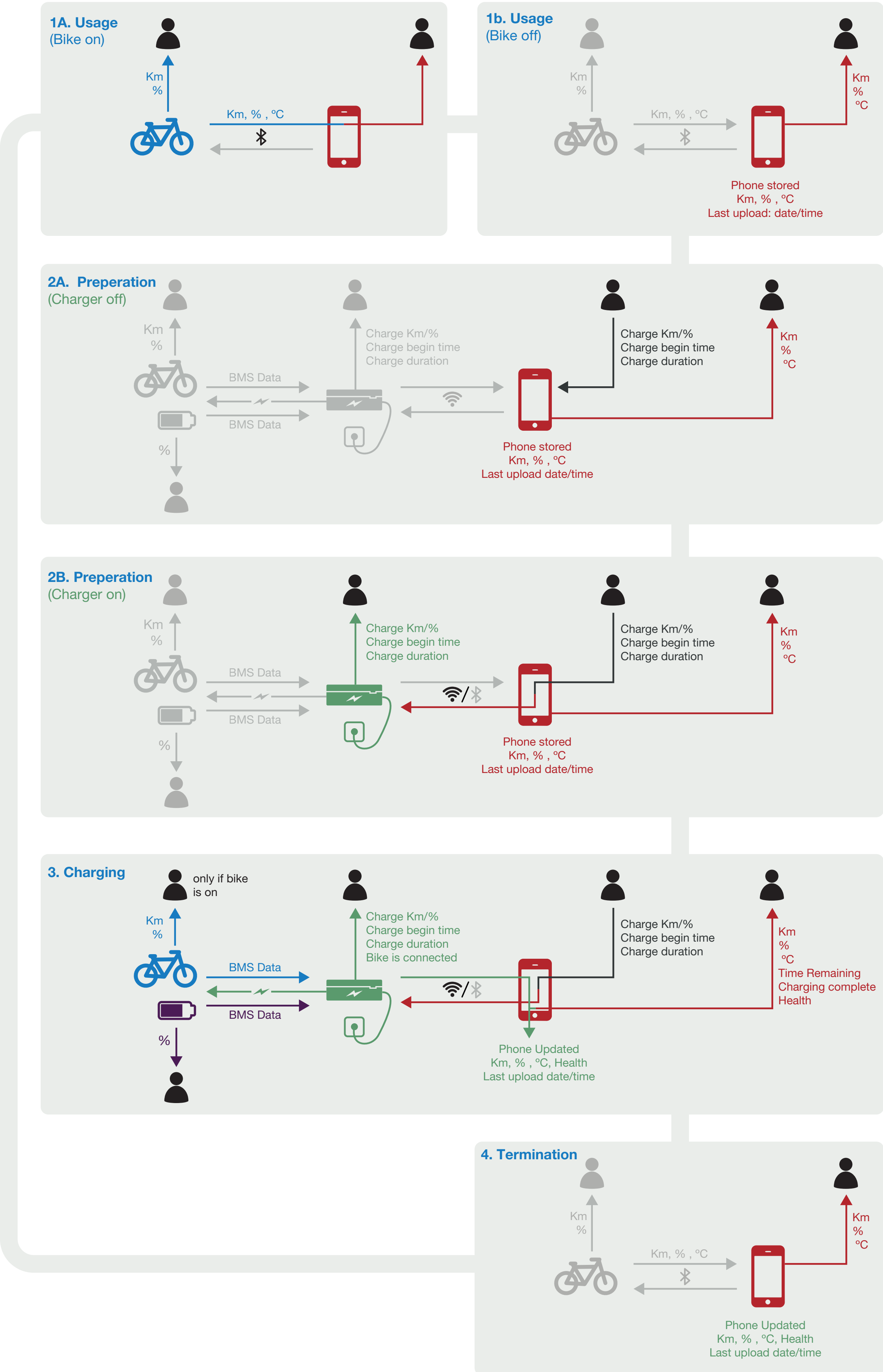


Figure 160: Communication structure between charger, bike, battery, and app

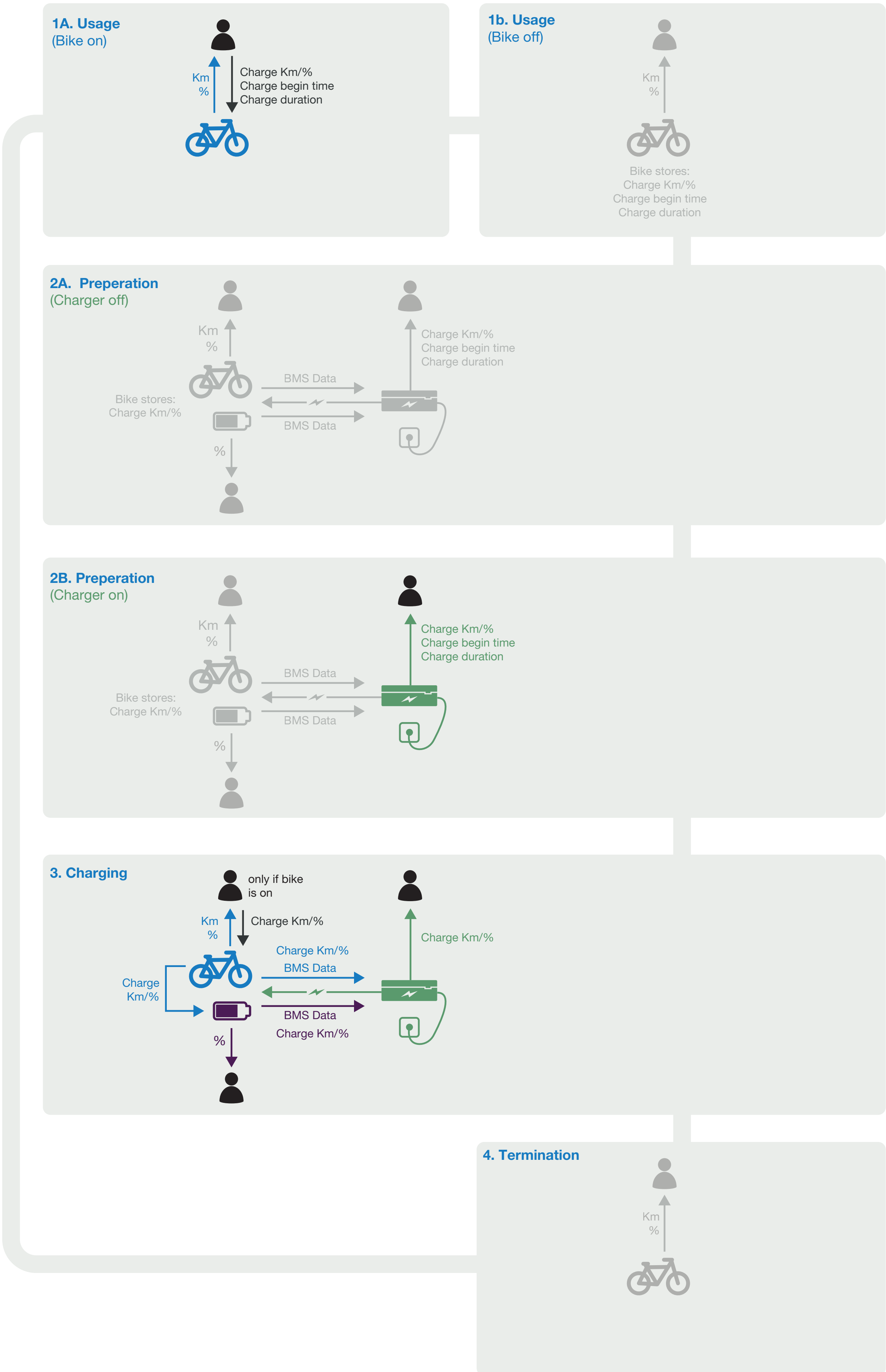


Figure 161: Communication structure between charger, bike, battery (users without an app)

7.3 Battery & Plug Integration

As seen to optimise the battery and plug to reduce this physical and mental workload several design requirements are necessary to include these are discussed below.

7.3.1 Plug and Cover Requirements

The requirements for the plug and cover are stripped back to the most important requirements. To measure the user experience of the plug and cover between the ideation and concepts the Metal and Physical workload will be used. The MWV and PWV will be the most important selection criteria and the requirements mentioned below must be fulfilled within the final design.

Category	Ref No.	Requirements
Form	PL1.1	Align with Giant, Liv & Momentum’s identity
Purpose	PL2.1	Connect the power and data to the bike/battery
	PL2.2	Compatible with Range extender
Performance	PL3.1	Able to safely transfer 2-6 amps
	PL3.2	Waterproof/ water resistant
	PL3.3	Mud resistant
	PL3.4	Case does not make a noise when riding
Connection/ data transfer	PL4.1	Contain 7 Pins (5 Data, 2 Power)
	User Input	Feedback that the plug is inserted in correctly
	Display	Feedback that charging is occurring/a good connection has been made
User Requirements	PL5.1	Eliminate need for adaptor
	PL5.2	Eliminate need to remove a cover
	PL5.3	Ergonomic
	PL 5.4	Does not ruin the aesthetics of the bike/battery

Figure 162: Plug/Cover Requirements

7.3.2 Plug Ideation

Based on the plugs that were ideated: they can be broken into two categories:

1. Plugs with a cover the user must open.
2. Plugs with no cover, or the cover opens automatically as user inserts the plug.

Plugs with a cover:
Looking at the plugs with a cover that must be opened (figure 164), 7 variations have been ideated. These 7 ideas have been given a physical and mental workload value to help determine which plug & cover could further improve the charging efficiency.

An example of how some of these values are derived: Idea 1 requires that the user rotates the cover 180° to reveal to plug compared to the other ideas would take the most time and physical effort from the user, resulting in a high score. Whereas for idea 7, the cover automatically pops up when a button is pressed leading to the lowest physical and mental workload since the automatic opening of the cover is doing the work for the user.

Comparing these ideas to the values generated for the current system, these values are lower therefore have resulted in a lower Mental workload, with less task complexity. However, there is still room for improving the PW value by eliminating the need to open and close a cover.

	Plug type with cover	PWV	MWV
1	Rotate cover up	5.4	33
2	Rotate cover down	5.4	33
3	Slide cover down	4.8	32
4	Press in cover then it pops up	4.8	43
5	Rotate the cover 180°	9.6	51
6	Press in top of the over and it rotates up	6.8	35
7	Press button and cover pops up	4.4	30

Figure 163: PWV and MWV for a plug with a cover

Plugs with a cover

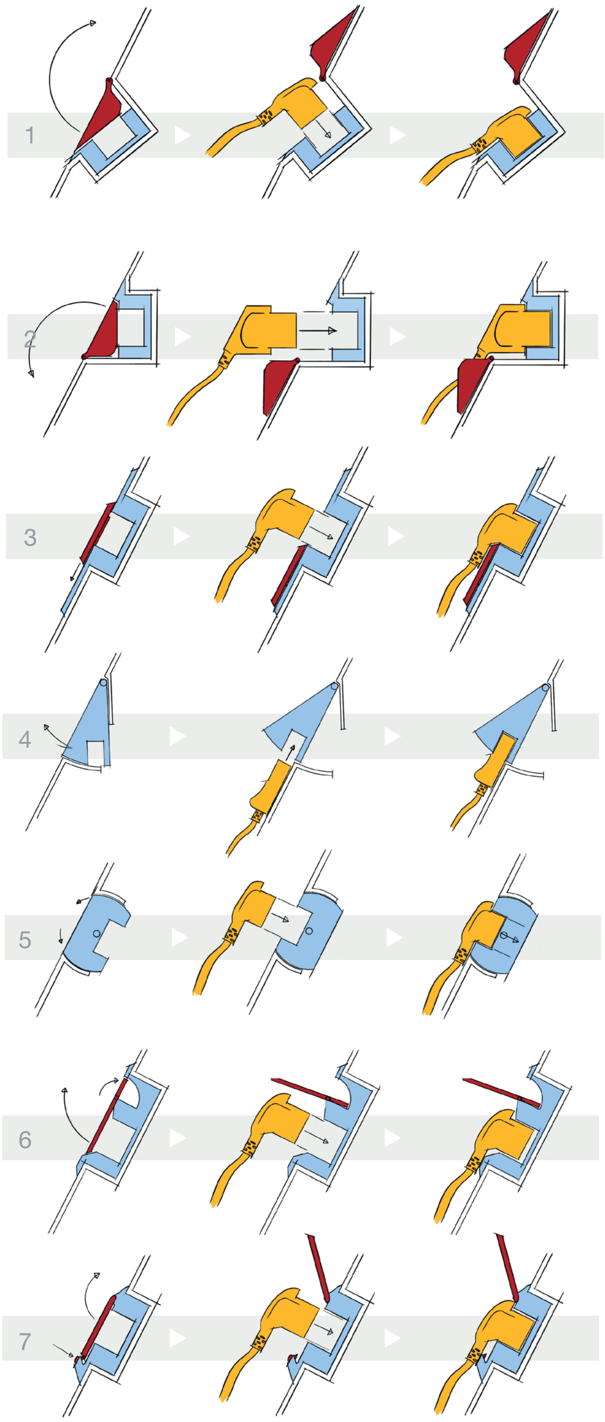


Figure 164a: Plug ideation with a cover

Plugs ‘without’ a cover

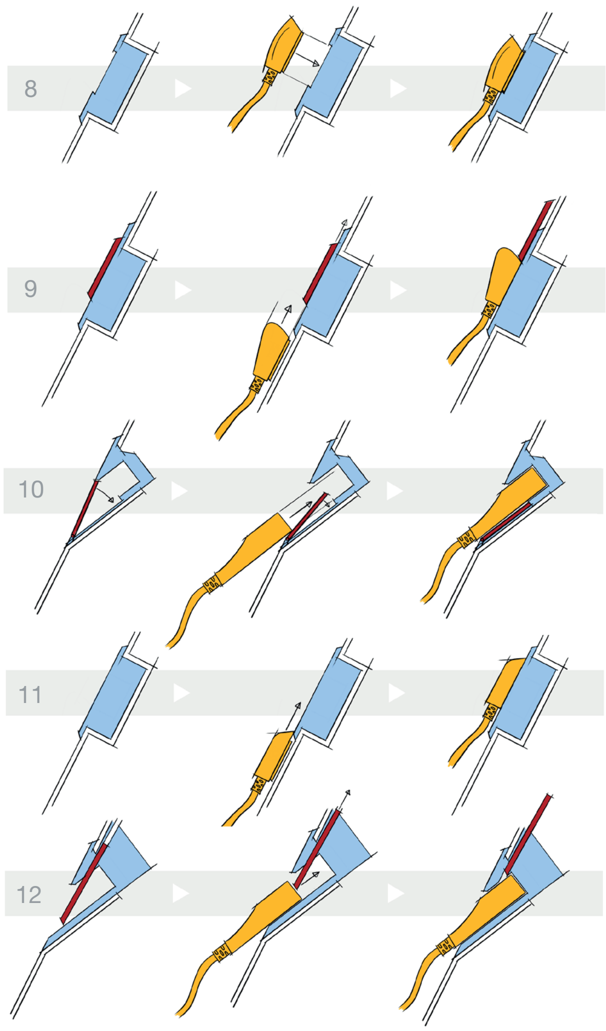


Figure 164b: Plug ideation ‘without’ a cover

	Plug type ‘without’ cover	PWV	MWV
8	Magnetic clip (no cover)	0.8	12
9	Slide on and cover slides up	3.6	18
10	Push in cover retracts	2.7	18
11	Slide up (no cover)	2.4	24
12	Slide in cover retracts	2.7	27

Figure 165: PWV and MWV for a plug without a cover

Based on the above values for the plugs ‘without’ a cover there is a significant improvement by eliminating the need for the user to manipulate the cover. The magnetic connection scored lowest suggesting the ‘best’ option, however with the increase in cost of magnets and the connections not being protected from the elements by a cover there is potential risk with this design. Which is why ideas 10 and 11 were incorporated within the concepts.

Plug integration within the display:
The integration of the plug within the display has also been explored. The benefit of this is that during charging the display can give the user direct feedback of the charging status as soon as they plug in the charger. However, the disadvantage of this is that the charger plug is limited to only the bikes where this display is used.

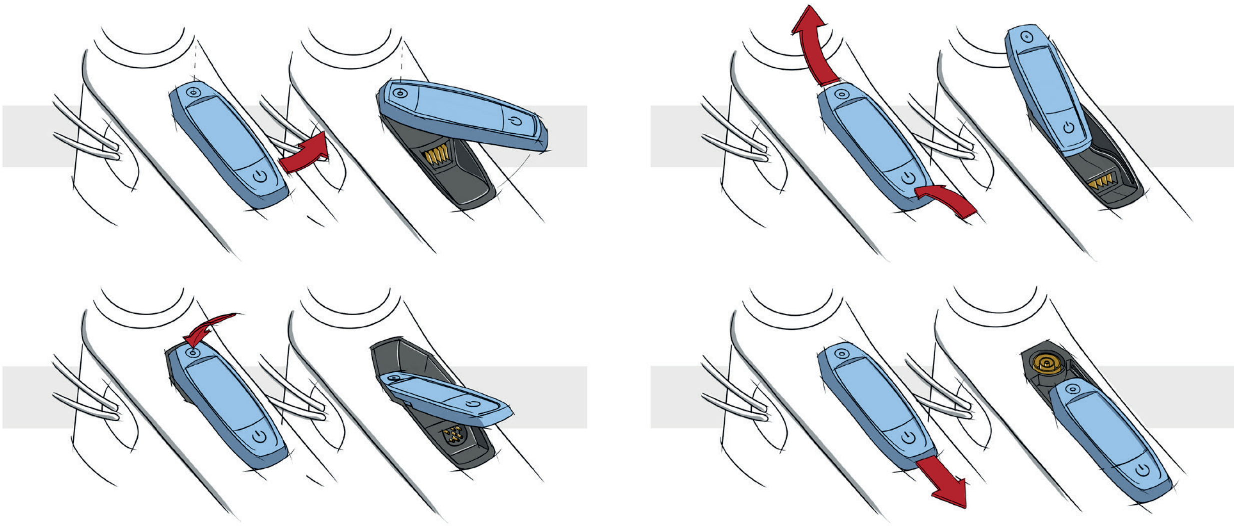


Figure 166: Integration of plug within the display

7.3.3 Battery Integration requirements

For the battery integration requirements, the same approach is also conducted, with the focus primarily on the PWV and MWVs.

Category	Ref No.	Requirements
Form	BI1.1	Align with Giant, Liv & Momentum's identity
Purpose	BI2.1	Securely connect the battery within the bike
	BI2.2	Allow battery to provide power to the bike's electronic features.
Performance	BI3.1	Able to safely transfer 2-6 amps
	BI3.2	Waterproof/ water resistant
	BI3.3	Mud resistant
	BI3.4	Not increase the weight more than 500g
	BI3.5	Not significantly increase manufacturing complexity
User Input	BI4.1	Feedback that the battery is inserted in correctly
	BI4.2	Feedback that battery is released/properly inserted within the frame
Display	BI5.1	Feedback of the charge status present on the battery
User Requirements	BI6.1	Eliminate need for adaptor
	BI6.2	Less Physical and mental work load to remove the battery from frame
	BI6.3	Ergonomic
	BL6.4	Does not ruin the aesthetics of the bike/battery

Figure 167: Battery Requirements

7.3.4 Battery Integration Ideation

For the battery integration with the frame, bottom release battery removal has been selected as the battery integration type to improve. While there are 'easier' ways to integrate and remove the battery within the frame, such as side release or using a carrier, a battery with a bottom release mechanism, is more aesthetically pleasing as the battery is hidden from view. However, this creates the most challenges and issues for the user; primarily the awkward angle the user must position themselves in conjunction with the tight constraints around the front wheel. This present a significant challenge to help improve the user experience, which is why it has been chosen as the focus to redesign.

For optimising the system, the focus in the ideation is to make removing the battery from the frame seamless, with as few steps and decisions as possible. With this as the focus 10 different ideations have been generated, these ideas can be broken down into two different categories:

1. The battery is separate from the outer casing. (1-7)
2. The battery and the case are joined (8-10)

Insert Key → Rotate key → Press button on side of case to release hatch → Twist out battery from supporting case →

Insert Key → Rotate key → Squeeze together two buttons to release battery → Use handle on top of battery to pull battery through forks →

Insert Key → Rotate key → Press button to rotate frame → Twist out battery by holding handle in top corner →

Insert Key → Rotate key (Battery base pops off) → Press button on inside of the battery case to unclip battery → Support battery as it slides down the hatch →

Insert Key → Rotate key → Pull open bottom hatch → Slide battery and fold in the centre to carry →

Insert Key → Rotate key (Opens hatch completely) → Pull battery out through side of the case →

Twist lock nut 360° (Hatch lowers) → Remove battery by pulling top corner →

Insert Key → Rotate key → Pull lever to release battery → Use lever to pull battery from frame →

Insert Key → Rotate key (Battery base pops out) → Press button on top of case to release battery → Use handle to lower and carry the battery from frame →

Insert Key → Rotate key → Push battery down into frame slightly (top is released) → Pull battery up and out of the frame →

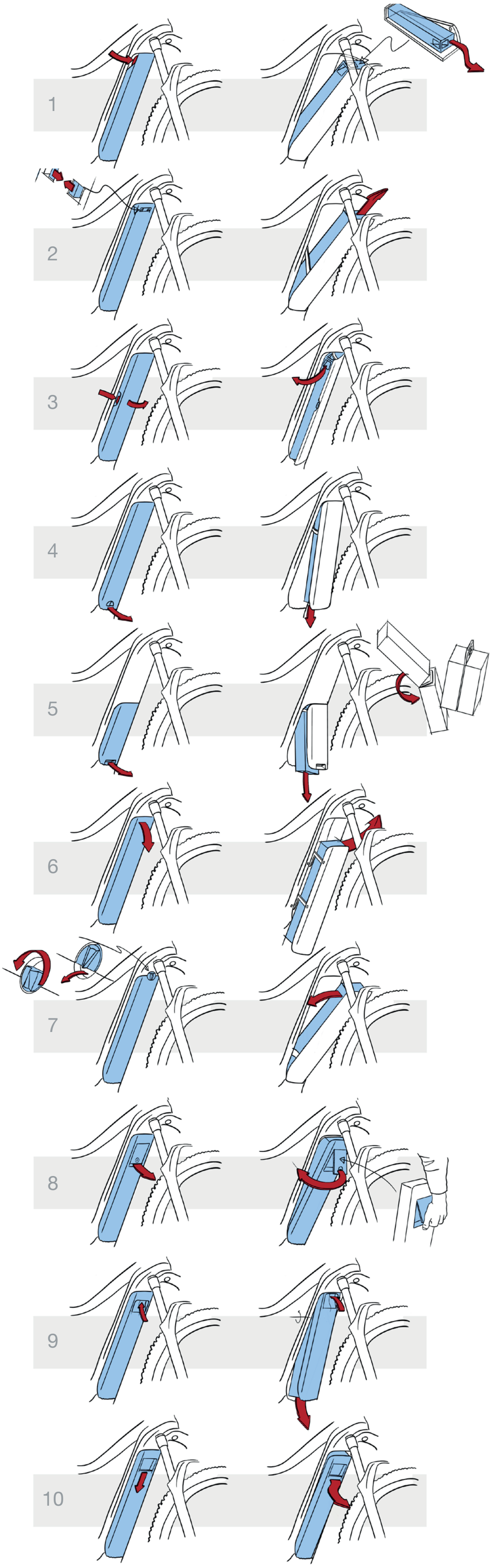


Figure 168: Ideation for optimising battery removal with flow charts used to calculate MWV & PWV

During this ideation process one element which was highlighted was to ensure that there is feedback when the key is rotated, something needs to happen, such as a clicking sound or the battery is released slightly.

Comparing the different scores for each of the 10 ideas, there is not one idea that significantly outperforms the others. The parallel swing and button rotate offer good potential but do not come without their challenges. Since the additional reinforcement of the hatch to support the battery would increase the overall weight of the bike and create more moving parts and/or opportunities for failure. The parallel swing also does not contain a 'safety button' like the other designs, which means one of the steps is eliminated, potentially highlighting the lower score. The rotate and lower mechanism is a promising design by reducing the need for the user to move lower down to support the weight of the battery. This design does not need the exterior cover to be reinforced adding benefit to this design.

	Distinct feature	PWV	MWV
1	Bottom rotate	17.5	62
2	Through forks	20.5	76
3	Side rotates	18	62
4	Bottom slide	26	74
5	Folding battery	27.8	72
6	Parallel swing	15.5	36
7	Twist lock	20.5	36
8	Pull lever	19	56
9	Rotate and lower	17.5	50
10	Push into frame	21.5	68

Figure 169: PWV and MWV Battery Integration

7.4 Conclusion

The ideation phase involved optimising the communication between the app and chargers along with what features/ feedback must be present on the devices to help inform the user of the current charge status of their bike. The ideation phase resulted in the conclusion that three different chargers will be designed: a charger that focuses on charging at home, One for charging on the move (away from home) and another for bike hire companies/users with multiple bikes to be able to charge a fleet (2-4) of bikes at the same time.

C8: CONCEPTUALISATION

For the conceptualisation phase three different concepts are generated. These are based on the three best plug types and three best battery integration types. In this section they have been thought out in more detail alongside the three charger types. This additional detail will allow better evaluation of the concepts to determine the best direction to optimise user experience.

8.1 Concept 1: Sliding Plug

8.1.1 Charging Hub

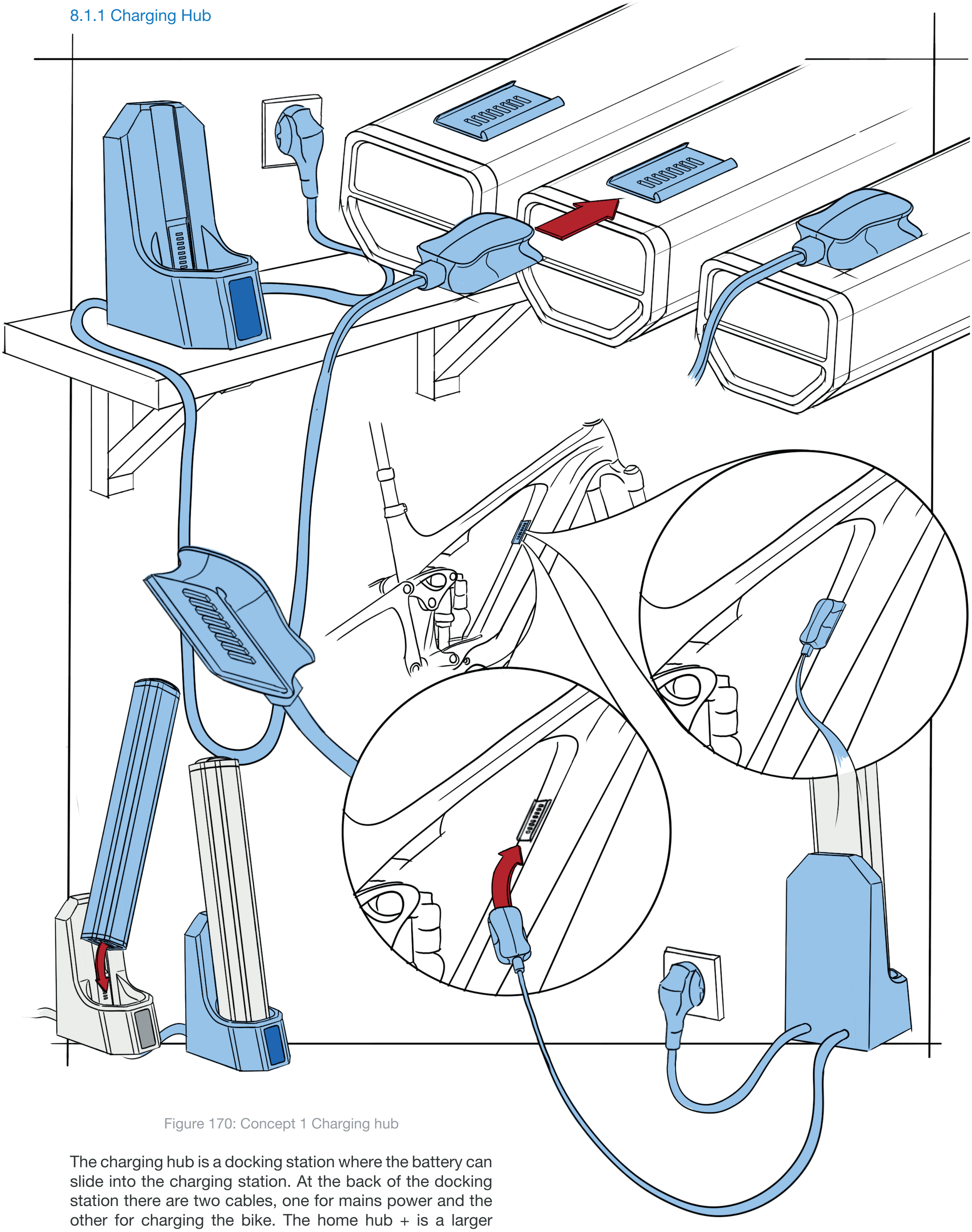


Figure 170: Concept 1 Charging hub

The charging hub is a docking station where the battery can slide into the charging station. At the back of the docking station there are two cables, one for mains power and the other for charging the bike. The home hub + is a larger docking station without the docking station capabilities.

8.1.2 Go Charger

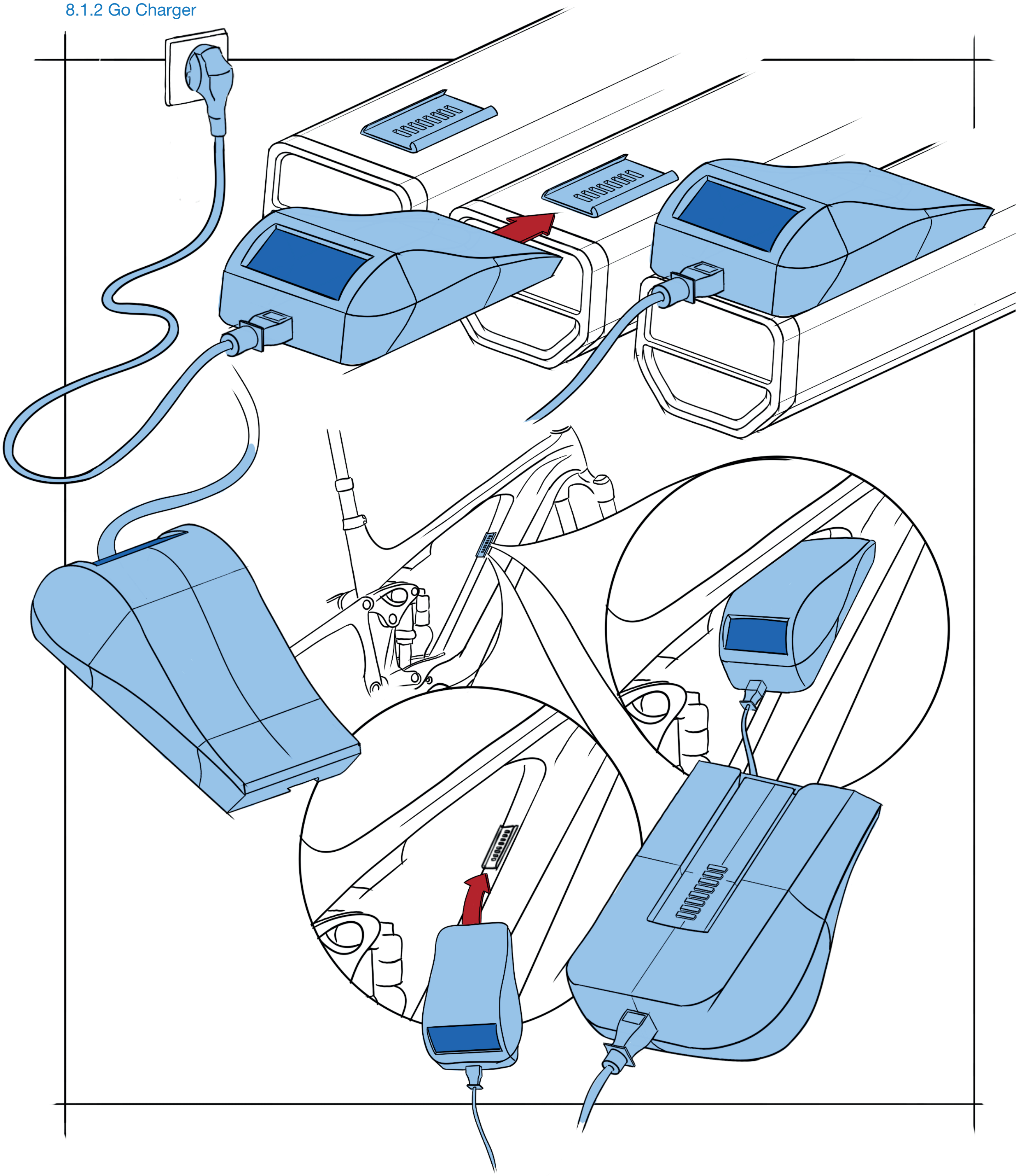


Figure 171: Concept 1 Go charger

The go charger can be slid onto either the battery or the bike without the need for an additional cable from the transformer to the battery/bike. The compact device has a large LCD display on the back allowing it to be easily viewed when it is attached to either the bike or the battery.

8.1.3 Battery Integration

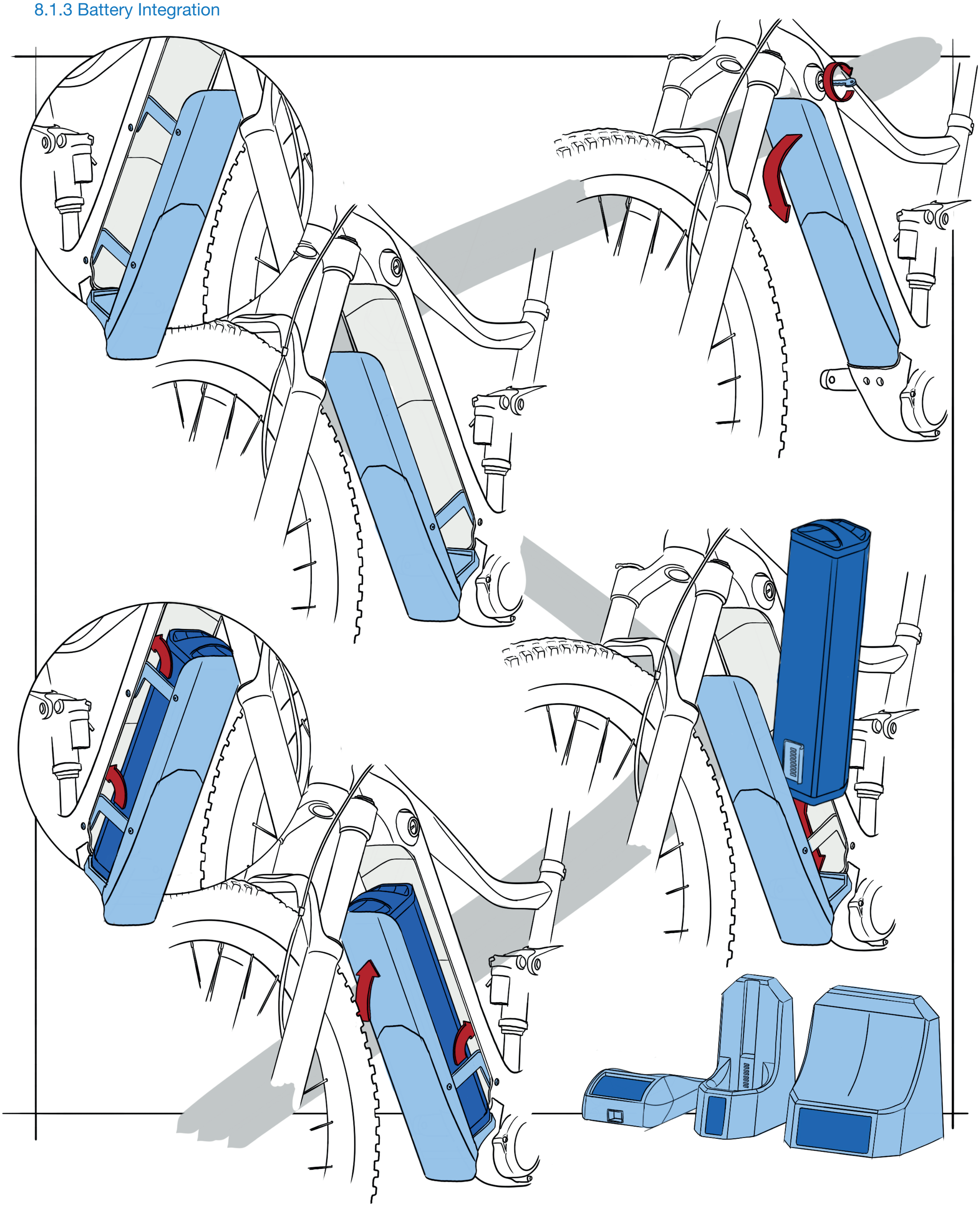


Figure 172: Concept 1 battery integration

Figure 173: Three charger configurations

The battery integration uses the parallel swing arm. Twisting the key causes the hatch to pivot and swing down, allowing the battery to be inserted and slid into the plug connector. At the top of the battery is a handle to make it easier for the user to insert and remove the battery, similar to the Gogoro battery design.

8.2 Concept 2: Magnetic Plug

8.2.1 Charging Hub

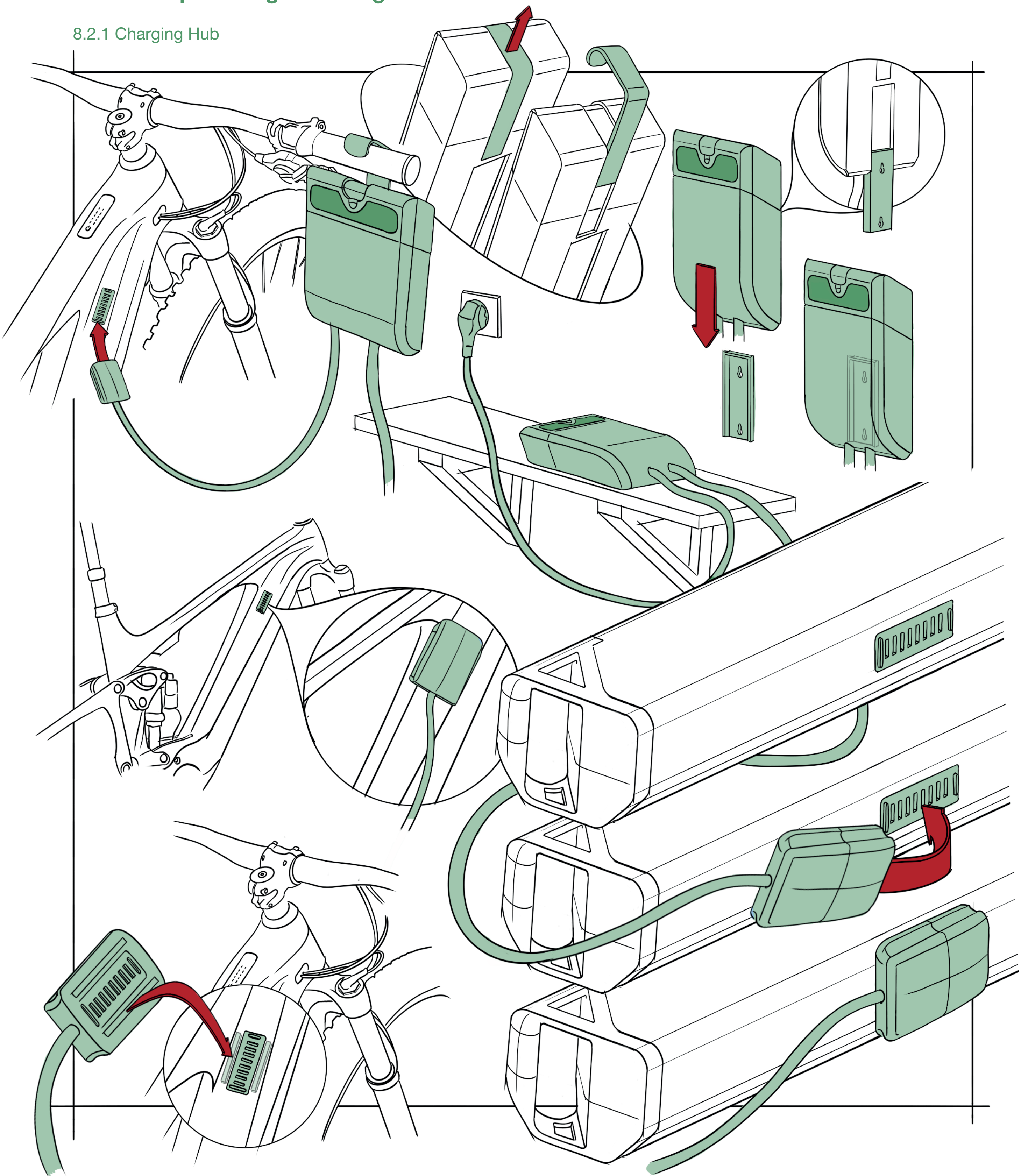


Figure 174: Concept 2 Charging hub

The charging hub includes a hook so it can be hung on the bike during charging, and a bracket so it can be mounted to the wall. There are two cables coming from the base of the charger: one for the mains power and the other for either charging the battery or the bike. On the front of the charger is a LCD screen to display the charging information. The Go charger and charging hub+ are both configurations for the charging hub either narrower and more compact or wider with more power outlets.

8.2.2 Battery Integration

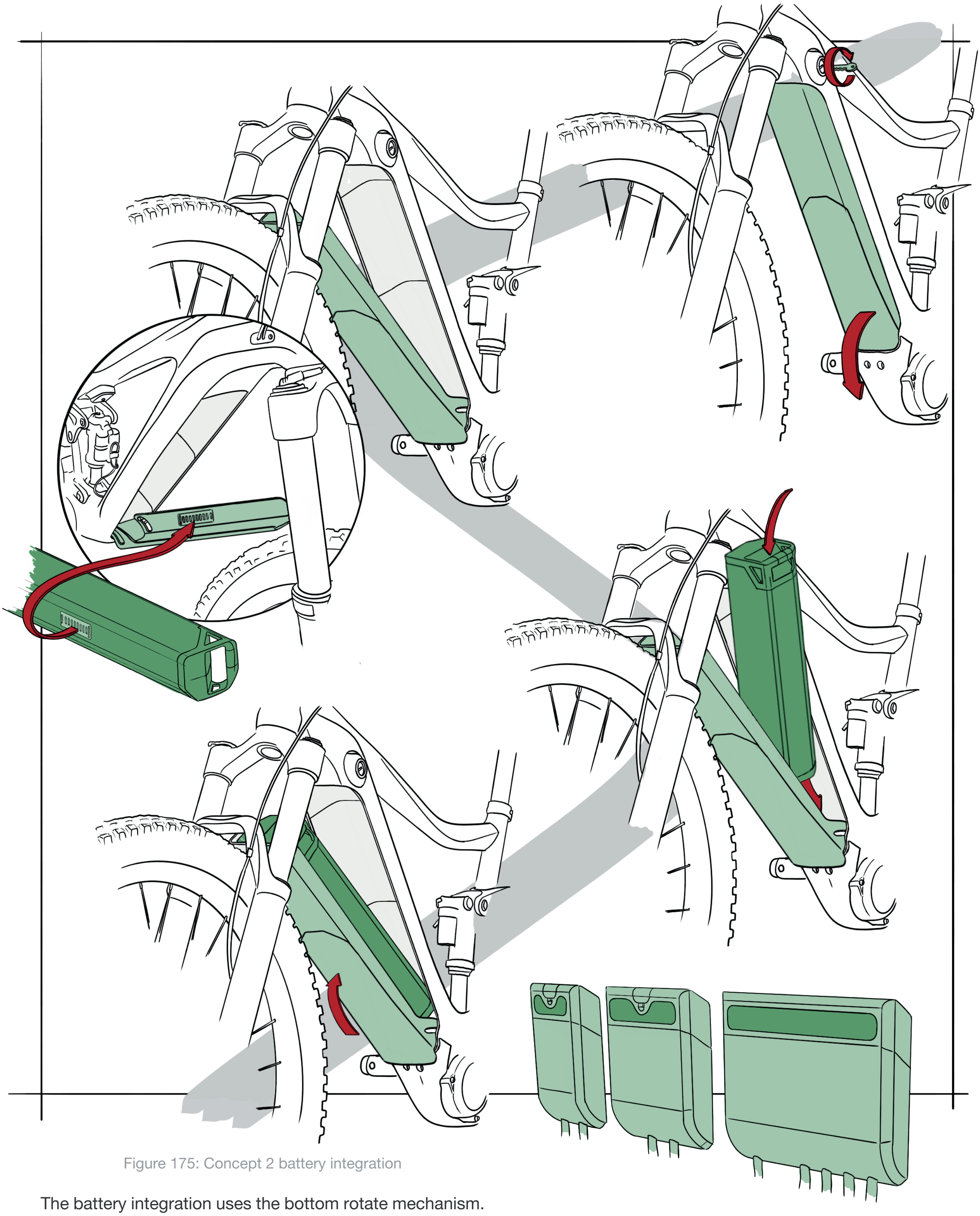


Figure 175: Concept 2 battery integration

Figure 176: Three charger configurations

The battery integration uses the bottom rotate mechanism. Once the key is twisted the hatch rotates down revealing the battery. The battery is then pulled out from the side using the handle in the top corner of the batter.

8.3 Concept 3: Push in Plug

8.3.1 Charging Hub

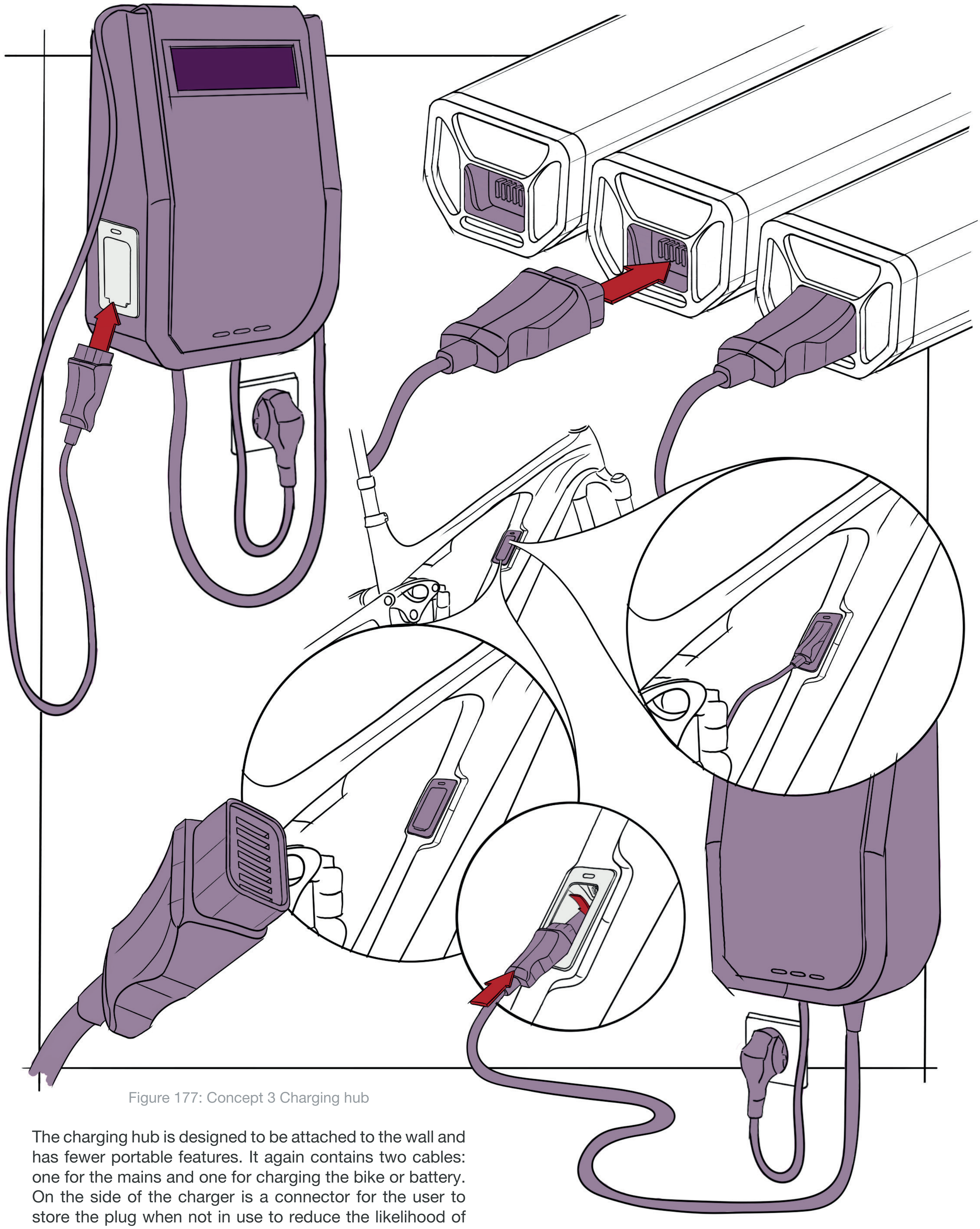


Figure 177: Concept 3 Charging hub

The charging hub is designed to be attached to the wall and has fewer portable features. It again contains two cables: one for the mains and one for charging the bike or battery. On the side of the charger is a connector for the user to store the plug when not in use to reduce the likelihood of dirt contamination.

8.3.2 Go Charger

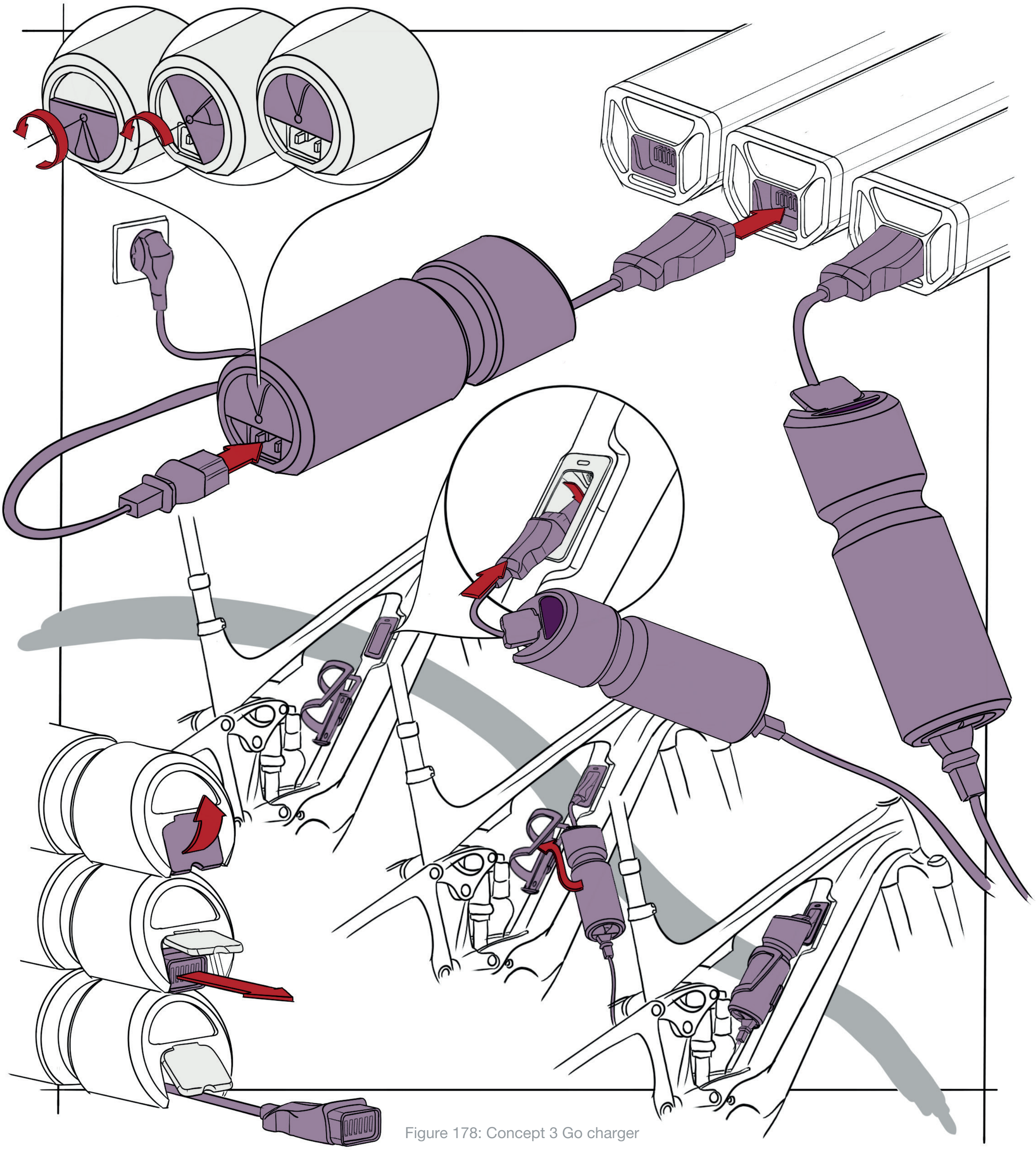


Figure 178: Concept 3 Go charger

The Go charger has the form of a water bottle. The plug connector can slide out from the front of the charger (approximately 15cm) to charge either the bike or battery. When not in use it can be slid back into the charger and is protected by a spring-loaded cover. On the other end a three-pin cable can be connected to the charger to provide mains power. This also has a cover so when the cable is not in use the connection is protected. The charger can be stored in the bottle rack on the bike during rides and the user only needs to carry the mains cable with them.

8.3.3 Battery Integration

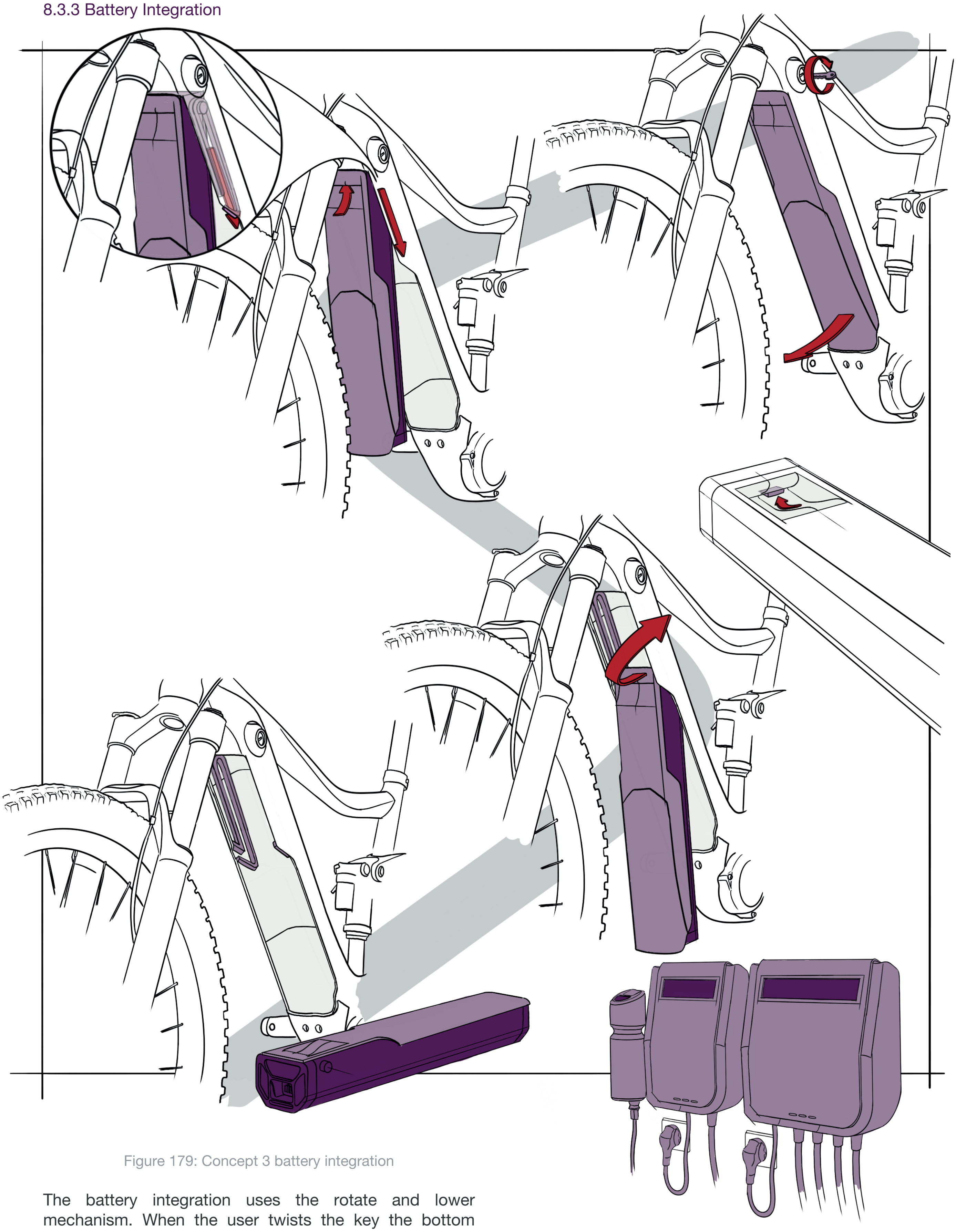


Figure 179: Concept 3 battery integration

Figure 180: Three charger configurations

The battery integration uses the rotate and lower mechanism. When the user twists the key the bottom section of the battery rotates due to gravity. The user can then press the button on the inside of the handle causing the battery to be released down the runners away from the front wheel. Once the battery reaches the end of the runners the user can lift the battery up by the same handle and remove the battery completely.

8.4 Concept Selection

To determine the best concept direction to develop the design further, the current three concepts need to be compared. To compare the three concepts, they will be broken down into their different elements to have a better comparison. The focus will be on the user requirements.

8.4.1 Charging Hub

To compare the charging hubs the main comparison between the designs are the user requirements. The performance, connectivity and display information can be incorporated within all three concepts, therefore the main distinction between them comes down to only a few requirements. The fulfilment of these requirements are based on a score out of 10. Figure 182 (below) compares the three designs against the identified charger requirements (there are strong and weak points from all three concepts).

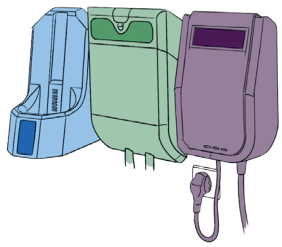


Figure 181: Home Hub charger concepts

	Charger Requirements	C1	C2	C3
Ch1.1	Align with Giant, Liv & Momentum's identity	6	4	7
Ch2.1	Charge battery/ Bike:	6	7	7
Ch7.2	Able to manage cables	7	4	6
Ch7.3	Elevate charger off ground	3	5	6
Ch7.5	Transportable	5	5	5
Ch7.6	Versatile	4	8	7
Total*		31	33	38

Figure 182: Home Hub concept comparison

*The total is not used to determine the 'best' concept and the table is used to see which design contains more positive features because of this no importance value has been factored into this total score.

Concept 1: Offers no cable management for the user. If the user wants to charge the battery they must manoeuvre a large heavy battery to the charger, rather than bringing a lightweight charger/plug to the battery.

Concept 2: Offers a high usage versatility, with the pull-out hook and sliding wall attachment. It is able to function on a shelf or the floor. However, the overall design lacks character and design flair with an awkwardly placed display.

Concept 3: Has a high design language and a plug in the side to help aid cable management, however it lacks versatility as it is designed to only be mounted on a wall.

There is, no clear optimum design based on the design analysis. A combination of concept 2 & 3 will be used for the final design taking forward each of their positive attributes.

8.4.2 Charging Hub+

The charging hub + has similar requirements to the charging hub but will be designed so that it is permanently attached to the wall as it is not designed to be portable. To ensure that it has similar design language as the charging hub it will also be a combination of concepts 2 & 3.

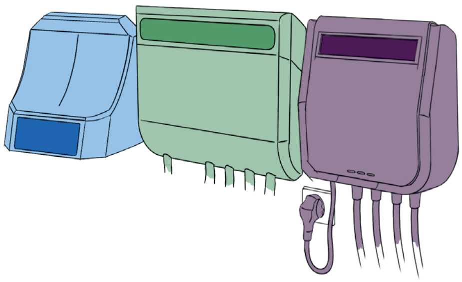


Figure 183: Hub+ charger concepts

8.4.3 Go charger

The similarity in design language of the hub and hub+ with the go charger is less important, as the priority should be the design portability and compactness, to ensure that it is best suited for the intended use.

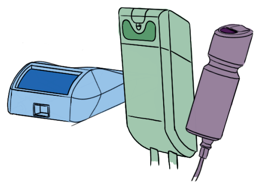


Figure 184: Go charger concepts

	Charger Requirements	C1	C2	C3
Ch1.1	Align with Giant, Liv & Momentum's identity	6	4	6
Ch2.1	Charge battery/ Bike:	6	6	6
Ch7.2	Able to manage cables	8	4	7
Ch7.3	Elevate charger off ground	4	5	7
Ch7.5	Transportable	7	7	8
Ch7.6	Versatile	4	6	7
Total		35	32	41

Figure 185: Go charger concept comparison

Based on the comparison of requirements there is, again, a range of scores, however concept 3 offers the most potential with the geometry of a water bottle. The shorter cable from the charger transformer to the bike helps with cable management, yet allows more versatility compared to the other concepts. The smaller display is better suited to the smaller amount of information which will be displayed. The biggest challenge with concept 3 is that the short cable creates more limitations on where the charge port can be placed reducing the design freedom between the brands which is something important to consider.

8.4.4 Plug

The plug type has important in the final battery integration method that is used. These three plug concepts have already been evaluated against the PWV and MWV, all showing similar scores with the magnetic plug scoring slightly lower. Since the interaction the user has with the plug and how it connects with the bike is important, prototypes of the three plugs were created so both the physical and mental workload value could be experienced and evaluated.

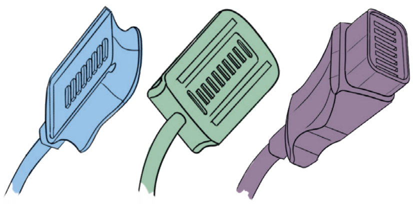


Figure 186: Plug concepts

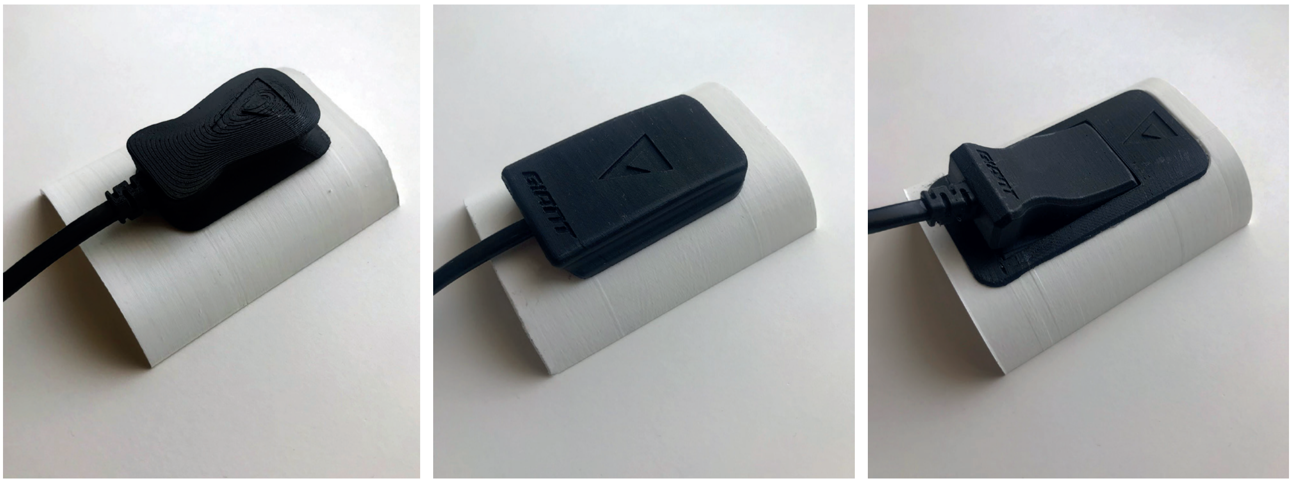


Figure 187: Plug concept prototypes ,slide, magnetic and push respectively

Based on testing and several users interacting the plugs certain benefits and disadvantages were highlighted between the different plugs, as shown in the table below:

Plug type	Benefits	Challenges
Sliding plug	At the end there is a clicking sensation giving the user feedback that plug is connected Secure connection as plug is dimensionally constrained in two directions.	Users struggled to align the plug onto the port. Plug could be slid on just one of the runners leading to improper connection. No cover over connections, risk of dirt contamination
Magnetic plug	Self-alignment of the magnets so the user does not have to think as much to attach plug. Clicking sensation when the plug connects	Magnets and no cover create risk of dirt contamination. Magnets need to be relatively strong so the plug can support the weight of the bike and the cable.
Push plug	Cover provides better protection against elements. Contains a feedback light on the cover to inform the user when the plug is connected.	Users struggled to know how to pull out plug when it was attached within the port. Charging port is considerably larger than the existing plug or other designs. When the bike hits bumps the cover may hit against the case and make a sound.

Figure 187: Plug prototype comparison

Based on the testing of the plugs with users, all plug concepts offered a significant time saving compared to the existing plug connectors. Depending on the plug which is selected alterations would need to be made to ensure that the risks associated with the design are addressed.

Based on these three concepts the chosen concept was the magnetic plug. Despite the increase in cost, due to magnets, the benefits it creates to the user experience are significantly higher. The flat plug socket design on the frame allows for the magnets self-alignment properties to be utilised while still resulting in a good connection with the pins.

8.4.5 Battery Integration

To compare the designs further, analysis against their requirements has been conducted with the requirement fulfilment scored out of 10.

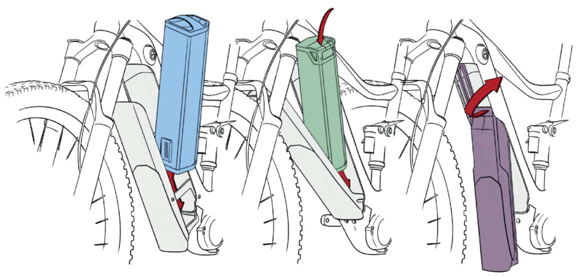


Figure 188: Battery integration concepts

	Charger Requirements	C1	C2	C3
BI1.1	Align with Giant, Liv & Momentum's identity	8	8	8
BI2.1	Securely connect the battery within the bike	7	7	7
BI3.4	Not increase the weight more than 500g	4	5	7
BI3.5	Not significantly increase manufacturing complexity	5	7	5
BI4.2	Feedback that the battery is inserted in correctly	7	7	7
BL6.2	Less Physical and mental workload	9	7	7
BL6.3	Ergonomic	7	7	6
Total		47	48	47

Figure 189: Battery integration comparison

Looking at the comparison table above, no design offers a significantly higher score compared to the other designs, making the selection process more challenging. Concept 1 performed the lowest MWV & PWV compared to the other concepts however would create more manufacturing complexity and components as a result would be less viable to manufacture compared to concept 3.

8.5 Final Concept

The final concept is a combination of the three concepts, utilising the benefits of each of the concepts. The different colours in the figure below represent how the different concepts were combined to create this final one.

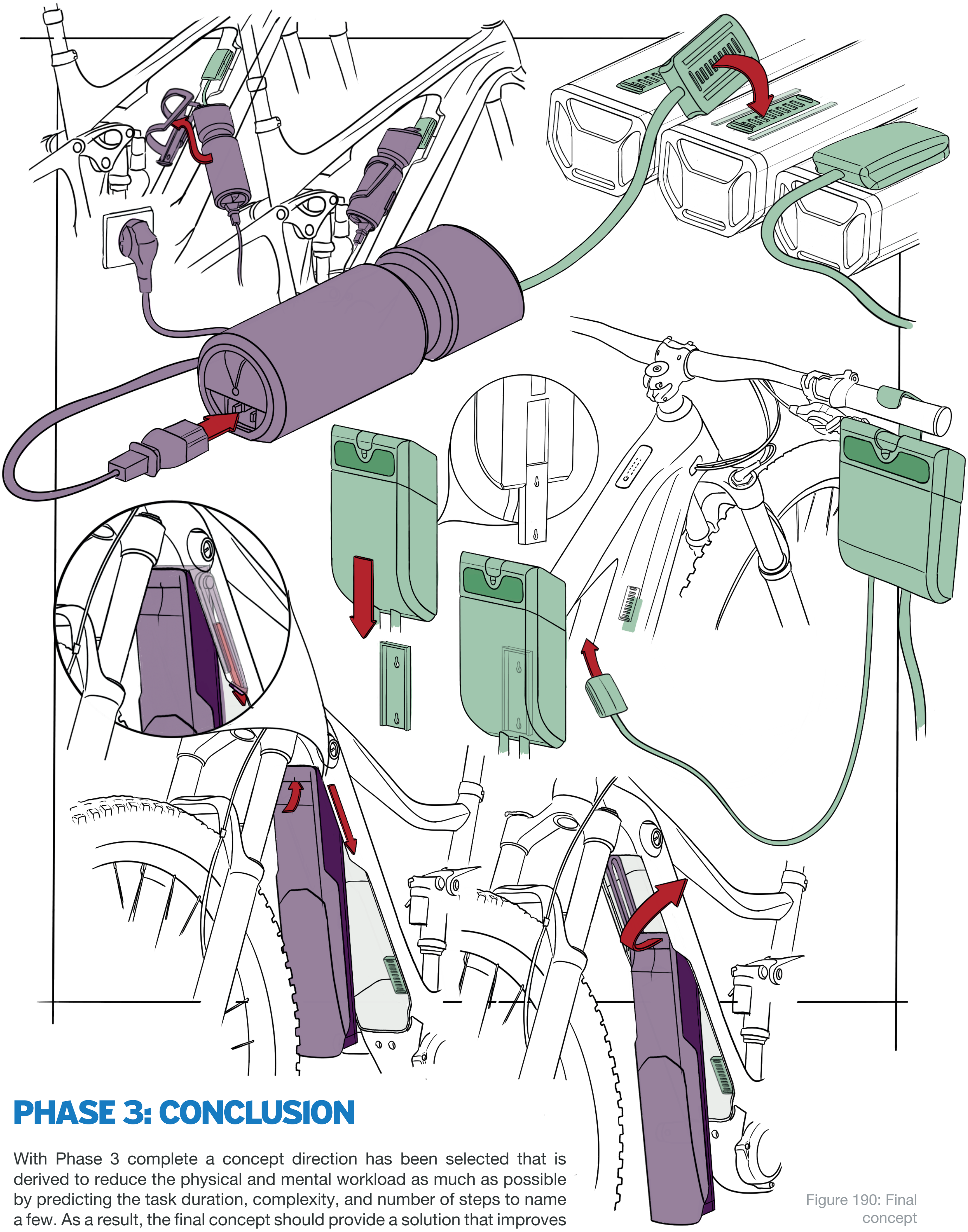


Figure 190: Final concept

PHASE 3: CONCLUSION

With Phase 3 complete a concept direction has been selected that is derived to reduce the physical and mental workload as much as possible by predicting the task duration, complexity, and number of steps to name a few. As a result, the final concept should provide a solution that improves the user experience.

PHASE 4

DEVELOPMENT

During this phase the final concept will be developed and the finer details of the concept will be determined. To achieve this the charging system is broken into its 6 different chapters

C9: Plug and socket	C12: Portable charger redesign
C10: Portable charger	C13: Hub + Charger
C11: Home hub	C14: Battery integration

For each of these components the rationale behind the design decisions are explained to create a product that prioritises user experience.

C9: PLUG AND SOCKET

9.1 Socket

The socket is the component that the plug connects to and will be in two locations on the charging system.

1. On the bike frame to support bike charging
2. On the battery to support battery charging.

9.1.1 Pin Arrangement

The pin arrangement may seem like an unnecessary feature, however during the user testing in the research phase (section 2.4.2) the pin arrangement was highlighted as an important cue for the user to determine the orientation of the plug.

The pins which must be present on the plug and socket are:

- Live wire – Large Pin
- Neutral wire – Large Pin
- 5 Data cables – Smaller Pin

This results in 7 pins in total; however an additional pin could be added to provide an option for an additional data cable, or as a conformation connection to ensure that the plug is properly secured before power is transferred. This additional pin would also allow for symmetry within the design. With the option of 7 or 8 pins, including two large pins, there are lots of different configurations as shown below.

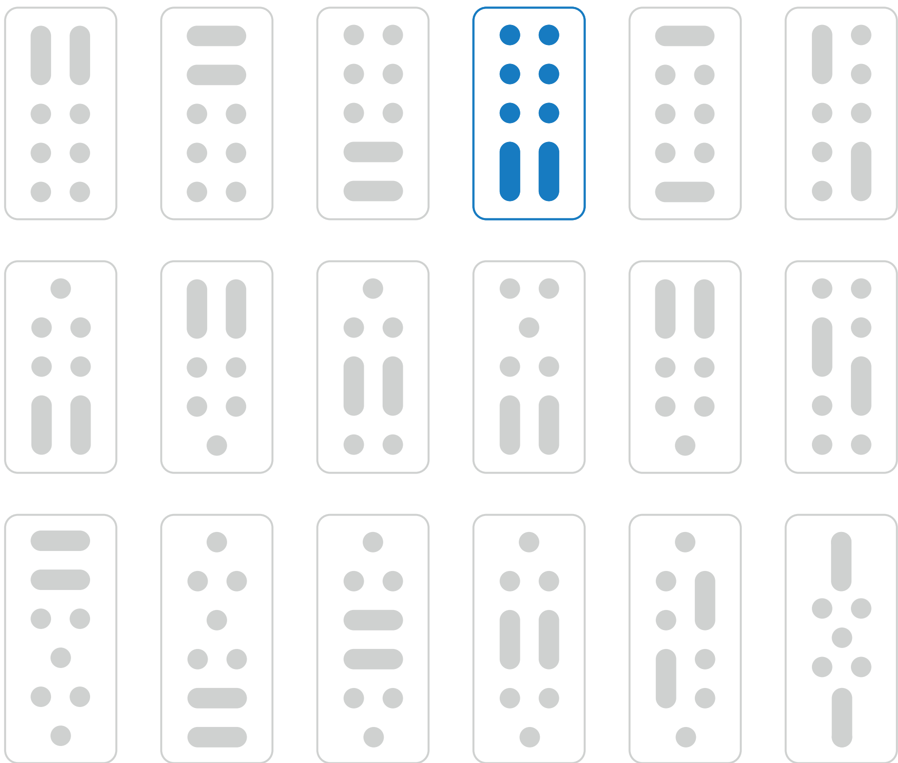


Figure 191: Different pin configurations using 7 or 8 pins

Out of these configurations the pin layout highlighted in blue was selected for several reasons:

Visual weight: The long pins in the lower section of the plug are larger. This creates a heavier feeling compared to the smaller pins and results in visual weight being created [111]. With the 'heavier feeling' pins at the base, the design will feel more balanced to the user. Making the orientation align with their expectation [111] .

Water removal: The long pins are vertical. The plug will also be vertical on the bike and therefore this orientation results in three channels for the water and dirt to run down, rather than having horizontal channels which would disrupt the flow of the fluid.

Symmetry: To attach the socket to the frame there will be one or two bolts. In the case where there is an odd number of pins the region where the odd pin aligns with the bolts look awkward and cramped creating an unsymmetrical design. If the design is not symmetric it can look unbalanced and the user will likely waste time trying to determine what is missing [112]. Which would increase the decision complexity and increase the mental workload of the user.

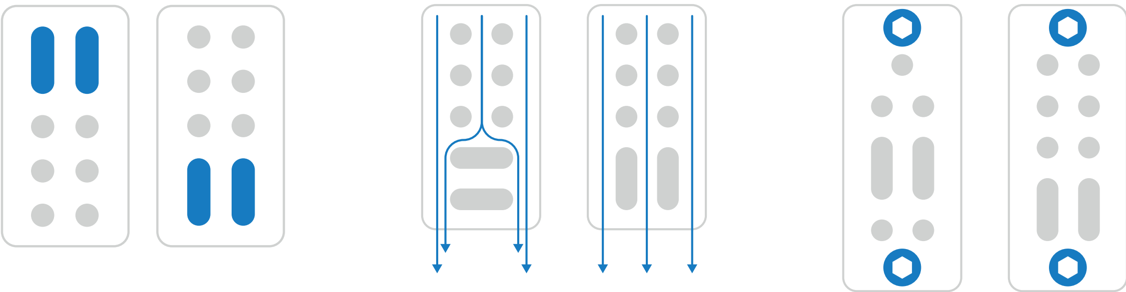


Figure 192: Visual weight, Water removal and Symmetry comparison

9.1.2 Form & Magnets

In addition to the pin configuration the overall form of the plug and how it looks on the bike also plays an important role; to reduce the mental workload caused by the orientation challenges which were observed with Giant's current circular plug. If the plug geometry was rectangular the orientation would be more intuitive since there is not an infinite rotational symmetry, and in this case the plug can only have two orientations this would reduce the decision complexity, reducing the workload on the user [98] . The addition of a distinct feature/difference to the top and bottom of the socket would mean there is a visual difference, and the user would not need to rotate the plug to look at the pin pattern. Allowing the user to achieve the correct orientation of the plug first time.

The greatest constraint to this form factor is the magnet size and where they are positioned to ensure that there is enough "clutch" power between the plug and socket. Looking at the current prototype, which was tested during the concept selection, the magnets are mounted from the underside of the frame. This configuration means that the footprint of the plug viewed from the frame can be made as small as possible. However, this design comes with two major issues.

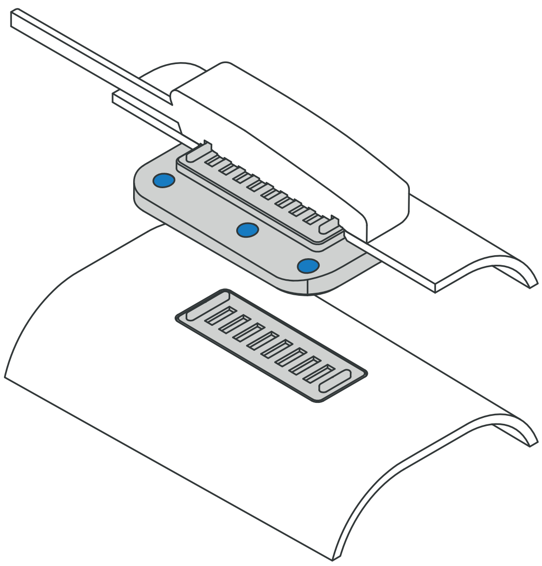


Figure 193: Initial prototype of the magnetic plug

Mounted from the inside: To attach the plug socket, the assembly is performed from inside the frame. This is a huge problem if the plug is to be in a position such as the seat tube where there is no internal accessibility and would limit the location to only the top side of the down tube or around the motor. To make the plug as versatile as possible (so that it can be used on all types of ebikes) the plug socket should be attached to the bike frame from the exterior.

Magnet distance: Currently the magnet distance between the plug and the socket is relatively large since the magnetic field must pass through the frame to connect to the plug on the other side. This results in a total gap of around 5mm. With all magnets the field strength decreases in an inverse square law relationship 1/R2 [113]. Where R is the distance from the magnet. Due to this rapid reduction in strength (attractive force between the magnets) the magnets should be as close together as possible to ensure that this 'clutch' power is obtained [113].

Looking at the current magnets used in the prototype the magnets are Neodymium magnets grade N38. The grade of the magnets range from N35 to N52 with N52 being the highest grade with the strongest magnetic force and the highest magnetic flux density. In the initial prototype there were 6 cylindrical magnets used with a 5mm diameter and 5mm in length. When looking at the force of one of these magnets the importance of distance is made apparent with a gap of 5mm showing a significantly lower force compared to if there was only a 2mm gap.

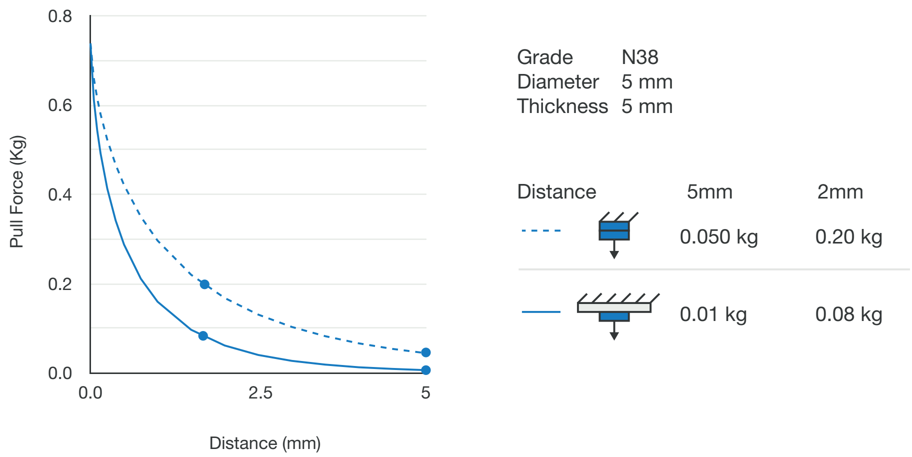


Figure 194: Relationship of pull force Vs distance for a 5x5mm cylindrical magnet [14]

The total force when 6 magnets are used with a gap of 5mm or 2mm is 0.3kg to 1.2kg respectively [114]. By using the force calculation tool by 'KJ magnets' the type and grade of magnet can be selected to select magnets with a suitable strength [114]. Based on the current prototype the magnetic strength needs to be increased, since the cable which is attached to the plug will also have a weight of approximately 80g, which the magnetic connection also needs to support. To achieve this larger magnets, higher grade magnets or a smaller distance between the magnets, or a combination of these must be incorporated within the socket. Combining this knowledge of the magnets with form factor considerations, several variations of the socket with magnets have been created:

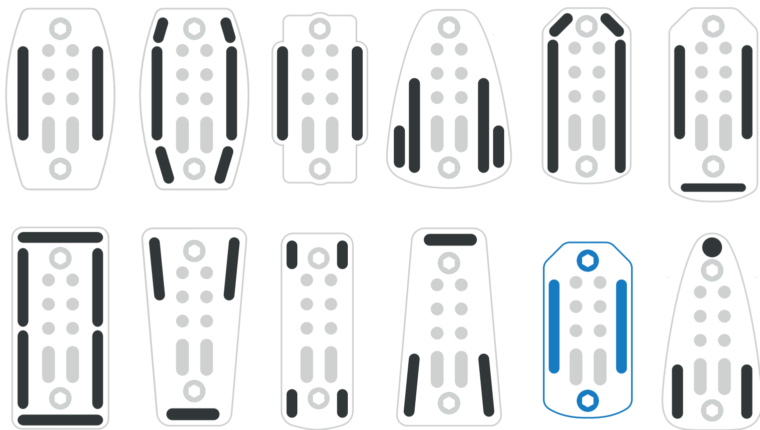


Figure 195: Magnet and socket shape configurations

Based on these different configurations the design highlighted in blue was chosen, since it is a balance between magnet size and compactness. The chamfered top and curved bottom create a distinct difference between the top and bottom of the plug socket and is also a feature which can be a transferred to the plug.

Having two magnets on either sides means that the magnets can have different pole orientations. If the plug is placed the wrong way around it will not 'snap' into position. This Error proofing approach draws on inspiration from the Poka yoke principle which is able to 'reduce time and release the mind of the user' by making it near impossible to make an errors [109] and helping to reduce the mental workload.

Ideally the plug socket would not have magnets to reduce the possibility of the plug attracting iron filing from the ground. However, looking at the graph above the addition of magnets in the plug significantly increases the strength and is something which will need to be experimented with, to determine whether a magnet-less plug is a realistic option. If the plug is to have magnets, a storage option on the portable charger and home charger should be made available to ensure that this connection is not left exposed, reducing the risk of attaching iron filings.

Increasing attraction strength:

To increase the total magnets strength, the gap between the socket and plug will be designed so that it is less than 1.5mm with two rows of 5 magnets are used. In the plug socket 5mm cylindrical magnets are used with a depth of 5mm and in the socket two rows of 5 magnets with a depth of 3mm are used, resulting in an average magnet thickness of 4mm. Based on this specification the final attraction curve should result a total attractive force of 2kg using the N38 grade neodymium magnets.

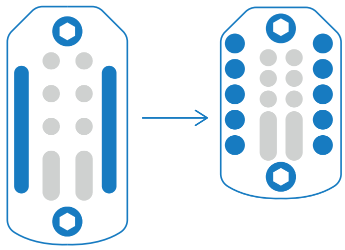


Figure 196a: Final plug socket form

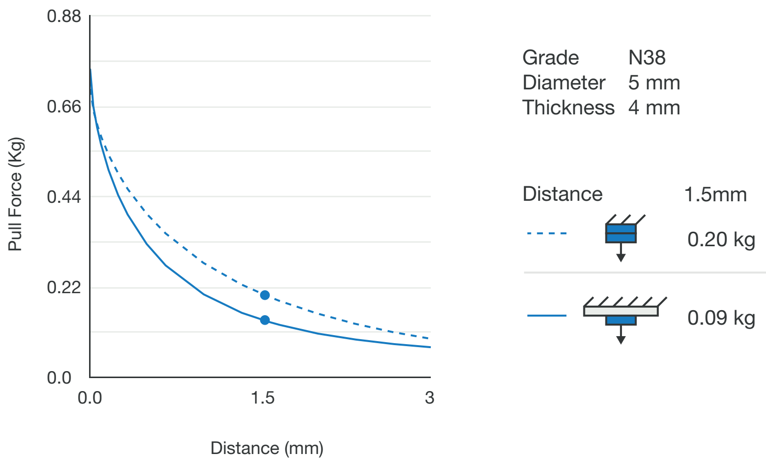


Figure 196b: Pull force vs distance for a 5mm diameter x 4mm magnet [14].

If a steel core is used in the plug the attractive force would be reduced just over one half. So even larger magnets in the plug socket would be required to compensate for this loss. Based on the prototype performance, the depth of the magnets in both the plug and the socket could be increased.

Looking at changing the grade of the magnets using this configuration in the table below: with ten magnets there is an increase in force by 0.9kg from the lowest grade (N35) to the highest (N52).

Size	Distance	Connection	Quantity	Force (Kg)							
				N35	N38	N40	N42	N45	N48	N50	N52
5mm Dia x 4mm	1.5mm	Mag – Steel	1	0.086	0.091	0.095	0.100	0.109	0.113	0.122	0.127
			10	0.860	0.910	0.950	1.000	1.090	1.130	1.220	1.270
		Mag - Mag	1	0.190	0.204	0.218	0.227	0.245	0.258	0.272	0.281
			10	1.900	2.040	2.180	2.270	2.450	2.580	2.720	2.810

Figure 197: Pull force vs distance for a 5mm diameter x 4mm magnet [14].

There is the option to use a higher grade of magnets to increase the overall clutch power, however this will result in a higher cost of the plug, which needs to be kept as low as possible.

9.2 Plug

The plug will be used on all three chargers to connect to either the bike or the battery. The plug geometry needs to be considered as its shape has a strong influence on how the plug should be gripped and removed. If there is a steep lip at the front of the plug this suggests that this is where the user should pull the plug, rotating it to release. However, if there are lips/grips on either side of the plug the user will know to pull the plug off vertically. Since the plug is attached to the socket by magnets the pull direction is not so critical allowing more freedom with the design. The main constraint is that the plugs base geometry must match the geometry of the plug socket. Above this base shape the design is free. Here are several different forms for the plug which have been explored.

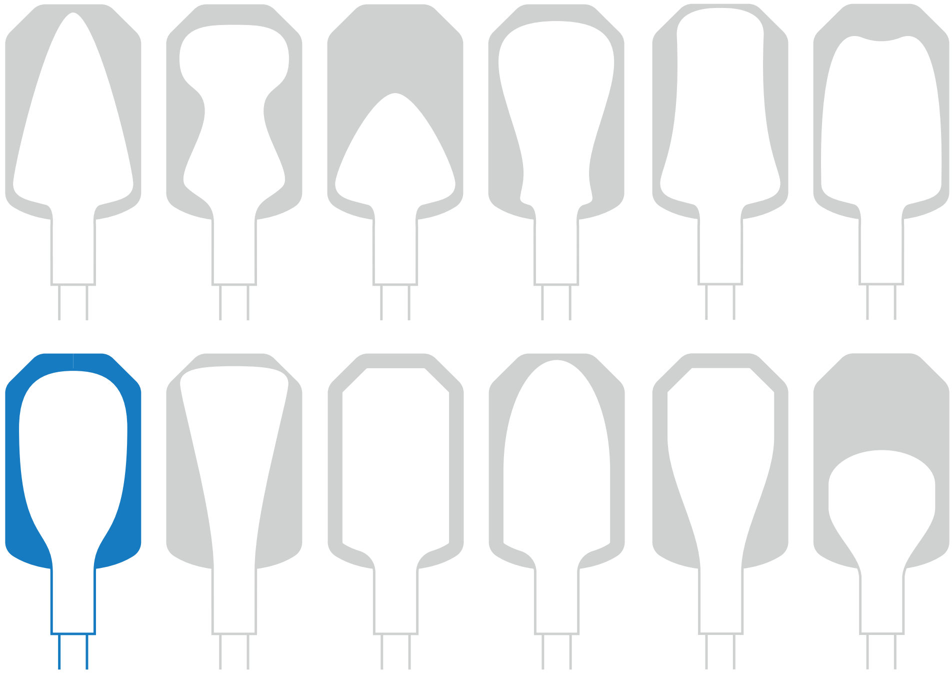


Figure 198: Plug forms top view

For these 'top' forms the goal is to get the plug to seamlessly transition into the cable. Something which is not often seen with common plugs. The form highlighted in blue was the chosen concept as it creates a wide area for the user to grip yet also has a seamless transition into the cable. For the side profile a similar design language was selected so that there is continuity with the cable and the plug. The plug must also be compact to slot into the portable charger but large enough it is easy to grip. The selected plug was 3D modelled and a prototype was produced. Based on the current form the front overhang was slightly too steep and the scale of the plug was increased slightly to allow for more room for the cables and a larger surface for the users to grip, increasing the accessibility for older users who cannot grip small/narrow objects.

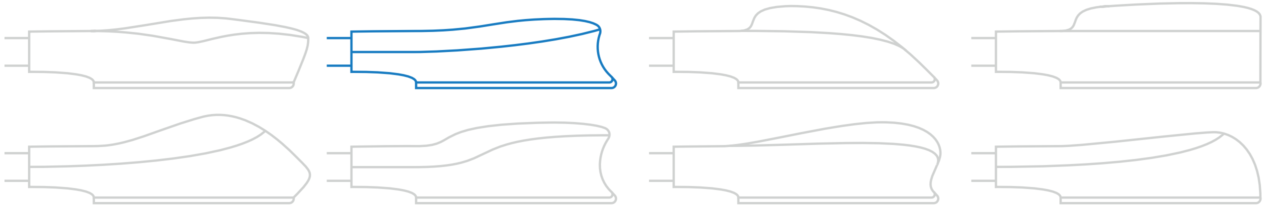


Figure 199: Plug forms side view

The selected plug was 3D modelled and a prototype produced. Based on the current form the front overhang was slightly too steep and the scale of the plug was increased slightly to allow for more room for the cables and a larger surface for the users to grip, increasing the accessibility for older users who cannot grip small/narrow objects.

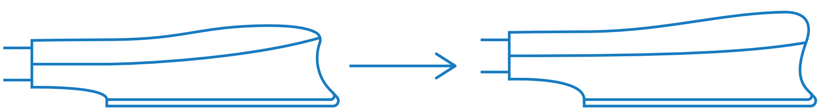


Figure 200: Plug form changed

C10: PORTABLE CHARGER

The portable charger is the smallest of the three chargers and is designed to be taken on longer adventure rides where a compact charger to charge the Ebike battery away from home would be ideal. As seen with the initial concept this will take the form of a water bottle, due to the versatility and compatibility with different backpacks, and bike packs.

Giant has recently been developing a range extender in the form of a bike bottle. However, to increase the number of battery cells within the charger and increase its capacity, this range extender is slightly bigger than a typical water bottle with a custom water bottle mount. Using this product as a source of inspiration and mimicking a similar design language within the portable charger will help to harmonise Giant's brand identity and create a unified system.

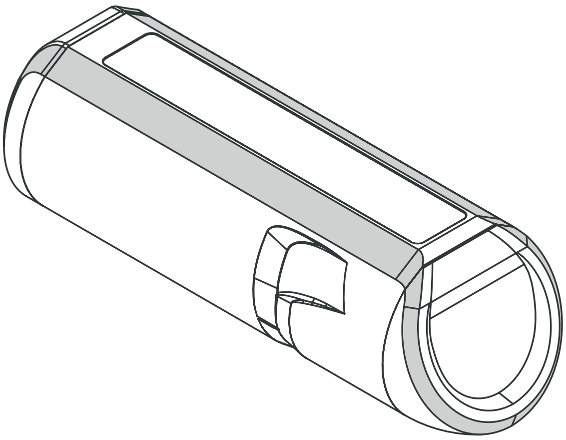


Figure 201: Giant's new range extender

10.1 Plug integration

The current concept involves the plug being integrated within the base of the charger. This plug is hidden behind a spring-loaded door to protect it from the weather. To remove the plug the door must be opened, and the plug slides out by the small openings on the side. This current design has multiple issues which need addressing:

- Eliminate the cover: The need to open a cover to pull out the plug introduces an unnecessary step that increases the physical and mental workload, thus reducing the user experience.
- Easier plug accessibility: With the plug positioned at the base of the charge it is close to the bike frame and difficult for the user to reach.
- Increase the cable length: With the plug sliding completely into the charger the cable length is significantly reduced.

To address these issues different plug locations were explored using the current range extender prototype to see where the portable charger cable could be positioned in relation to the plug location and how long the cable needs to be. Based on this exploration, the final development is shown below:

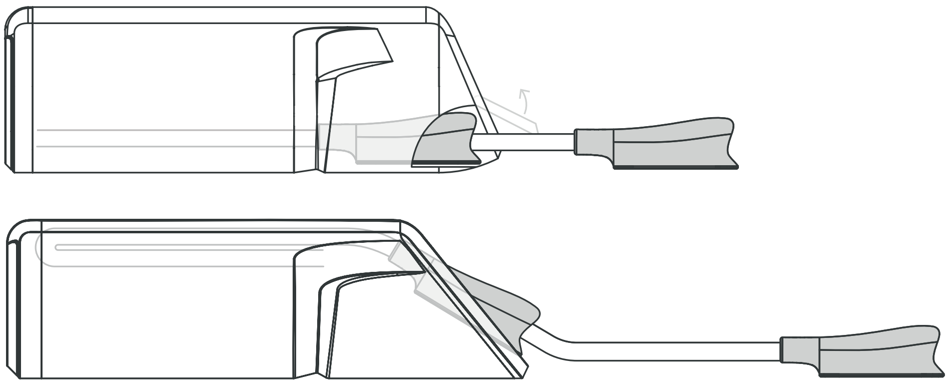


Figure 202: Current design and new design

The new design utilises the magnetic plug with the plug socket (without pins being exposed) on the front of the portable charger. The plug can be 'unstuck' from this socket, pulled out and clipped onto the bike for charging.

To increase the length of the cable the cable, it will loop once within the top section of the charger, effectively doubling the charger cables length. When the cable is pulled out fully there will still be a slight kink in the cable within the case. This will ensure that the plug can retract easily. The cable length does not necessarily need to be as long as what the new design achieves, however it increases the versatility of the charger and does not restrict the charging port location to only one position, ensuring flexibility for Giant's large product portfolio.

The front angle of the charger was also made steeper to increase accessibility to the plug if the user was to place the bike within the triangle of the bike frame.

Figure 203: Portable charger on the bike

10.2 Cable tidy/organising

The cable from the battery to the bike has been catered for, however the cable from the mains plug to the charger needs to be stored in some way. The common approach is to wrap the cable around the device when it is not in use, however this will limit being able to store the charger in the bottle holder when it is not in use. The other solution is that there are no cable tidy options, and the user places the cable either in the bike saddle bag or backpack.

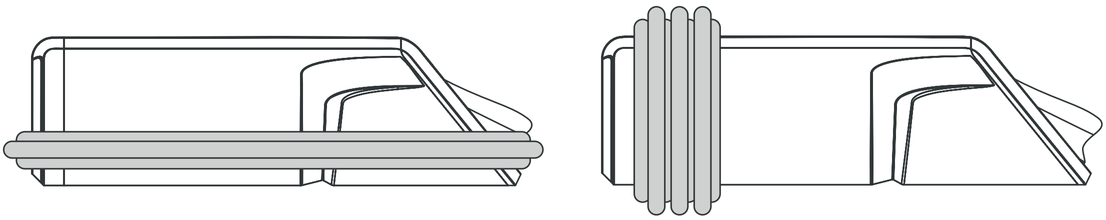


Figure 204: Different ways to wrap the cable around the charger.

10.3 LCD display

Based on the requirements the LCD display must display the battery percentage, range and the remaining time for the battery to be charged 100%. To determine the best display different ones were ideated. As well as the location of the display on the charger was also explored. To develop the display and ensure that the information can be quickly interpreted Gestalt principles were used [110]. Features such as symmetry, order and proximity were used to help keep the display minimal, reduce the mental workload and ensure that the most important information (battery percentage is the most visible [110].

Figure 205: LCD Display evolution

Since the portable charger will be stored in the bottle rack when charging the bike, the display must be in a location where it is visible within the rack. If the display is too high up on the charger the top tube of the bike is close to the display and limits the view of the battery status, meaning that the time taken to obtain the feedback would increase as the user would have to move their head to be able to see the display. Therefore, a lower location was selected to increase the display visibility.

Figure 206: LCD Display location

10.4 Mains plug

The mains plug cannot be changed because it must be a universal connector, because of this a cover to prevent dirt from entering the connector is required. Typically, a rubber cover is used that pops over the plug. This cover usually flaps around and gets in the way when the user is plugging in the cable. To overcome this problem a swivel cap is designed, on the charger which can be rotated 180 degrees to reveal the plug hole. By constraining the plug cover this way the movement is constrained reducing the likelihood of error and overall making the process more efficient, helping improve the user experience. [109]

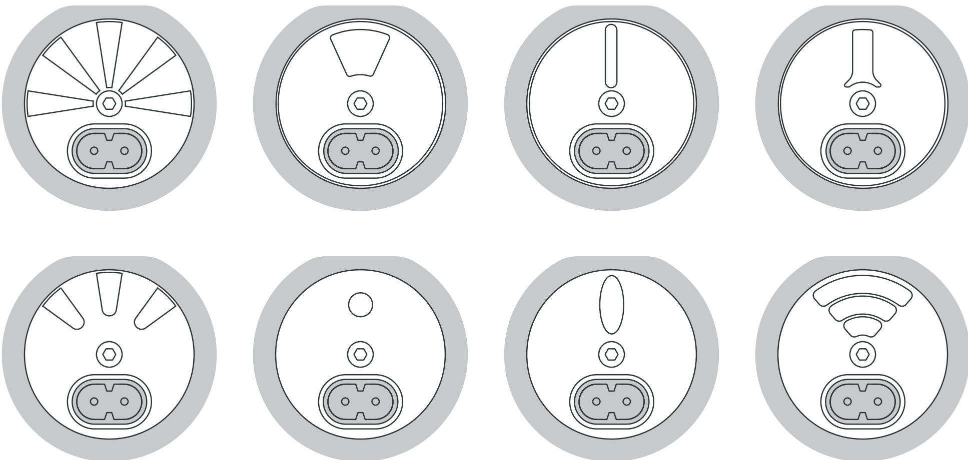


Figure 207: Selection from mains cap design.

Out of all the different cap design ideas the final cover which was selected was a very simple design, this was to ensure that the overall charger is not overloaded with design features and is kept minimal and stylish. The final designed cap is a covered-up version of the plugs outer form, this helps reduce the amount of information the user must process as the shape of the plug socket is mimicked. The Profile is debossed providing a place to grip and twist the plug. To 'snap' the cover into both the open and closed position two sets of small magnets are placed on either side of the cover. This snapping of the cover helps guide the cover into position. This small level of assistance will reduce the decision complexity of the task and keep the mental workload [104].

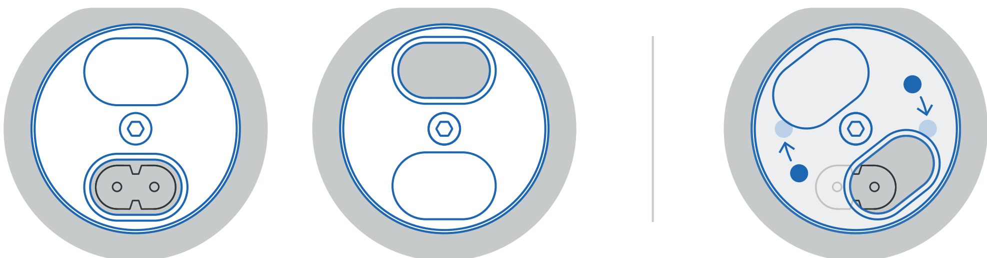


Figure 208: Selection from mains cap design and magnetic open/close feature

10.5 Prototype

A prototype was produced based on this development. It was shown discussed with the other designers within Giant's Ebike design development department to receive feedback on how to improve and develop the portable charger further. The feedback was positive and saw the opportunities with the idea of having the charger in the shape of a water bottle, especially for commuters, who cannot charge their bike at home (would have to remove the battery) yet are able to charge their bike easier at work due to less space constraints. Carrying such a small charger either on their bike or in their backpack to and from work would be ideal.

Figure 209: First portable prototype

One element which Giant felt there could be better improvement was overall appearance of the charger. They felt that while the design had been based on the new range extender it was too generic and lacked Giant's design language. Taking this feedback on board, the home hub will be designed with a different form direction to create one which is less generic and incorporates more of the feature lines within Giant's bike frames. Based on the new form, which is derived and approved by Giant, the form of the portable charger will also be changed so that its design language matches that of the home charger hub.

C11: HOME HUB

The home hub is the main charger that will make up the majority of all the charger sales, therefore it must be the most refined product. The home hub will incorporate all the features discussed in the final concept with a wall bracket and a hook.

11.1 Form Development

To begin development a new form must be created to better align with Giants vision while still incorporating the features to reduce the physical and mental workload. To aid this development inspiration was taken from the original range extender which contained more of Giant's design language.

The challenge with feature lines is that too many results in a design that does not age well, as is evident with this old range extender, however without any feature lines the design become too generic. So, finding the balance is key. To determine a new form different side profiles were translated into 3D and refined to find the best compromise between having a timeless design that is not generic, while incorporating Giant's design language.

Figure 210: Different forms based on the original range extender

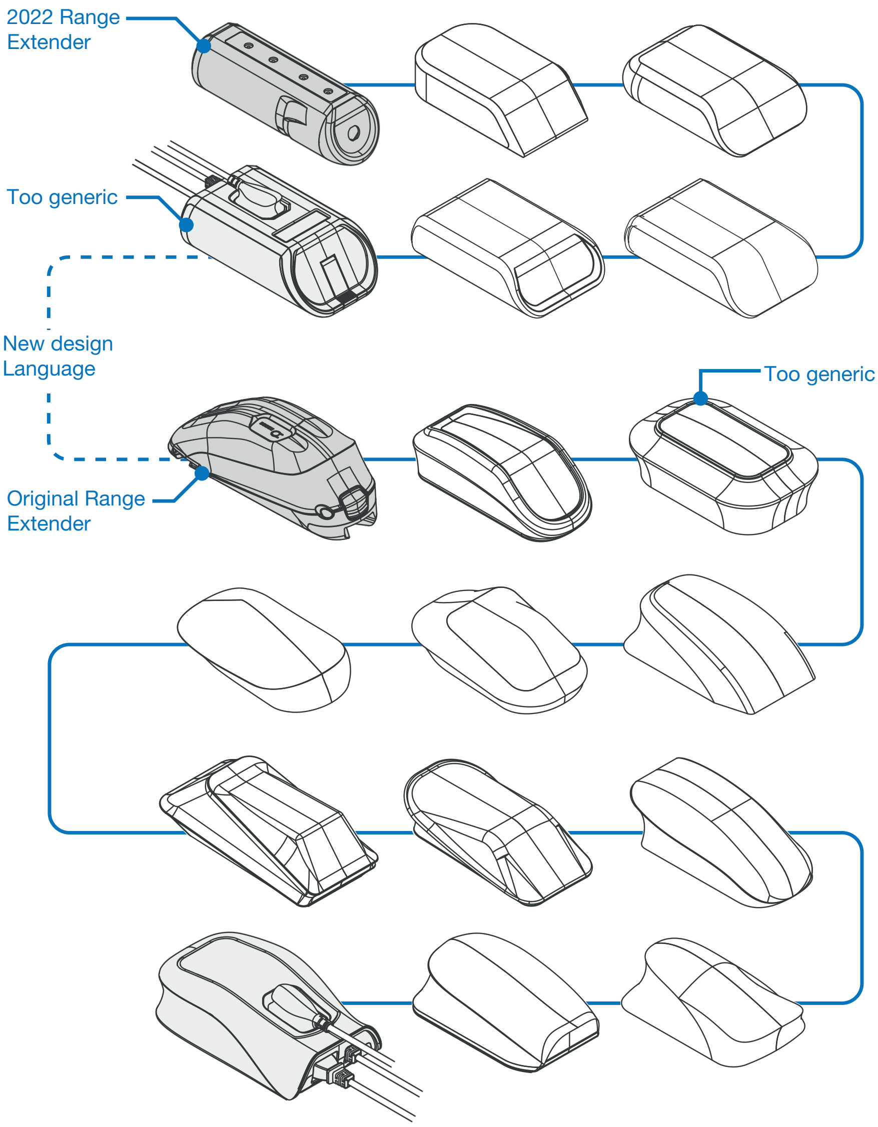


Figure 211: Form evolution of the home hub

The final form used seeks a balance between Giant's design language and a minimal design that isn't too generic. Without any branding on the charger there are only a handful of potential bike companies this could be associated with.

To create coherency between the plug and the charger the final forms are very similar, with matching feature line and silhouettes. This design decision was based of Gestalts law of similarity [112]. By using similar features the two entities appear alike and therefore become grouped in the user's mind [112]. This helps the user interpret that there is a connection between the two devices, reducing the decision complexity and overall mental workload, improving the first time user experience.

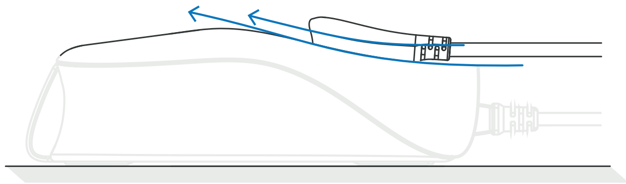


Figure 212: Flowing lines of the plug incorporated into the design

11.2 Cable tidy/ Organising

Since the home hub can be stored on the wall, hung on the bike, or laid on the floor, the home hub must be capable of keeping the cables tidy for all usage scenarios. To achieve this cable management: the exterior of the case is concave, a hook slides upwards, and the cables are unwrapped around in and then the hook is slid back down, securing the cables in place. At The base of the charger the cables are constrained because they are attached to the case, therefore there is no need for a clamping action.

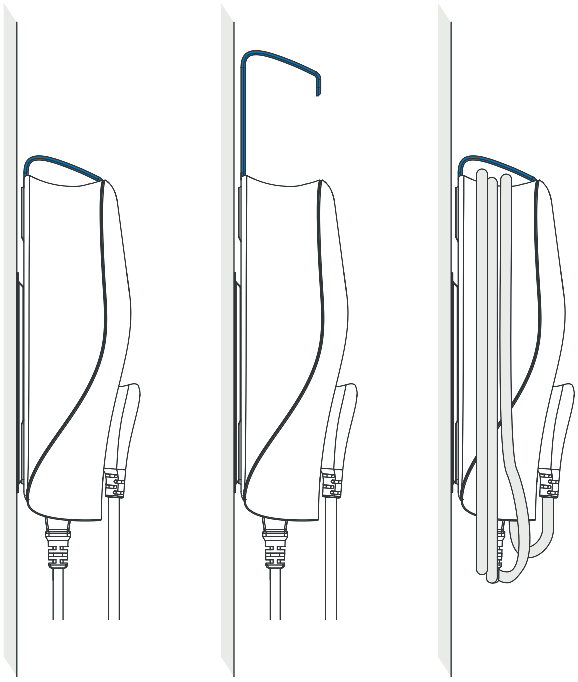


Figure 213: Cable organising

When the charger is hung on the wall and the hook is pulled out it will slide back down due to gravity. This is not ideal as the hook should stay up so the user can loop the cable around it. The same is true when the hook is closed, it must stay closed. To achieve these positions, three magnets have been incorporated within the design ensuring that the hook snaps into its open and closed position. Like the swivel cover on the portable charger this snapping into position provides a small level of assistance reducing the decision complexity of the task reducing the mental workload [104].

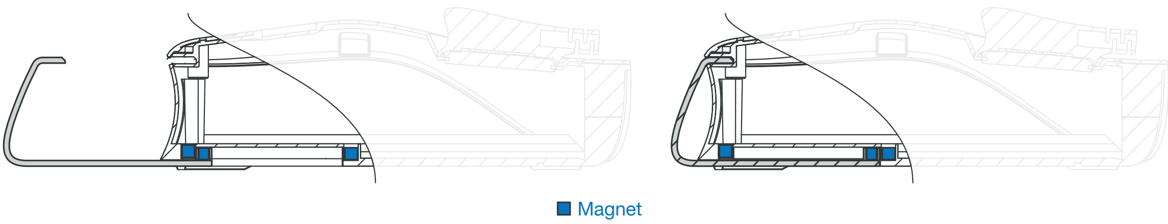


Figure 214: Magnets within hook mechanism

11.3 LCD display

Based on the requirements the LCD display must display the battery percentage, range, how long till the battery is charged till (which is set by the user through the Ridecontrol app) and the charge schedule. This display was created from using the portable charger interface as a basis and using the Gestalt principles to ensure the most important information can be interpreted first [110]. To see the other examples of the Hub displays, refer to Appendix F.

Figure 215: LCD Display

Since the user experience is dependent on the context the product is used in it is important to acknowledge these different contexts [47]. Which is why the viewing angle of the LCD display was also considered within the design. The slope of the top contour changes direction, tapering towards the hook, this is so that the display is pointing slightly up when the device is hanging on the wall or by the hook. This angle is very subtle as it is important that if the charger is placed on a shelf, it could be seen from any angle, helping reduce the time for the user to obtain the charge status.

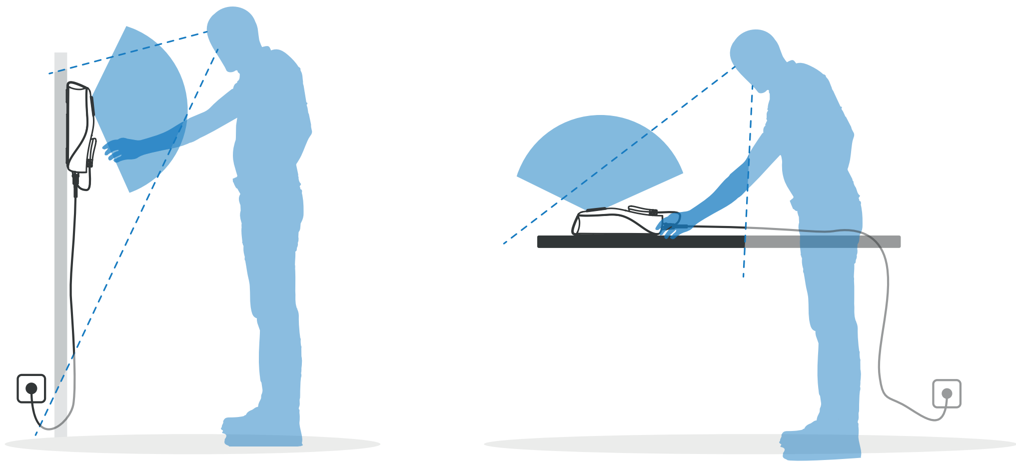


Figure 216: Viewing angle of the charger.

11.4 Mounting wall bracket

The mounting wall bracket is a typical injection moulded plate designed to be screwed to the wall. The design of the bracket was important to ensure that the charger could be securely attached if the user wants it to be mounted to the wall permanently, or quickly and easily removable if the user want to use the bracket as just a storage option for the charger. To achieve this at the base of the charger is a small clip which utilises the natural compliance of the plastic to create a spring clip. This means that when the charger is slid onto the bracket it ‘clicks’ into position and is secure. Yet it can easily be removed by just sliding the charger off the bracket which causes the clip to be released. The ‘click’ also provides the user with clear feedback that the task has been fulfilled helping improve the task effectiveness which will lead to a better user experience [56].

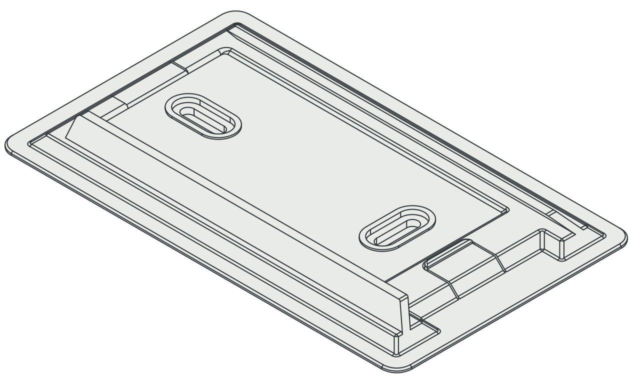


Figure 217: Wall charger bracket

11.5 Clip on cover & Name plate

One unique feature with this charger is the clip-on cover. The cover contains 5 different clips as well as 4 alignment pins which slide into the holes where the screws have been inserted to join the two halves of the case together. This clip-on cover not only completes the external form of the charger but also creates opportunities to customise the charger and unify it with the bike.

To achieve this the charger has the possibility to come in three different variations.

1. Basic charger: Black cover that is fully integrated within the case.
2. Standard charger: Cover is separate and coloured in a single colour.
3. Premium charger: : The cover is separate and painted in a colour that matches the paint job of the Ebike. This variant could be used for the flagship, premium models, and limited-edition bikes.

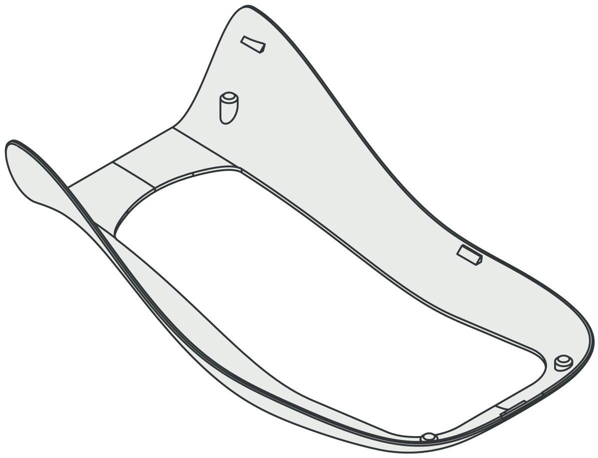


Figure 218: Clip on cover

Figure 219: Different charger variants.

Along with these different variants the Giant name badge is also an injection moulded plate which is stuck on. This is interchangeable so that all three brands can use the same charger.

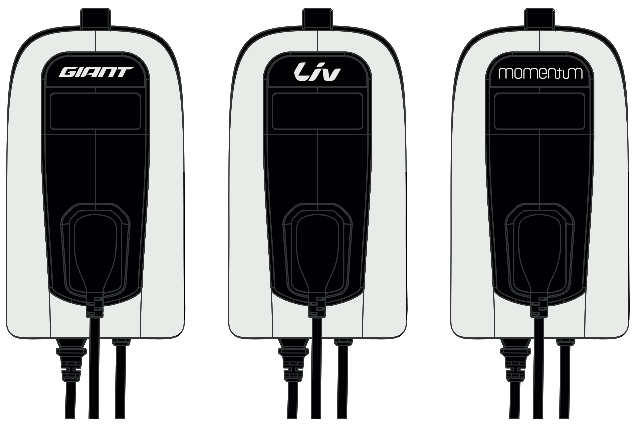


Figure 220: Standard home charger with different brand plates.

11.6 Prototype

To help visualise the design and test the usability of the designed product a prototype was made. The following images highlight the assembly stages of the prototype and how the electronics fit within the frame. These electronics are taken out of Giant's 6A smart charger. To enable the electronics to fit into the frame 20mm was cut from the circuit board reducing it in size by around 12%. The corner of several of the heat exchangers also needed to be trimmed. These adjustments were kept minimal to ensure that it would be achievable for the electronic engineers to design a new circuit board that would be able to accommodate these new changes.

The final prototype, when placed by the side with the original 6A charger it is about 10% smaller, but visually looks much smaller and more compact due to the curved forms and feature line between the white and black casing, helping to 'breakup' the charger.

Figure 221: Assembly process of the home charger

Figure 222: Home charger prototype

C12: PORTABLE CHARGER REDESIGN

12.1 Form development

Creating a ‘family’ of products will ensure familiarity between the designs and help the user more easily transfer knowledge from one charger to the other, reducing the mental workload. This means that portable charger needs to be redesigned so it in line with the home hub’s design language. Based on the previous prototype all the features from the previous design will remain but the new design language of the home hub will be incorporated. To achieve this several variations were modelled and visualised in CAD. The major challenge was incorporating the swooping cover within a bottle form (highlighted in light grey in the figure 223, below)

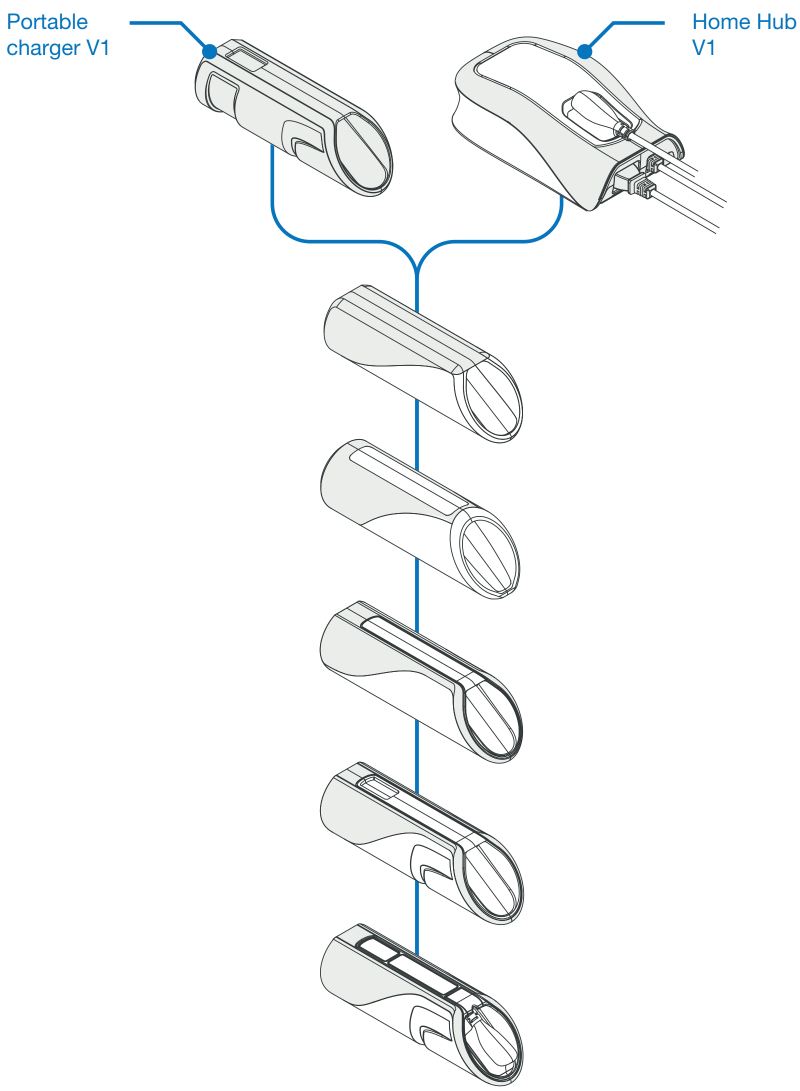


Figure 223: Deriving the form of the new portable charger to match the design language of the home hub

12.2 Cable Tidy

Having tested the previous version of the portable charger, the ease for the user to wrap the mains cable around the charger in a compact way was limited. If the user wrapped the mains cable around the circumference there were lots of layers of cable and the charger ended up being wide and no longer compact. If the user wrapped the cable along the charger’s length the sloped section by the plug made it difficult to securely wrap the cable around without it sliding down the charger.

To overcome these challenges a hook was added to the top section of the charger. The hook is incorporated in a way that when it is clipped close it is seamless with the design. Yet when it is clipped open a hook like form is created allowing the cable to easily be wrapped around the design.

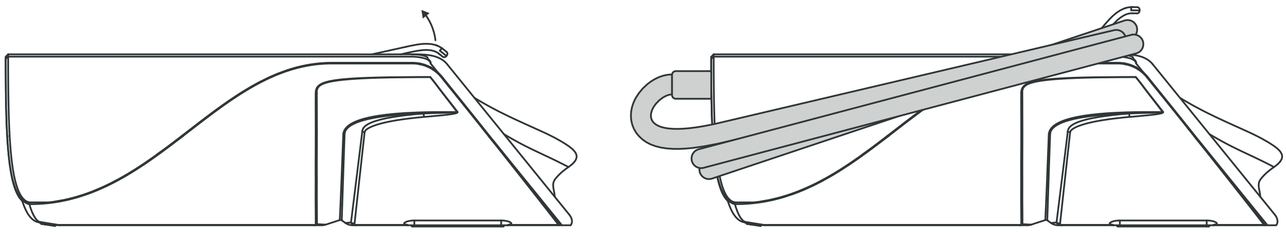


Figure 224: Portable charger cable management solution

12.3 Mains plug

The design of the mains cable port was changed slightly having tested the previous design on several different bikes/bottle cages. Most bottle cages have a plastic lip at the base to stop the water bottle sliding further down. This lip obstructed the plug port location in the original design which is why it was moved higher up so that the bottle cage did not obstruct this. The rotating cover in the original design functioned well and was easy to use which is why it was kept in the new redesign.

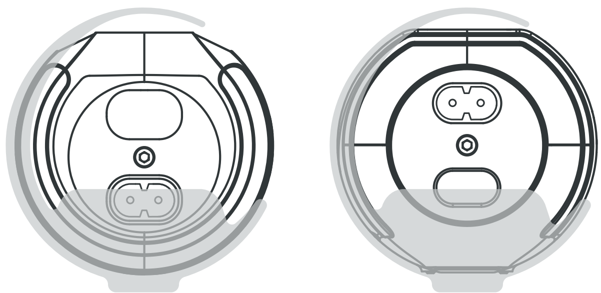


Figure 225: Version 1 Vs Version 2 with the new mains port location

12.4 Clip on cover & Name plate

The new design of the portable charger also contains the removable cover which can follow the similar customisation options as the home hub. This cover clips over the black body of the charger, covering up all the holes for the screws which are used to join the two halves of the case together.

Along with the clip on cover there is a recess within the design to allow for the name badge of either Giant, Liv or Momentum to be attached, depending on what bike brand the charger is sold with.

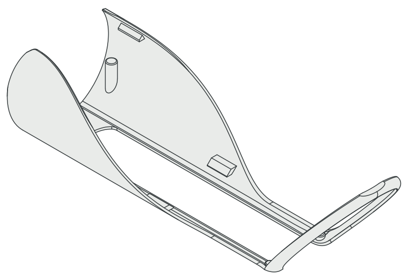


Figure 226: Clip on cover

Figure 227: Custom cover to match the paint job of the bike that the charger was purchased with. Go charger edited on Giant's trance x advanced e+ elite [1]

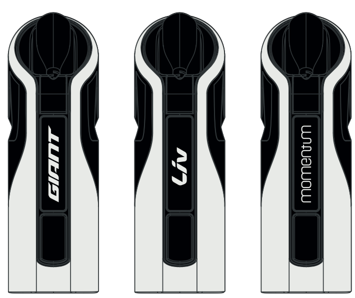


Figure 228: Portable charger with different name badges for Giant Group's three different brands

12.5 Prototype

A prototype of the portable charger was also made so that it could be used in the usability testing. Within the charger the 4 Amp circuit board was used. To get the circuit board to fit within the design the aluminium heat sinks needed to be cut and folded slightly. If the product was to be produced a custom circuit board with heat sinks that match the curvature of the bottle form would be necessary to be able to fully utilise the spaces within the casing.

Figure 229: Assembly process of the portable charger

Figure 230: Portable charger V2 prototype

C13: HUB+ CHARGER

The Hub+ is designed to be an extension of the home hub. This charger is designed to be used for more industrial applications such as bike hire, takeaway companies or for users that have a fleet of Ebikes. The reason for the larger charger is the design will allow for two less mains cables as well as creating a more compact look in the companies/ user's garage.

13.1 Form development

The Hub+ contains all the same design features as the home hub but is wider with more charging connectors. The Hub+ charger contains 3 charging connectors; this number was selected to ensure that the Hub+ was not too large and because the cable length from the charger to the bike is limited. With more charging connectors each cable would need to be longer to extend beyond several bikes. Having long cables is not good for the efficiency of the charger, due to the high current, there are high energy losses.

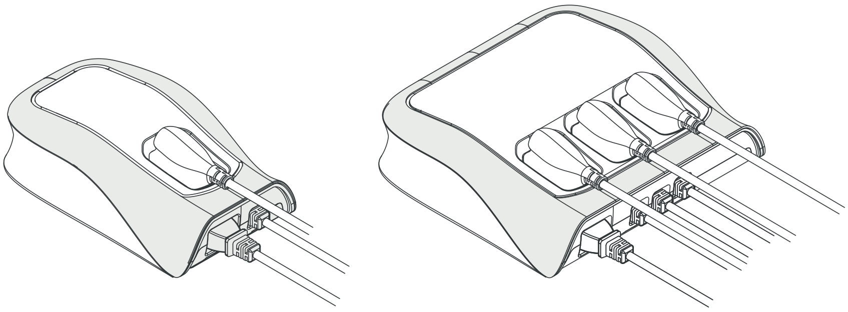


Figure 231: form evolution from the home hub to the hub+

13.2 Cable tidy/Organising

Like the home hub there is slide out hook in the centre. The hook is designed to help organise the cables for transport and if the device is not mounted on the wall. However, the most likely usage will be that the hub+ is permanently mounted to the wall and the cables hang below the charger. This hook follows the same magnet functionality as the home hub to help maintain the similarity with the design, reducing the mental workload if the user was to change charger type [104] .

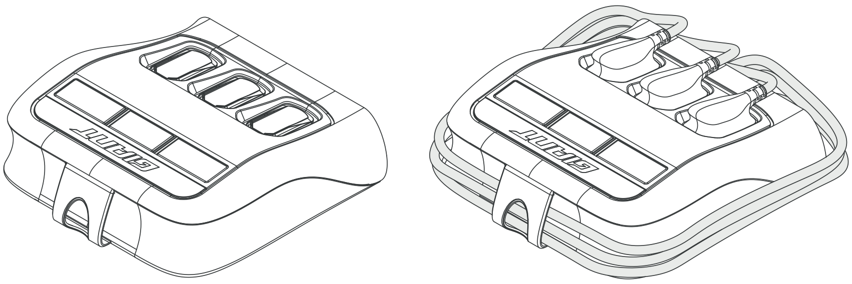


Figure 232: Cable tidy hook integration

13.3 Display

There will be 3 displays for the Hub+ with each display designated to each of the charging ports. When the charger is plugged in there will be a transition screen showing that the plug is connected to the bike. The displays are designed following Gestalt principles to ensure that the most important information, the battery percentage, is seen first [112]. Creating a well-structured interface with repetitive layouts is important because there is now more information on the charger than ever before. A display that is easy to interpret will ensure that the task demands to not become too high and there is no mental overload [98]. The location of the displays was selected to match the Hub charger with the same design rational discussed in section 11.3. The location of these displays are shown in the figure above (figure 232).

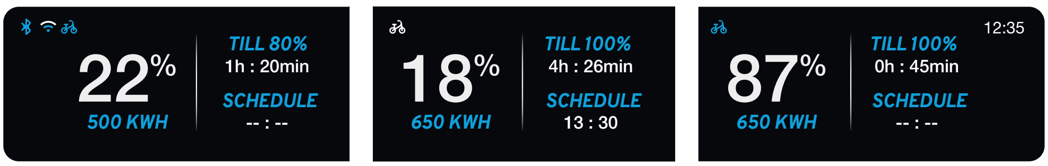


Figure 233: LCD Display

C14 BATTERY INTEGRATION

The final physical component of the charging system is how the battery is inserted and removed from the frame. To integrate the battery within the frame, the new Giant Fathom will be used to create a prototype which can then be tested on users to determine whether there is an improvement in user experience.

14.1 Movement

To begin development of the battery integration first the moving sequence was explored, based on the chosen concept. The movement sequence is the priority, the components will be designed to accommodate this new moving sequence. Comparing the new design sequence to the current sequence of the Fathom, the number of steps has been reduced by 1. This is because the battery cover is already attached to the battery, although not entirely novel, as this was the case for other predecessors of the Fathom, manufacturing had challenges with alignment and tolerances. To address this there will be multiple points of adjustability built within the design.

Figure 234: Existing Design removal procedure

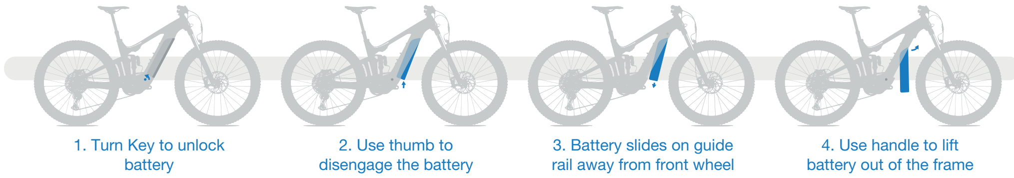


Figure 235: Proposed Design removal procedure

For the new sequence there is the incorporation of a guide rail within the frame and the battery is released via a bottom pivot. This leads to three significant benefits which will reduce the physical and mental workload for several reasons:

- **The guide restricts the movement of the battery.** This constraint reduces the number of errors the user can make, making the process more efficient [109]. With the aid from the guide rail the user can perform the battery removal from an upright position, therefore the level of movement required is lower. Reducing this PWV further which in turn will increase the user experience.
- **The guide rail supports the weight of the battery once the battery has slid down.** This provides the user with a point to rest before moving on to removing the battery completely, reducing the total amount of physical exertion lowering the PWV. Since the battery cannot fall out of the frame the decision severity is also less helping reduce the overall mental workload.
- **When the user presses the release mechanism it is in the direction that supports its weight.** Whereas with the original design the button is pressed in the direction the battery falls. This subtle difference means the users hand placement for the new design will already be in the correct position for the battery removal reducing the need for the user to quickly alter their hand position reducing both the physical and mental workload.

14.2 Guide rail

The guide rail insert is designed to be retrofitted within the top section of the down tube. To secure the insert into the frame it is bolted at the base and glued to the inside of the frame. In the real version the attachment method would be more robust and two additional bolts would be used on the inside of the frame to attach the insert securely.

The two different Colours (figure 137) on the Guide bracket highlight the two different guide rails.

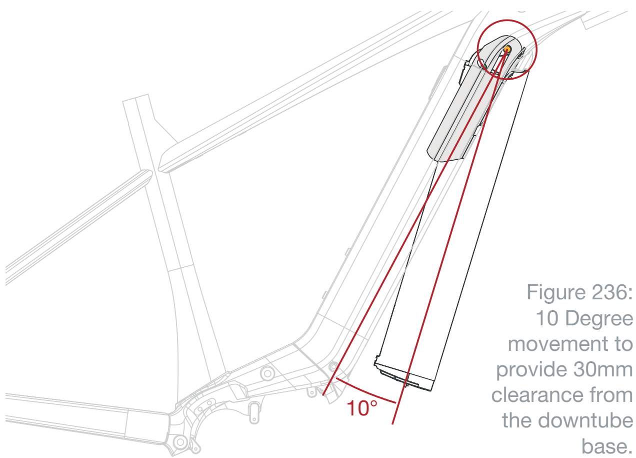


Figure 236: 10 Degree movement to provide 30mm clearance from the downtube base.

Yellow Guide: This guide rail is the main support. Taking the weight of the battery as it is inserted and removed from the frame. At the base of the guide rail there is a catchment area that allows the battery to hang freely without dropping out of the frame. From this point the battery can either be pivoted into the frame or lifted out by the battery's handle, discussed in section 14.4.1.

Green Guide: This secondary rail pivots the battery by 10 degrees and supports the battery as it slides down the frame preventing it from hitting the bike frame and the front wheel. Once the yellow pin has slid all the way to the catchment area the green pin is no longer restricted within the guide allowing the battery to swing forward where it can be removed.

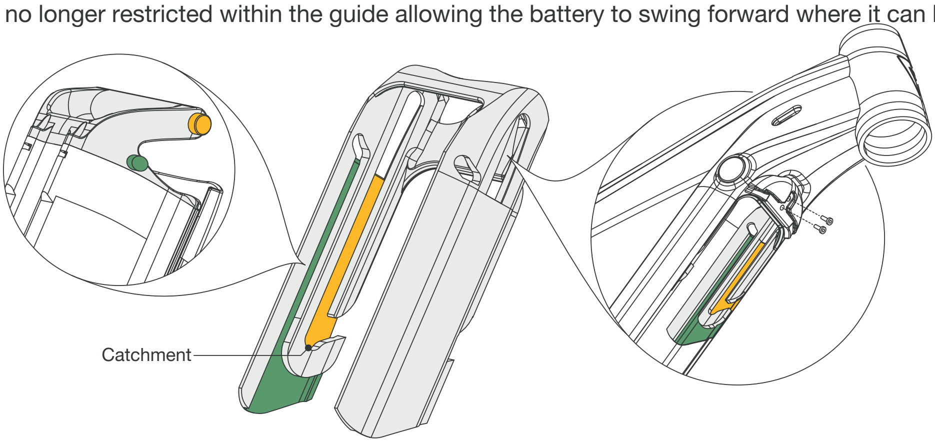


Figure 237: The guide rail which is retrofitted within the frame

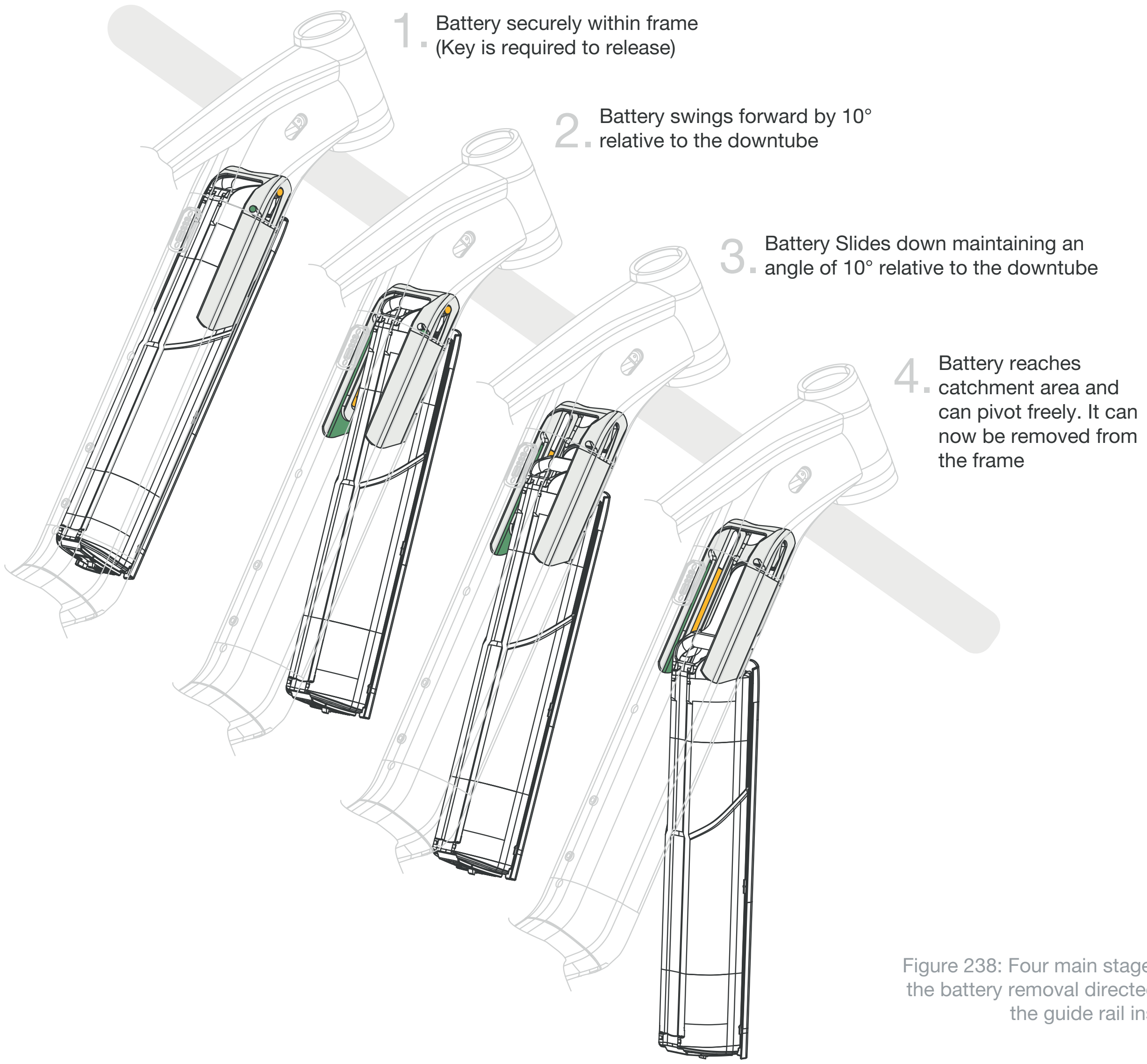


Figure 238: Four main stages of the battery removal directed by the guide rail insert.

14.3 Securing the battery

Being able to 'lock' the battery into the frame is an important feature to prevent theft of the battery. The lock also acts as a safety mechanism preventing the battery from falling out in the middle of a ride. The locking mechanism is already present in Giant's Ebikes, however it has been altered so that it can be mounted in the lower section of the down tube rather than the in the top section where the guide rail is now mounted.

The locking mechanism contains 4 main components. The only component which required redesigning was the adjustable mounting bracket (Yellow), this mounts the locking mechanism to the frame. This bracket contains slotted holes to allow for adjustability in two directions so the lock can be adjusted to perfectly taking up any tolerances or slight misalignments which may occur during manufacturing, allowing the battery to click into place every time. By choosing the lock position so that the rests on it, will mean the 'click' sound of the battery will be significantly louder. This will increase the feedback the user receives to tell them that the battery is secure. With good feedback, the level of satisfaction is increased, which will lead to an improved user experience [47].

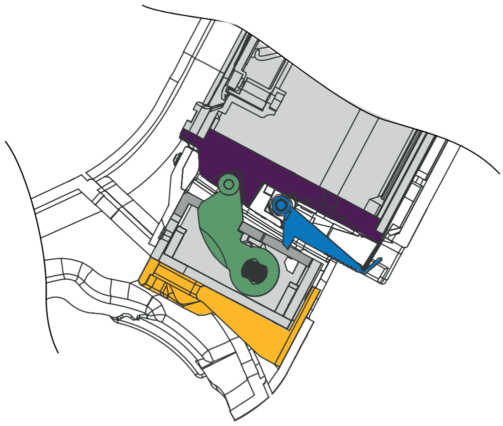


Figure 239: The four main components of the locking mechanism

The way the mechanism works is shown in three stages. In reality the stages are blended into two as the weight from the battery causes step 2 & 3 to merge into one.

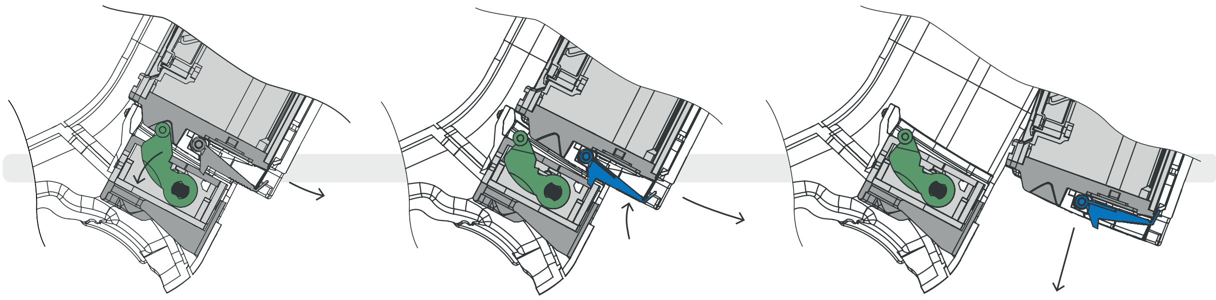


Figure 240: Battery removal procedure for the lock mechanism

14.4 Battery

The battery consists of several components: The Top Cover, Bottom Cover (included in the locking mechanism section 14.3), Charging/ Discharging port, the main case and cover. These will be discussed in this chapter.

14.4.1 Handle

A handle was added to the top of the battery to provide a place for the user to easily lift the battery in and out of the frame. The handle also reduces the physical exertion for users who need to carry the battery to their charger once they have removed it. This is because the handle allows the battery to be carried with a better posture reducing the overall strain on the users body [115]. The protruding sections highlighted in green and yellow slot into the guide rails.

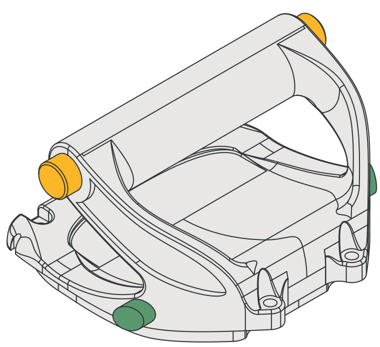


Figure 241: Charger handle

14.4.2 Plug location

The charging plug socket is positioned on the top side, lower section of the battery. This location was selected because it clearly visible for the user when the battery is out of the frame and laid down reducing the likelihood that the user will be looking for the charging plug, reducing the efficiency of the process. The chamfered edge around the plug socket matches all the three chargers. It helps guide the plug into the connector and create similarity between all the products, making it easier for the user to subconsciously group together certain tasks they have previously performed [112]. As a result the improvement in usability which improves overtime (as the product familiarity improves) will be increased much faster with the maximum usability achieved in a shorter period of time [8].

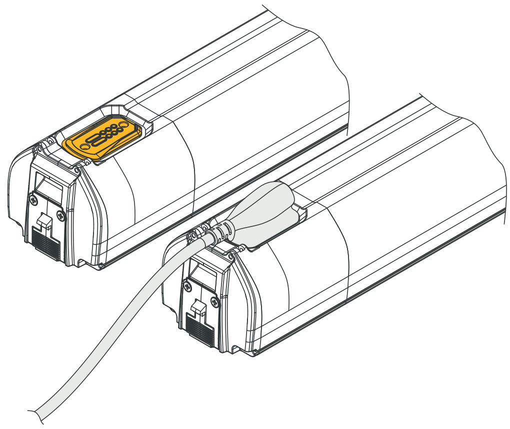


Figure 242: Plug on the battery in the lower section.

When inserting the battery into the frame the plug is mounted to the top section of the downtube. When the battery is clipped in there is a strong, stable connection between both the battery and the frame. Other benefits for this location are that the plug is less prone to dirt and weather when the battery is removed. This location is close to the motor allowing the discharge cable from the battery is as short as possible allowing.

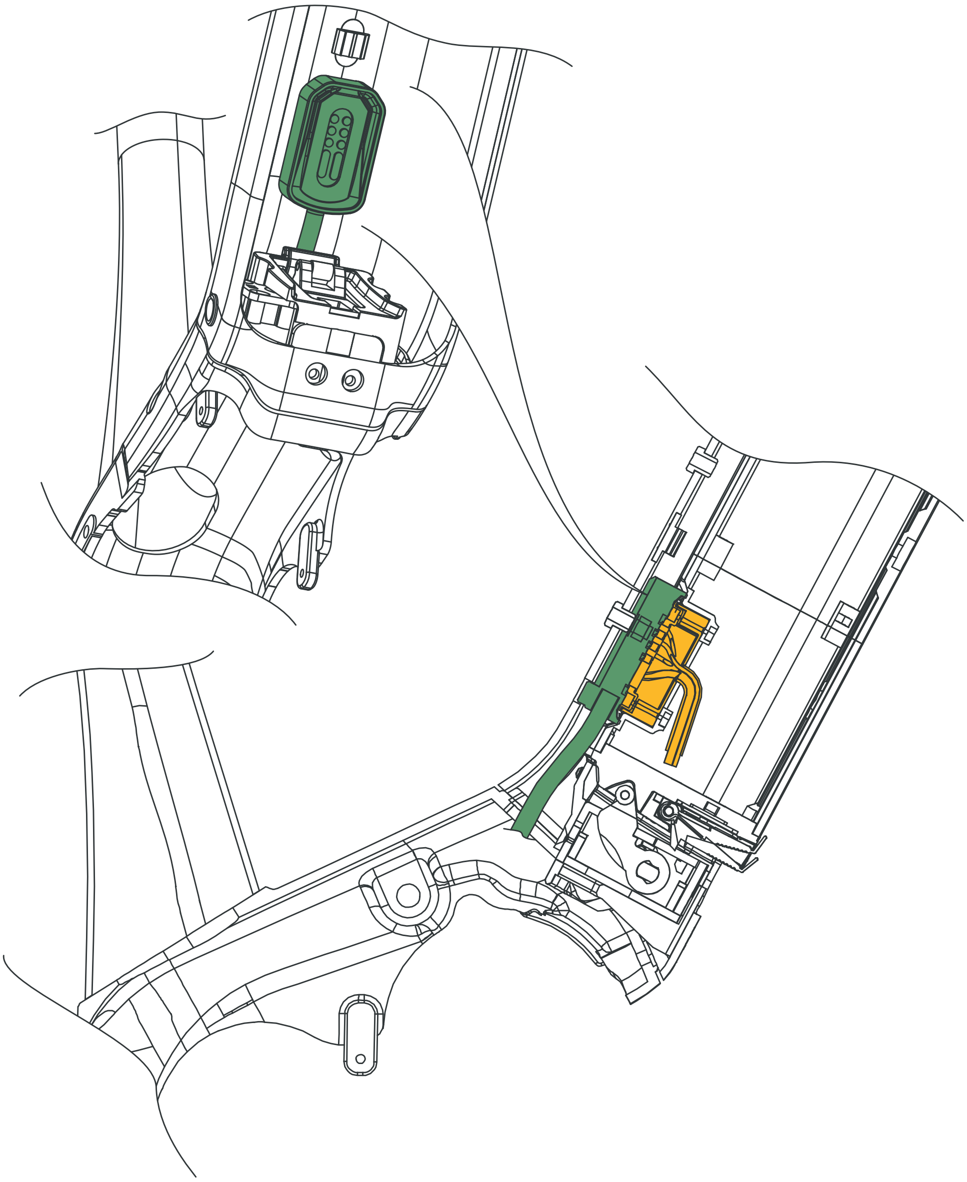


Figure 243: Plug integration on the inside of the downtube

14.4.3 Main case

The top of the battery was made narrower by 3mm on each side so it can slot between the guide rail insert. Tapering the battery towards the top creates visual weight [111]. The 'heavier feeling' section at the base and the 'lighter feeling' section at the top, follows the same design cues as architecture. With the inclusion of the cover and handle the battery orientation will align with the user's expectation [111]. Helping reduce the mental workload when inserting the battery back into the frame.

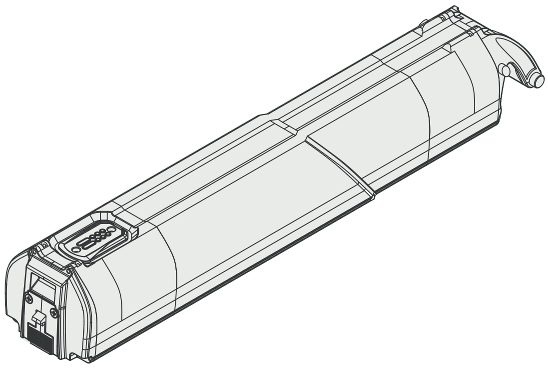


Figure 244: Battery with narrower top section.

14.4.4 Battery cover

The last section of the battery is the cover, to create a seamless transition between the battery and the Ebike frame. This cover clips over the battery and will be permanently attached to the battery. For the new design the battery needed to be altered slightly since it is attached to the battery and not removed first. Also, a hole in the lower section of the cover was created to reveal the safety catch where the user must push the safety catch in once the lock has been released.

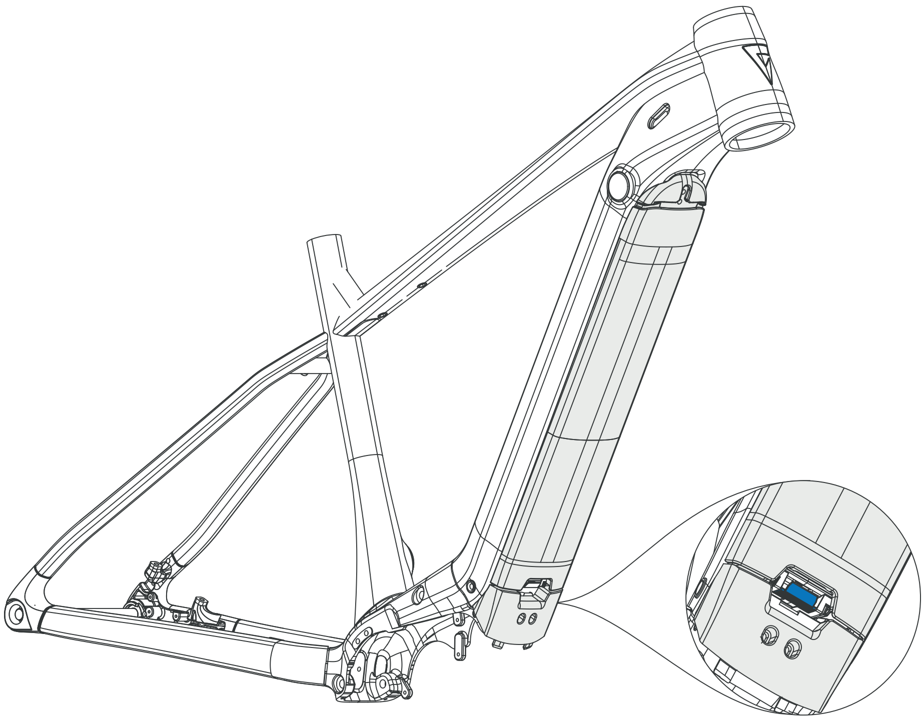


Figure 245: Battery cover

14.5 External plug integration

In section 9.1.2 the plug connector form was developed. In this chapter the location still needed to be determined. There are multiple options where the plug connector could be located. As seen in the research phase, the location for this plug socket should be high up on the frame, but not too far from the motor.

Based on the different locations discussed in 1.4.3, the chosen location was at the top of the down tube. This was selected because it is a convenient location for the user but is also compatible with the range extender and portable charger.

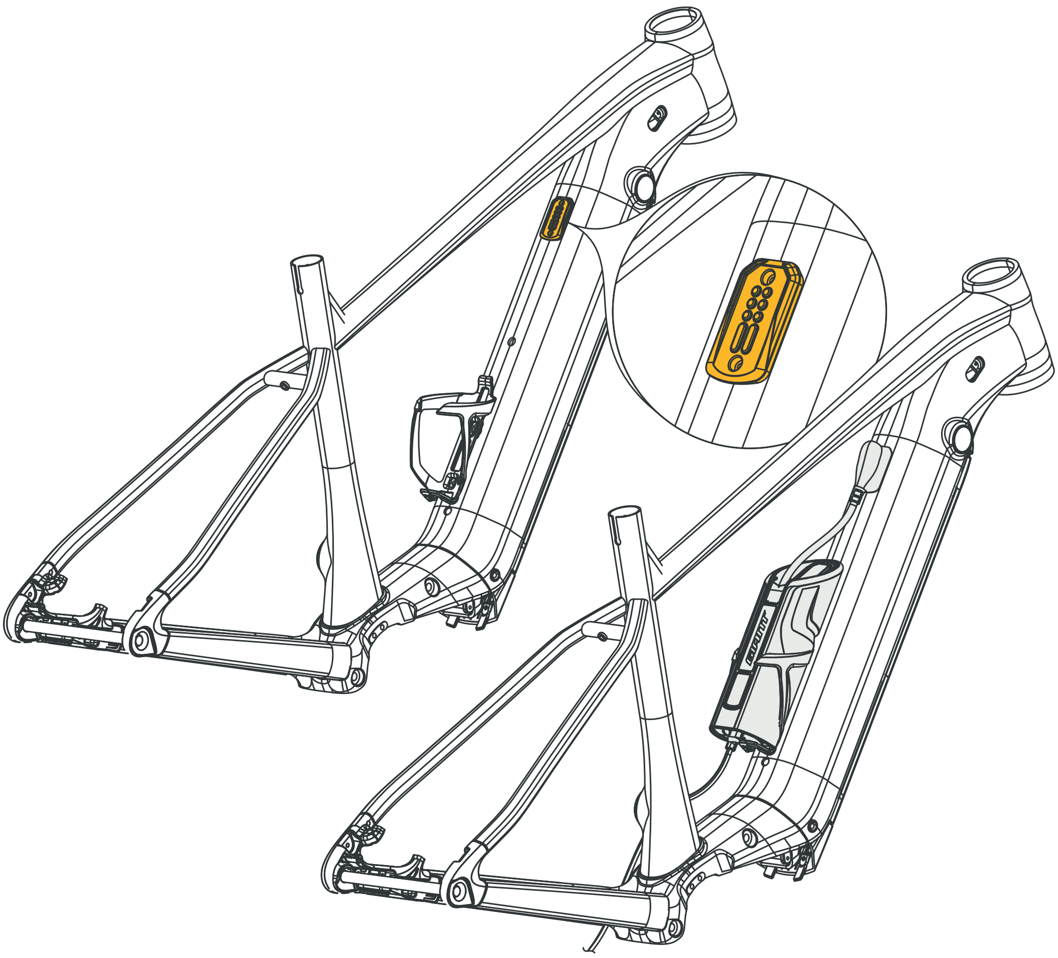


Figure 246: Plug location

14.6 Prototype

To visualise the developed battery integration and test the usability a prototype was made using Giant's Fathom bike frame to house the prototyped components. The following images show how the final battery is integrated within the frame and how the battery can hang on the catchment area. This prototype included changes to increase the strength of the battery handle so it could be user tested without breaking, to overcome the limited strength of 3D prints. The decision was also made to remove the 'green' pins on the battery handle (discussed in section 14.4.1) because although these pins kept the battery away from the front wheel, by limiting its rotation, this benefit reduced the freedom the battery could move and led to confusion. Therefore benefit of removing these additional pins outweighed the benefit of keeping them.

Figure 247: Removal of the battery from the frame, Also including the Go charger

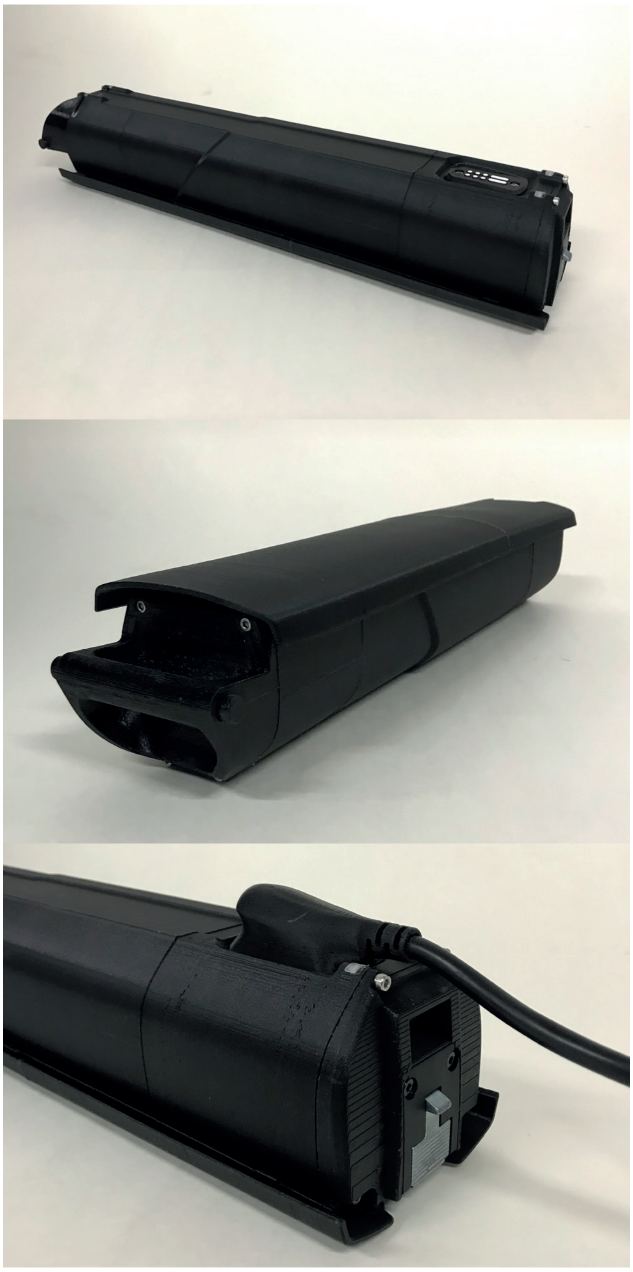


Figure 248: The battery prototype

PHASE 4: CONCLUSION

With the product development phase complete. The whole charging system has been developed with a family of products that in line with Giant's design language and vision. The products were developed with the reduction of physical and mental workload at the heart of the design. With the view of creating product which elevates the user experience. The prototypes which have been tested will be used within phase 6 to develop the following phase the final product features will be summarised.

PHASE 5

FINAL DESIGN

The final design phase provides a summary of the different features discussed in the development phase and is used to visualise the usage contexts of the charger. For detail on the design rational and academic underpinning refer to phase 4 (Development).

15.1 The Family

The family of 3 chargers are designed to accommodate the needs for any cyclist, reducing the burden of charging. Whether it is charging one bike on the move, or three bikes all at one time, one of the three chargers will be able to cater for the user's needs. The three chargers all share similar characteristics, bringing coherency, but also compatibility within each of the designs, allowing all the chargers to be interchangeable with either charging the battery or the bike.

Go	Hub	Hub +
3 Amp	6 Amp	3 x 4 Amp
0.44 Kg	0.9 kg	1.8 Kg
0.3m	1.3m	1.8m
225L x 75 Dia	220L x 120W x 75H	220L x 220W x 75H
-		
-	Set %	Set %
-		
180 €	200 €	500 €

When comparing the three chargers the biggest differences are the size and software capabilities. The Go charger, designed for charging on the move, is the most compact design without wifi, charge scheduling and the option to choose.

Figure 249: Charger family concept

15.2 Plug

The plug is a magnetic sandwich design with 10 small neodymium magnets nestled in the centre. The position of the magnets was selected in a way that ensures that they were away from the pin connections, so if any debris was to be attracted to the plug the debris would not interfere with the connection and could be easily removed.

Another notable feature is the ‘connection check’ pin. This is the additional pin on the plug which is used to confirm that the plug is properly connected. Only when the circuit is completed with this pin will the power for the other pins be connected. Eliminating the any chance of the user getting an electric shock.

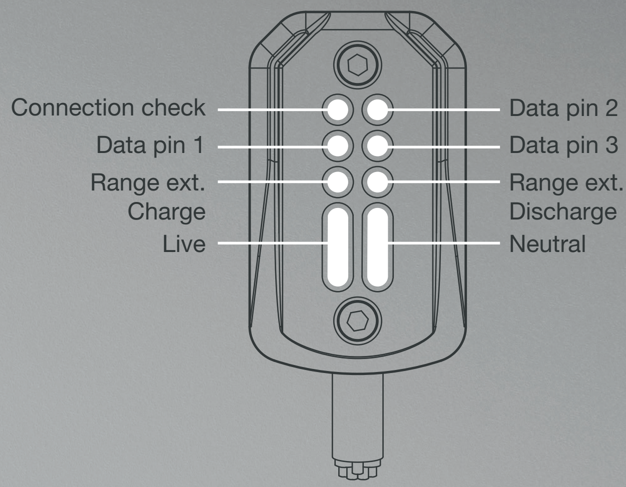


Figure 250: Plug concept

15.3 Go Charger

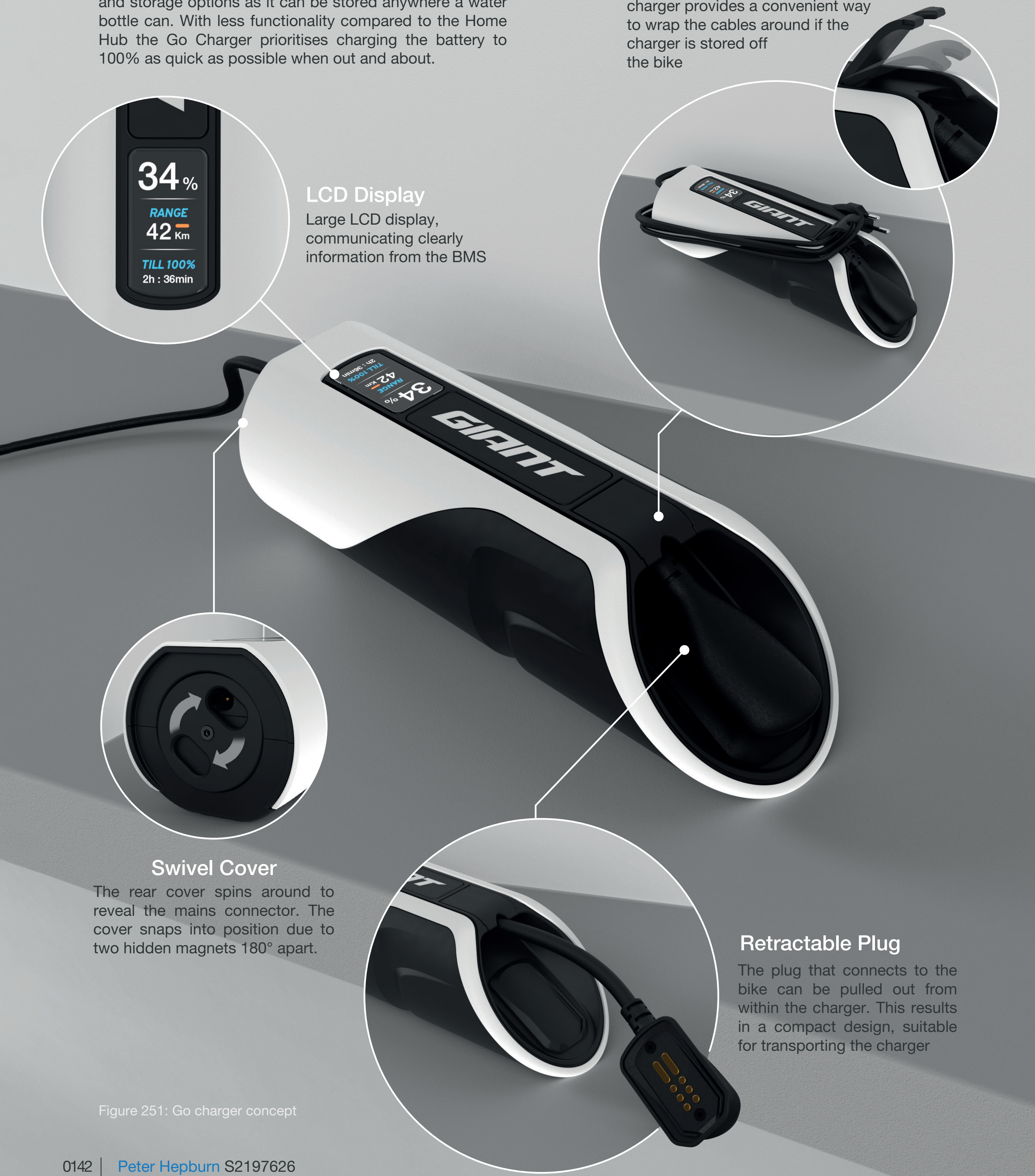
The Go Charger, designed to be used on the move, is a compact charger with the same geometry as a water bottle. This provides the charger with additional versatility and storage options as it can be stored anywhere a water bottle can. With less functionality compared to the Home Hub the Go Charger prioritises charging the battery to 100% as quick as possible when out and about.

Cable Management

The fold out clip on the front of the charger provides a convenient way to wrap the cables around if the charger is stored off the bike

LCD Display

Large LCD display, communicating clearly information from the BMS



Swivel Cover

The rear cover spins around to reveal the mains connector. The cover snaps into position due to two hidden magnets 180° apart.

Retractable Plug

The plug that connects to the bike can be pulled out from within the charger. This results in a compact design, suitable for transporting the charger

Figure 251: Go charger concept

Figure 252: Go charger mounted to the Fathom bike

15.4 Hub

The charging hub is designed to be used around the home; with Wi-Fi capabilities the user is informed of the status of their Ebike charge anywhere.

2kg of pull force between plug and connector

LCD Display

Large LCD display, communicating clearly information from the BMS

Wall mountable

The Hub can be slid into a wall plate for use or storage. Allowing the charger to be kept off the ground.

Customisable case

The case clips over the charger allowing chargers to be sold with different covers. A feature that is incorporated across all three chargers

Designed for every situation

The screen placement was carefully selected so that is clearly visible during all situations.

1.3m cable with enough reach to charge the bike from a wall mounted position

Figure 253: Hub concept

Versatility

The retractable hook, can be used to support the wrapped cables around the charger for storage as well as provide a place to hang the charger on the bike for charging. This increases the versatility of the charger allowing the user keep the charger of the ground during any usage situation.

Figure 254: Hub concept mounted to the Fathom’s handlebars

Details

The way in which the hub is constructed will be the same as the Go charger and Hub+ The electronics are housed between two main black polycarbonate cases with a silicone band running around the circumference to create a tight seal and reduce to achieve a resistance of IP66.

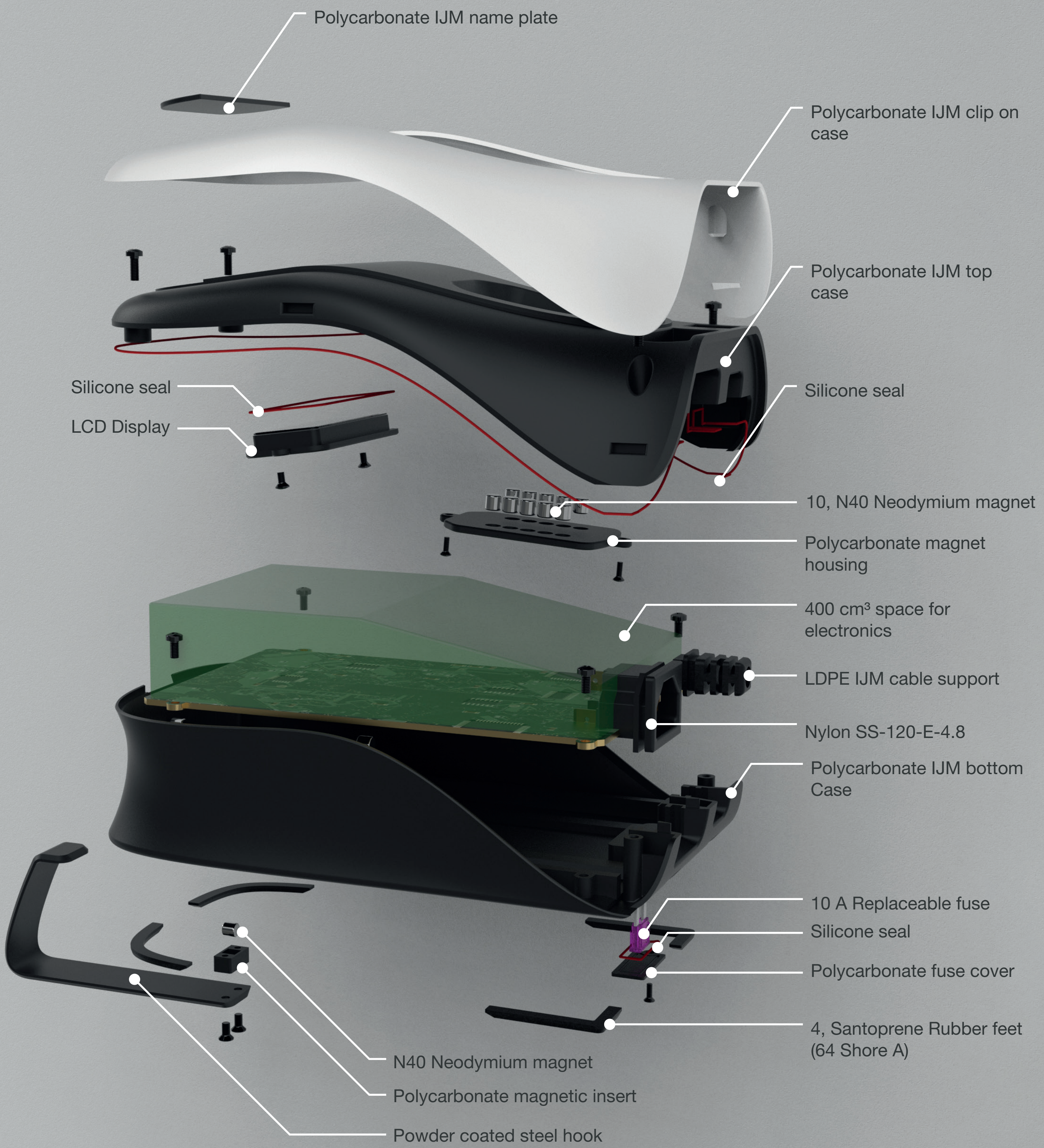


Figure 255: Exploded render of the Hub concept

Ease of Repair

Once the cover plate has been removed there are 4 easily accessible screws as a means of entry into the main electronics. The choice of this design means that the screws are hidden behind the cover, reducing the likelihood of the user accessing the electronics, yet it is easily accessible if a component was to fail.

Since the charger will be synced via Wi-Fi there is an opportunity for wireless firmware updates to the charger, allowing the charger to be updated as new Ebike technologies are introduced. This means it will not become obsolete as the technology evolves, resulting in a charger which can be maintained within Giant's product portfolio for the next decade.

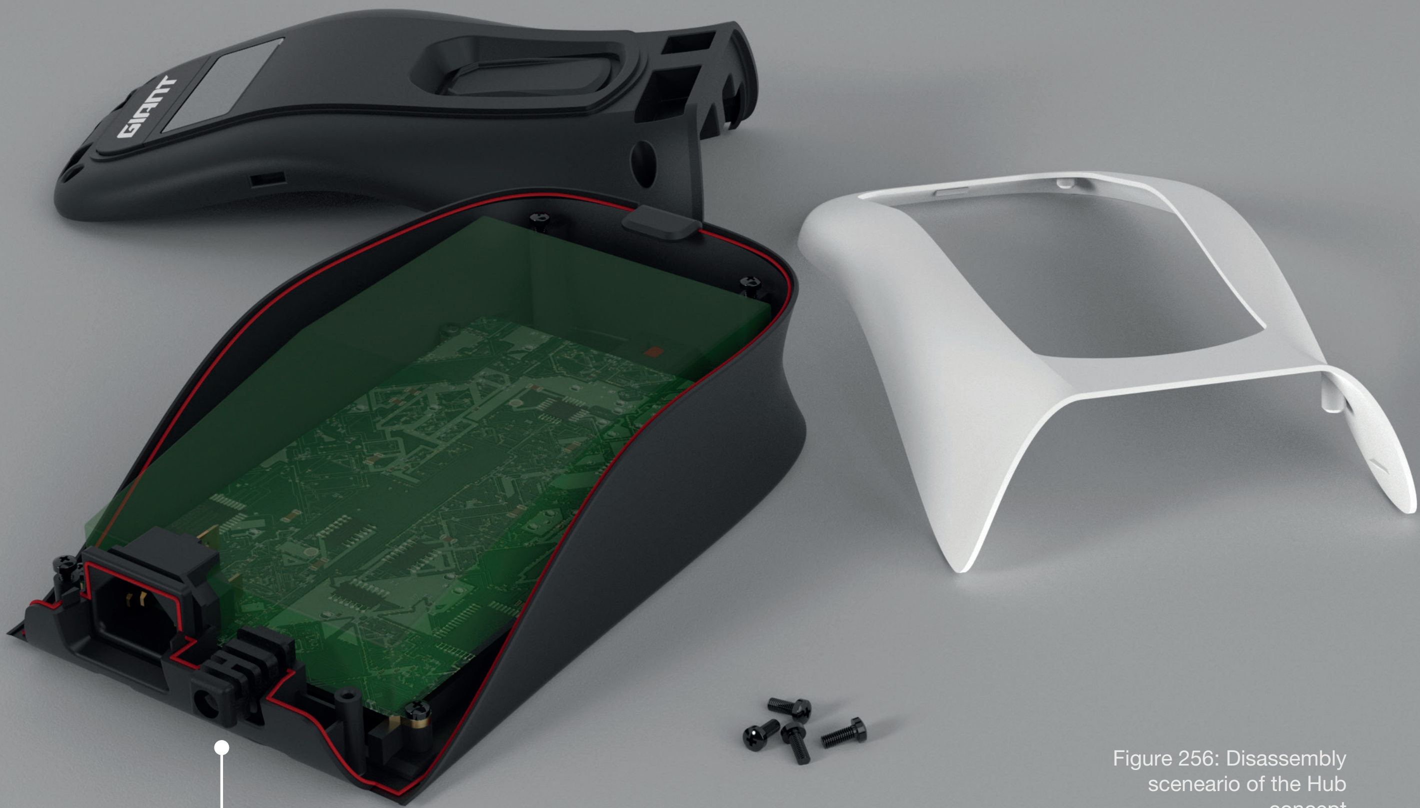
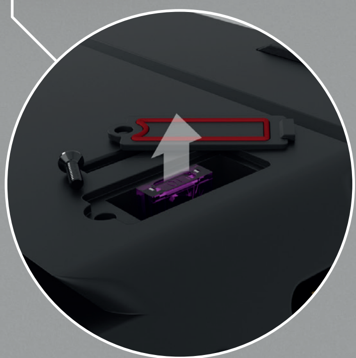


Figure 256: Disassembly sceneario of the Hub concept

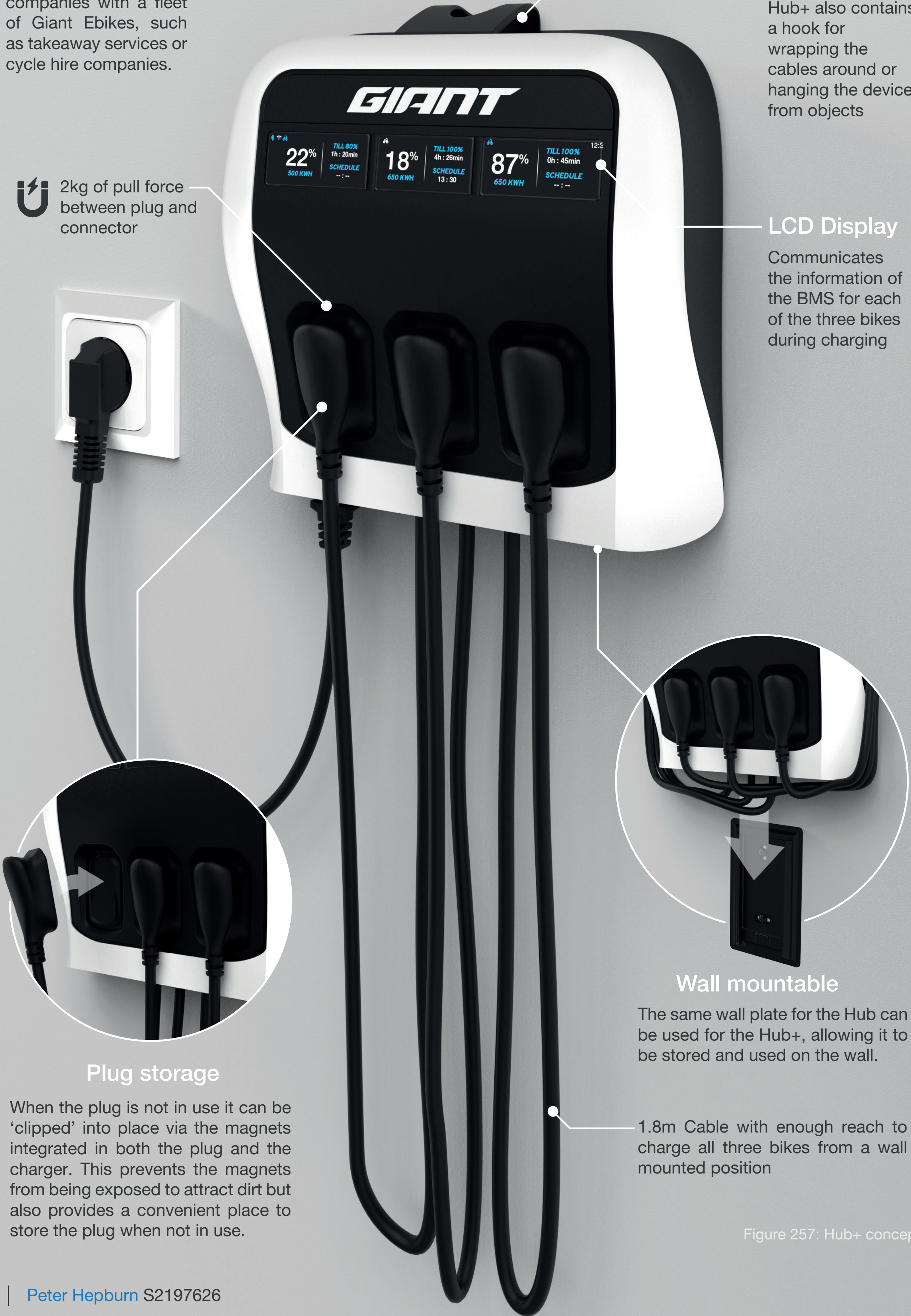


Extending the Chargers life

Within the underside of the case there is a 10A mini fuse. This is the same type of fuse used within cars. As discussed with Ebike Service Support in section 2.5, the addition of a replaceable fuse is a highly useful element for repairability. In the current chargers the fuse is built into the circuit board so if the fuse is blown the whole charger needs to be thrown away and cannot be repaired. This is not a sustainable solution, especially since the charger's life is well beyond the time it takes before it is likely to fuse.

15.5 Hub +

The charging hub+ is designed for users or companies with a fleet of Giant Ebikes, such as takeaway services or cycle hire companies.



Hook

Like the Hub the Hub+ also contains a hook for wrapping the cables around or hanging the device from objects

2kg of pull force between plug and connector

LCD Display

Communicates the information of the BMS for each of the three bikes during charging

Wall mountable

The same wall plate for the Hub can be used for the Hub+, allowing it to be stored and used on the wall.

Plug storage

When the plug is not in use it can be 'clipped' into place via the magnets integrated in both the plug and the charger. This prevents the magnets from being exposed to attract dirt but also provides a convenient place to store the plug when not in use.

1.8m Cable with enough reach to charge all three bikes from a wall mounted position

Figure 257: Hub+ concept

Cable management

With the same functionality as the Hub, the Hub+ provides options for the user to charge up to 3 bikes at the same time. This reduces the number of chargers and cables “scattered across the ground” creating potential safety issues and trip hazards.

Figure 258: Hub+ concept connected to three Ebikes

15.6 Battery

The new battery is designed to be compatible with the new charger family and the new battery integration.

LCD Display

Communicates the battery percentage and the range.

Universal connector

Plug socket is the same construction that is used on the bike frame. This is bolted to the extruded aluminium battery case.

Handle

The handle at the top of the battery makes it easier for the user to transport the battery to the charger, while also providing a place for the user to hold when removing and inserting the battery into the frame.

Integrated cover

The cover of the battery is clipped on creating a seamless transition between the battery and the frame.

Figure 259:
Battery concept

Battery Details

The construction of the battery remains very similar to the current battery, with two IJM Polycarbonate endcaps and an extruded aluminium case. The two main differences are; firstly the top endcap is now the handle with the integrated pins to guide the battery within the frame and secondly the battery extruded casing will need additional processing to stamp and machine the recess for the new plug and LCD display.

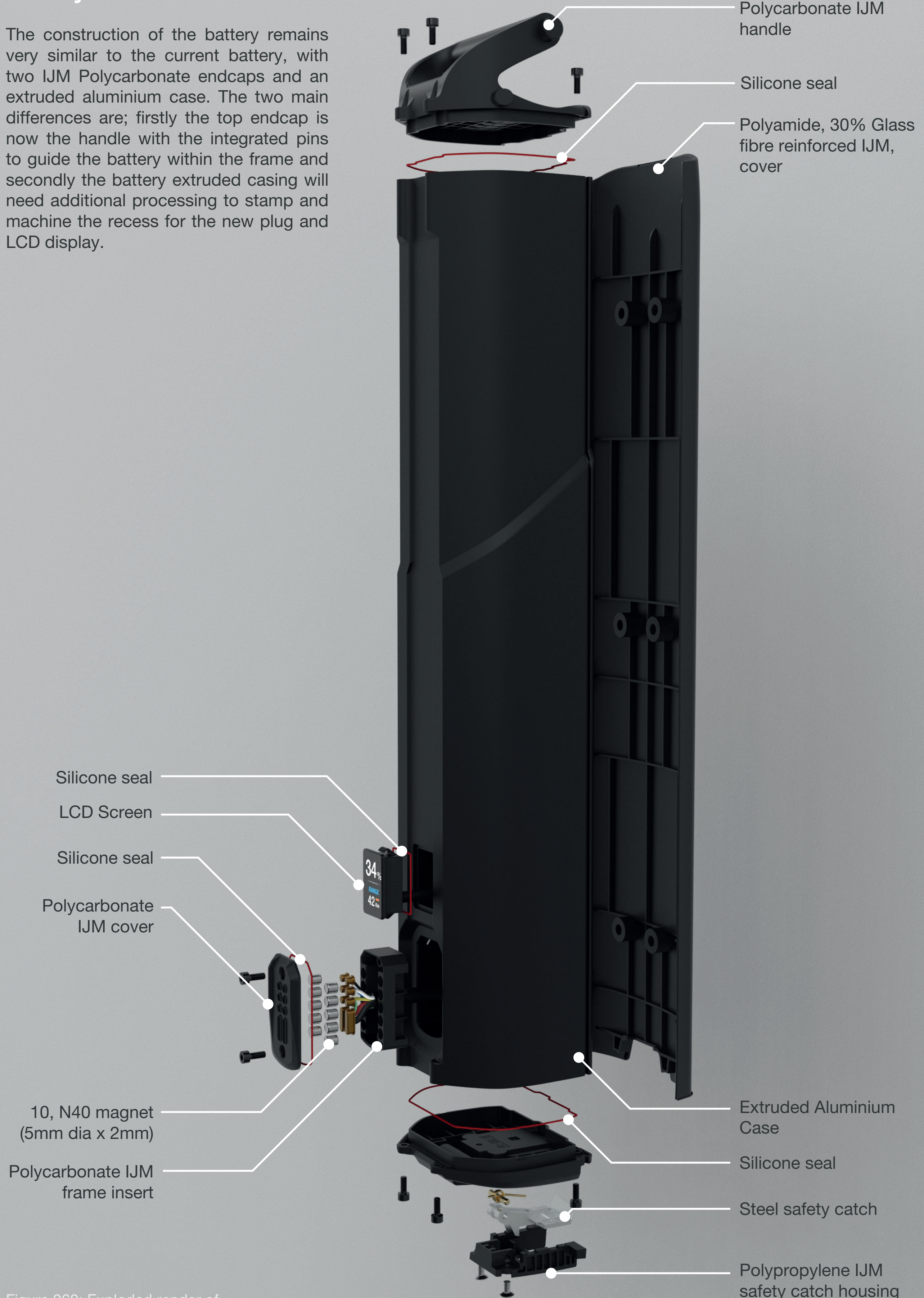
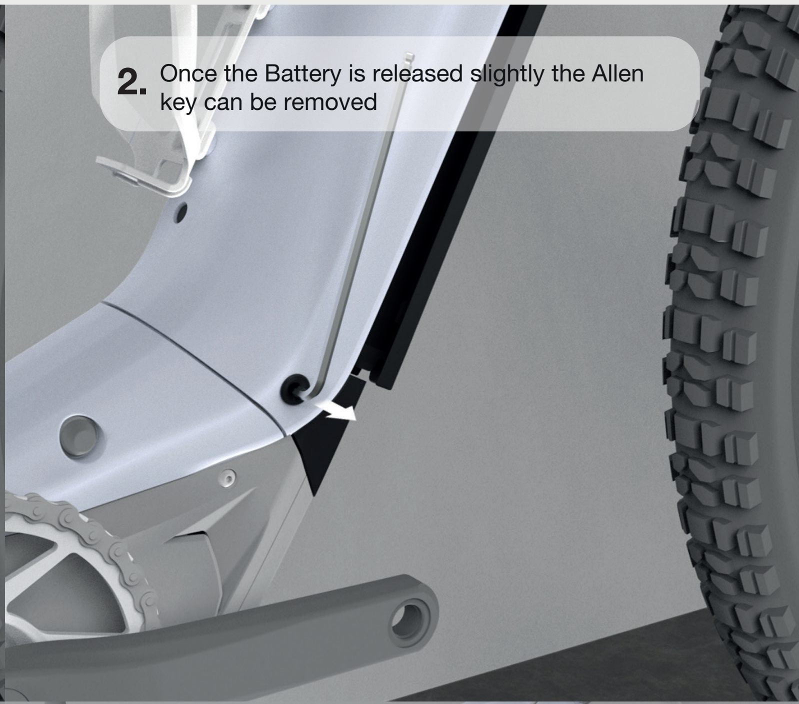
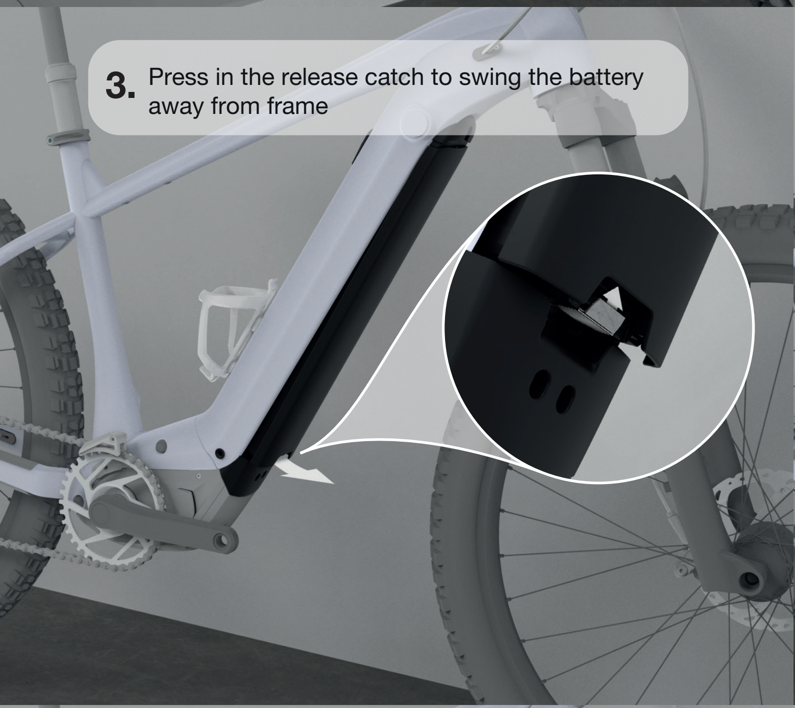


Figure 260: Exploded render of the battery

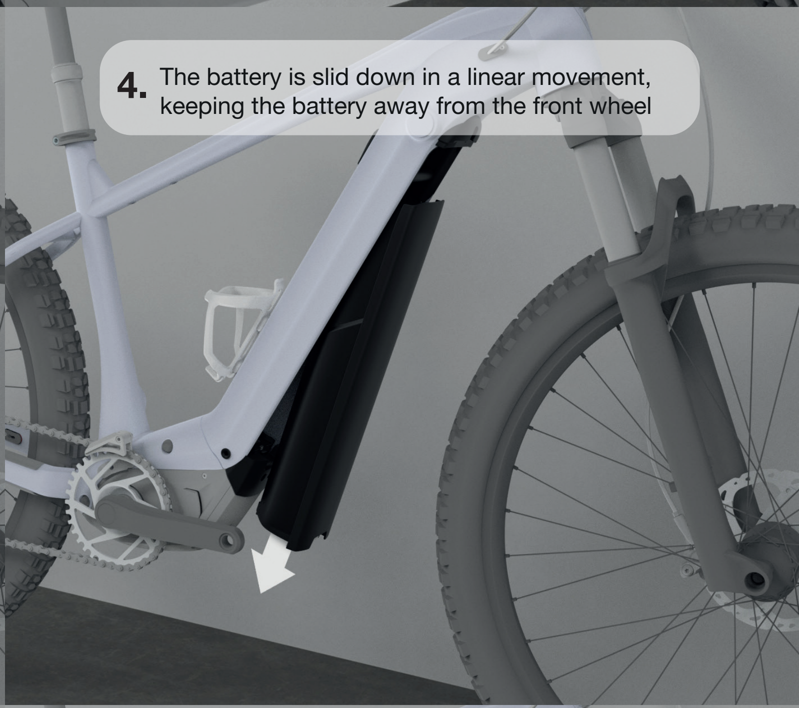
1. Insert the Allen key and turn 90° Anti clockwise



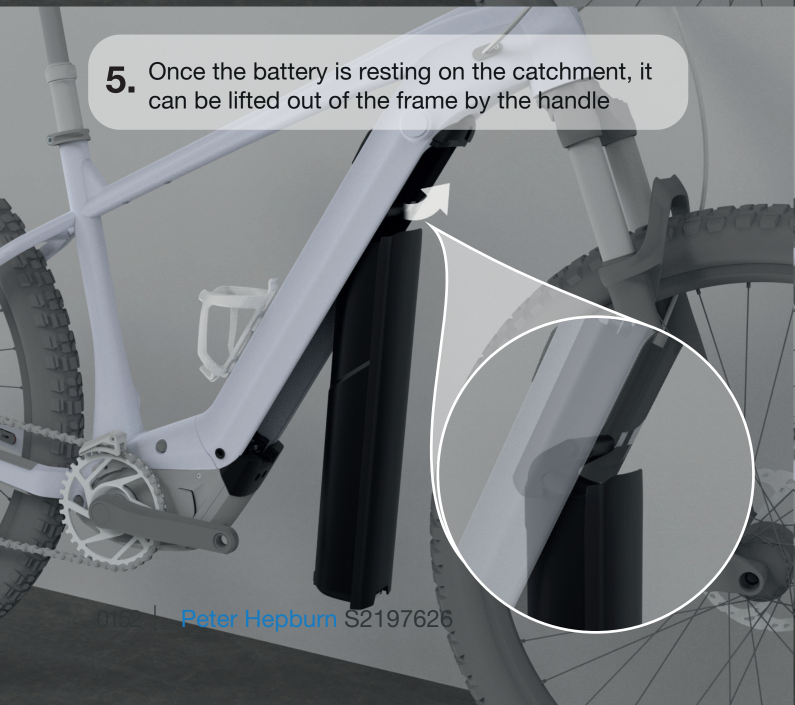
2. Once the Battery is released slightly the Allen key can be removed



3. Press in the release catch to swing the battery away from frame



4. The battery is slid down in a linear movement, keeping the battery away from the front wheel



5. Once the battery is resting on the catchment, it can be lifted out of the frame by the handle

6. The battery is removed and transported to where it will be charged

15.7 Battery Removal Procedure

To remove the battery there are 6 small steps, which the user must perform to remove the battery, The two stage battery removal steps 1,2 &3 are not required when inserting the battery making it a more simple task. These steps for removing the battery are necessary to ensure that the battery does not fall out mid ride.

Too see the sequence of inserting the battery refer to Appendix G.

Figures 261 & 262: Battery Removal steps and the battery hanging on the catchment rail

15.8 App

The app is designed to work in conjunction with any three of the chargers. Based on the communication discussed in section 7.2. For potential app notifications see Appendix F.

Range

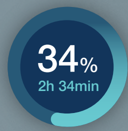
The range that is available at the current battery percentage is displayed. This range is based on the mode the user most frequently uses. In this case that is sport mode depicted by an orange line.

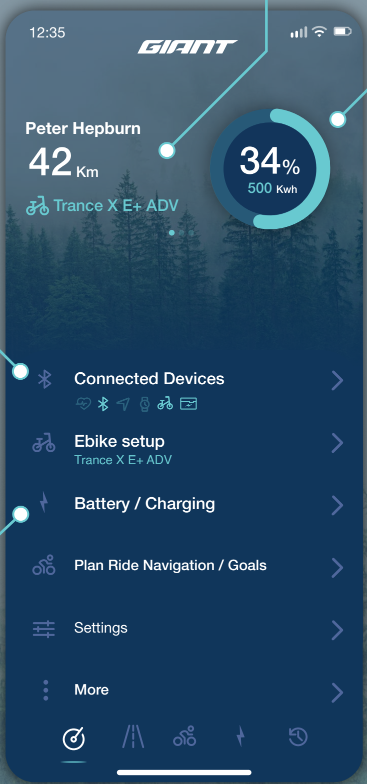
Connected Devices

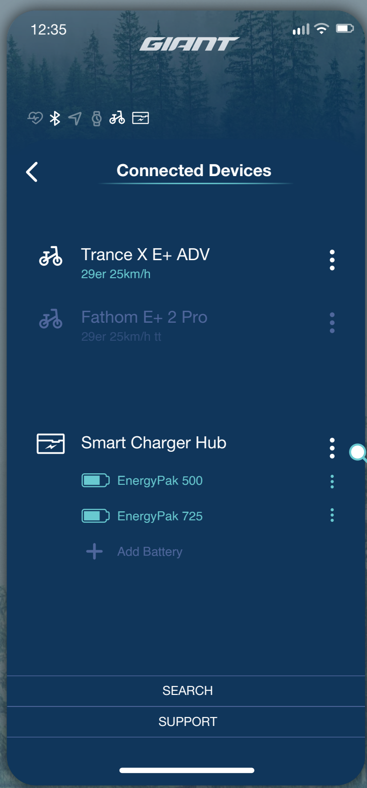
Shows an overview of all the devices that are connected through the app. In this case both the bike and battery are currently connected via Bluetooth.

Percentage

Once charging commences, the battery percentage display updates how long the battery has left to charge. Along with a loading wheel (turquoise ring around the outside).







Home Page

The homepage provides all the essential information of the bike's status. From the home page the user can chose different pages for features such as navigation, riding and battery charging.

Connected Devices

The connected devices can be accessed through the setting tab on the home page. It provides an overview of what is connected to the bike, In this case the bike and battery are connected to the app.

Battery / Charging

The battery / Charging tab takes the user to the charging preferences. This is linked to the charger via Bluetooth or WiFi.

Customisation

The user is able to customise the name of their bike or battery so they can know which battery charge preferences are being altered in the app.

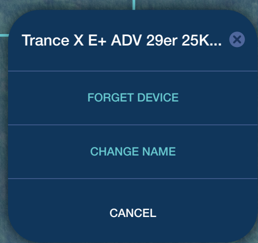


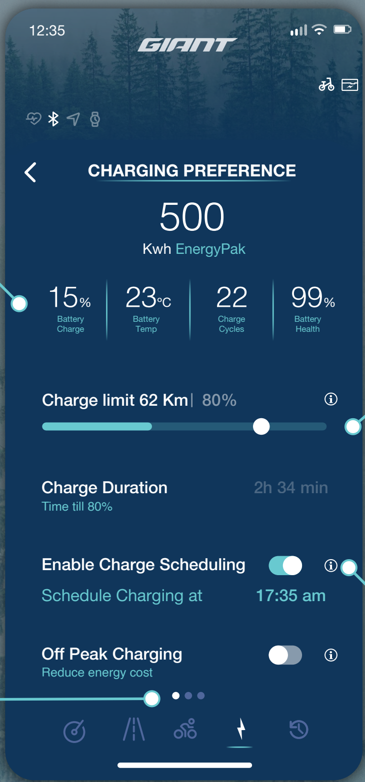
Figure 263: App concept

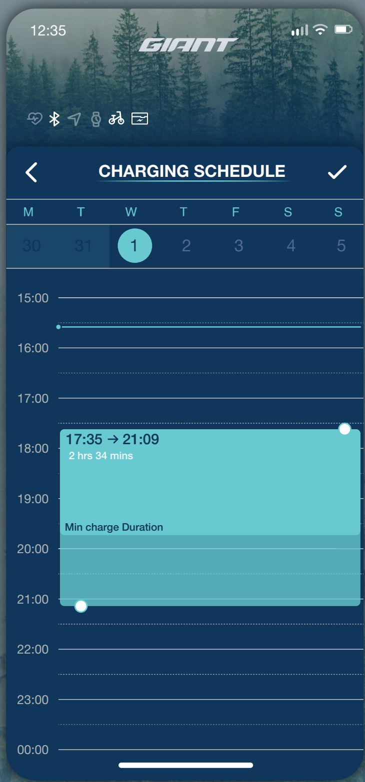
Charge Percentage

The user is able to choose the percentage they want to charge their battery to. Once set the battery will be charged to this level. Every 6th charge the battery will be charged to 100% to increase the longevity of the battery.

Battery overview

A clear overview of the battery information helps the user look after their battery more.





Charging Preferences

On the charging preferences landing page the user is able to choose how fast they want their battery to charge and what percentage they want the battery to charge to.

Charging schedule

For the Home Hub & Hub+ the user can schedule when they want their charging to begin and end. Allowing them to schedule charging in low energy cost times or to ensure the bike is charged when they want to use it next.

Multiple Batteries

The user can link multiple batteries to their app and scroll between them to change the settings.

Charge duration

The time it takes to charge the battery with or without scheduling is shown so the user knows exactly how long the battery will take to charge.

PHASE 5: CONCLUSION

In conclusion, the design of the charging system for Giant Ebikes has been research-led created to meet the diverse needs of cyclists, while incorporating innovative features for convenience and safety. The family of three chargers offer flexibility, with each charger catering for different usage contexts whilst sharing similar characteristics to ensure compatibility and continuity of user interaction between all three devices, aimed at reducing any ambiguity between the devices and ensuring optimum usability is as intuitive as possible.

The new Giant Ebike charging system offers a user-centric approach with three chargers designed for different contexts: The portable Go Charger prioritizes quick battery charging, whilst the Hub and Hub+ chargers provide Wi-Fi monitoring for home/work use. The plug design ensures a secure connection with the use of magnets and a “connection check” pin for safety. Repairability has been considered with a replaceable fuse and accessible screws, together with wireless firmware updates providing a charging system that is well thought out and future-proof.

PHASE 6

EVALUATION & REFLECTION

In this final phase a reflection of the final design was made to see if there was an improvement in the predicted PWVs and MWVs. Then the prototypes produced were tested with users to determine whether the design approach taken resulted in an improvement in the user experience. Based on the outcomes, suggestions on improvements which should be made to the design approach and guidelines were discussed. These outcomes helped provide a conclusion with recommendations as to the potential of applying a similar approach to future projects within Giant and other companies.

C16: EVALUATION

16.1 Comparing the PWVs, MWVs and Feedback

16.1.1 PWV & MWV

Comparing the flow diagram of the final concept with the predicted optimised system, the final concept has fulfilled most of the optimised system. The only difference, as shown in yellow, is during charging and uncharging the battery, where there is an additional "catchment step", which prevents the battery from falling out during both the insertion and the removal of the battery.

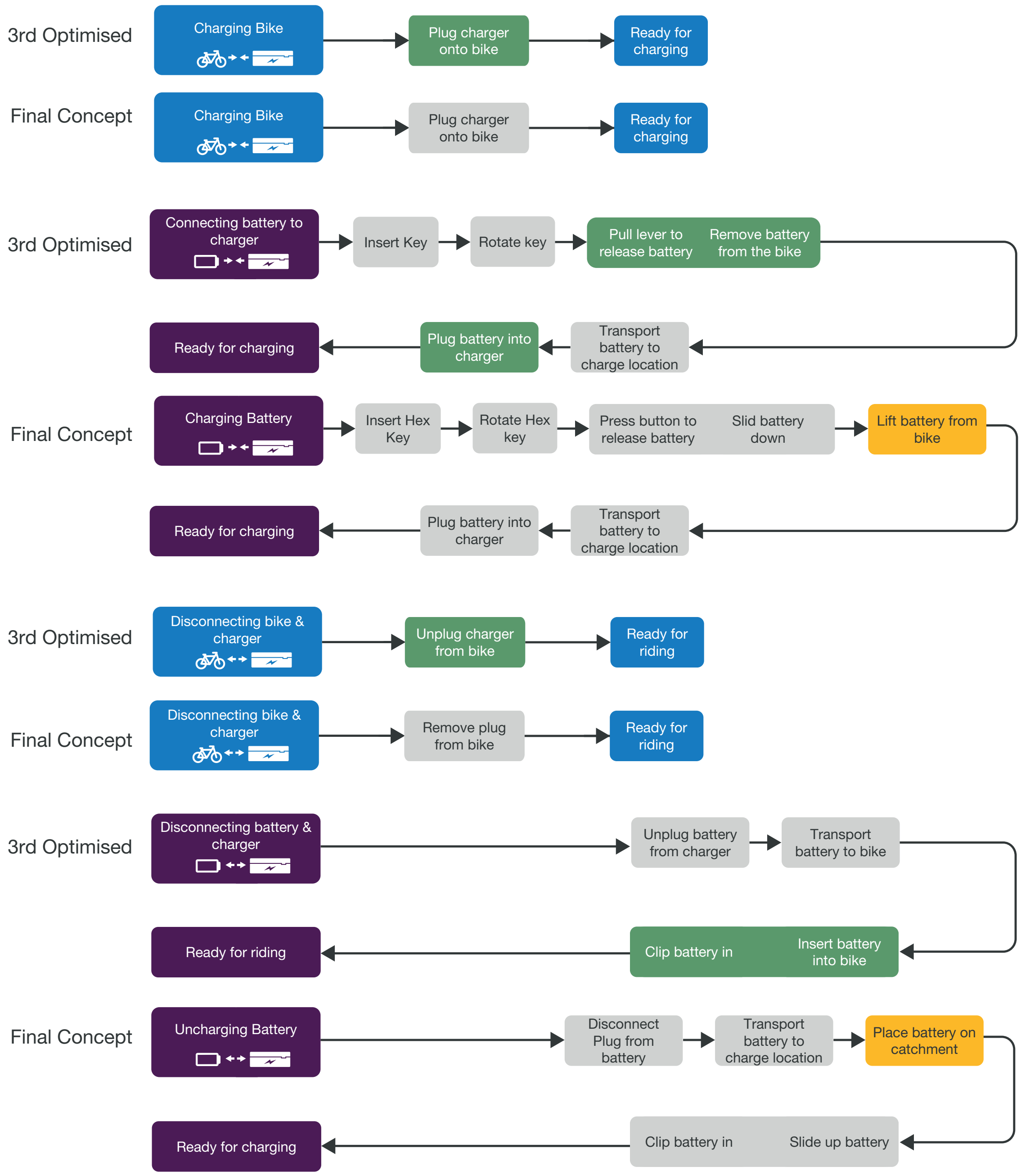


Figure 264: Flow Diagram of the predicted Optimised flow diagram with the final concept, the steps shown in 'green' shows the optimised procedures discussed in section 6.1

The table shows the PWV and MWV for the original, 3rd optimised and final concept allowing comparison as follows:

		Original	Optimised	Final Concept
Bike charging	PWV	9.3	3	1.8
	MWV	88	16	12
Bike Uncharging	PWV	7.8	1.5	1
	MWV	11	3	3
Battery charging	PWV	193.8	129.8	86.6
	MWV	134	83	43
Battery Uncharging	PWV	156.4	112.8	77.2
	MWV	62	22	23

Figure 265: Summary of the different PWV & MWV for the Original system, Optimised and Final concept. To see raw data of the workload components refer to Appendix C

While the values are hypothetical and based on a comparative analysis, by predicting how the user will interact with the charging system, it highlights that the physical and mental workload should reduce. This will prevent overstimulation and allow the user to maintain a high performance as the task demands are designed to match the users capability [98]. Taking battery charging for example; the new design does not have any orientation challenges due to the incorporation of the magnet polarity and Gestalt principles [112], causing the mental workload to be significantly reduced. This also has an impact on the PWV as the confusion with the orientation is eliminated, therefore the duration of the task is significantly reduced. Looking at the battery charging or uncharging; the addition of the handle allows the user to hold the battery with a better posture, resulting in reduced physical exertion and leading to a reduced PWV [115].

16.1.2 Feedback

Comparing the feedback score of the new system to the original charger; the charging confirmation monitoring feedback score is much lower meaning that it will be easier for the user to understand whether they have set up charging the bike/battery correctly and what to do if there is a problem.

Feedback	Confirmation			Monitoring		
Feedback required by the user	Plug is inserted correctly	Charging has begun	If there is a problem What must the user do	%	°C	Range
Is this feature Present (Y/N)	Y	Y	Y	Y	N	Y
Number of steps to obtain feedback	1	1	3	1	4	1
Amount of Physical Workload (focus on level of movement)	1	1	3	1	3	1
Time to obtain feedback (seconds)	3	2	5	3	15	2
Clarity of feedback	1	2	2	1	1	5
Feedback score	**3**	**4**	**90**	**3**	**180**	**10**

Figure 266: Feedback score for confirming charging and monitoring of the final design

The feedback score for the user to monitor their battery temperature (°C) is still high because the user is required to open the app or switch on the bike display to be able to view this. The same is true for diagnosing a problem, If be bike is not charging, e.g. the charger has fused, the charger screen will tell the user to diagnose the problem through their app or RideDash display where details will be given to the user on what steps to carry out to identify and correct the problem.

Comparing this to the original concept the display on the charger means feedback is much more efficient aiding the user by confirming and monitoring the charging process.

16.2 User test – Procedure

To determine whether these predicted PWVs and MWVs still hold in real life the produced prototypes were tested to compare Giant's original charging system with the new one to see if there is an improvement in user experience. This user testing was conducted using the Giant Fathom bike to measure both the original charging system and the new proposed charging system including battery integration. The reason for using the exact same bike on both occasions was to help reduce the variation between the tests.

The user tests have a very similar structure to the test conducted in chapter 2. After the short user profile has been created such as age, gender, and the level of Ebike experience, the main body of the test was conducted. This was divided into 5 sections:

Section 1: Usability test 1A: Charge the bike: The user was asked to charge the bike directly.
(Focusing on testing the user experience and interaction with the Home hub+ as well as asking general perception on the home Hub)

Section 2: Usability test 1B: Un-Charging the bike: The user was asked to get the bike ready for a ride.
(Focusing on testing the plug and whether the cable management solutions on the home hub are used)

Section 3: Usability test 2A: Charging the Battery: The user was asked to charge the bike battery.
(Focusing on testing removal of the battery)

Section 4: Usability test 2B: Un-Charging the Battery: The user was asked to get the bike ready for a ride.
(Focusing on testing the insertion of the battery)

During these sections: Observations were made including: the order in which the steps were performed, any errors/struggles the user had. The user was asked to reflect on the emotion they felt during performing the task based on the Emo-cards. This allowed for the same analysis which was conducted during chapter 2 which led to a useful comparison and insight into the user experience.

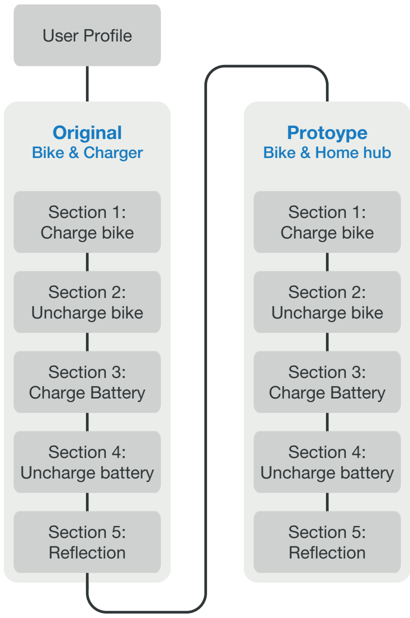


Figure 267: Stucture of how the tests were conducted to make the tests as independent as possible.

Section 5: Reflection: In the final section a reflection phase was conducted. The user was asked to reflect on their experience and rank the ease of use of the product they used, comment on anything that surprised them and complete the UMUX. This will give an indication of the overall perceived user experience.

Why test the original system first?

The decision to test the original charging system first was to provide a baseline for the participants to compare the new design to. Another option could be allowing the user to only test the new charging system which would limit the ability to compare the two designs. Due to the difference in the charging systems, it was decided that performing the user test on the original charging system would not influence the second user test. If there was any influence the prototype experience would likely be hindered as the user would be trying to perform the task in a similar way to the original. This situation is representable of reality, as experienced Ebike users would be accustomed to an existing charging system, so with any new system may initially try to perform the task in a "known way" until they realise it is different.

16.3 The original charging system - Results

The Fathom bike used had the same plug, additional cover and screw as the Explore E+ tested in section 2.4. As a result the challenges and issues the participants encountered were consistent with the previous test. Some of the issues experienced by the users are highlighted below:

- Charger is big, bulky and heavy
- Orientation of the plug
- Inconvenience of the additional adaptor
- Double locking sensation with the key and the screw cap on the cover
- Several participants placed the battery in the wrong orientation.
- Difficulties aligning the battery cover with the frame.

The above issues led to a less well perceived user experience. For more details of these problems see section 2.4 which shows the results of the same test performed on a similar bike.

16.4 The new charging system - Results

For this test the exact same procedure was conducted as that using the original Fathom charging system with a few additional questions, asking the user to compare the experience.

General view on the charger: The participants were asked to comment on their first impressions of the charger. They stated that it was reminiscent of an EV charger, looked professional, had a nice finish, appeared more compact and modern. One participant also expressed that it was nice that it was not all black.

16.4.1 Charging the bike:

To charge the bike there were very few problems encountered by the participants. Two participants did not notice the hook feature; as a result they were confused on how to unwrap the cable from around the charger. Three participants struggled to find the charging location as they were looking in the same location as the previous test as the though the plug port was low down. After looking at the geometry of the plug they were able to find the location. When asked to comment on charging the bike, one participant stated they preferred it in the centre because it did not matter from which side you approached the plug.

When asked to compare the experience to the original Fathom, participants said that they felt it was easy to connect the plug, especially with the magnets causing self-alignment between the plug and socket. Several participants stated that it was satisfying that the plug ‘clicked’ into place.

16.4.2 Display:

No participants had any problem in determining the battery percentage and could be achieved very efficiently compared to the original charging system where 2 of the 9 participants could not find the battery percentage. All participants could say what was shown on the display and were able to determine that the charge time was the time until the battery was charged to 80%. One participant would have like a power button on the charger so they could switch it off and on and expressed that they did not like leaving appliances on standby. A feature which could be included in future designs.

The time schedule did pose a bit of confusion as the participants all thought that this was the time the charging would terminate and not the time the charging would start. One participant suggested that a solution could be a system similar to scheduling on a washing machine where you can delay the start time within 30min increments, another solution could be changing the word from ‘schedule’ to ‘start at…’ to help the user understand when charging would begin.

Figure 268: possible word change on the Hub display

16.4.3 Uncharging the bike - Removing plug from the bike

No participants encountered any problems uncharging the bike. They said it was even faster and more intuitive compared to the previous plug. One participant did say that they would have liked a clicking sound as it was removed.

When asked to reflect on this experience compared to the previous Fathom. They stated that it was more intuitive and faster, with less friction between the plug and the socket. One participant stated that ‘it was even more simple, and more seamless since there were fewer steps in the process’.

16.4.4 Charging the battery – Removing battery from the frame:

The charging of the battery posed the most challenges out of all the tests. All the participants took a long time to figure out where the keyhole was and many thought that the safety catch at the base of the battery was the first step needed to be performed. After pushing it in and nothing happened, they carried on exploring other options.

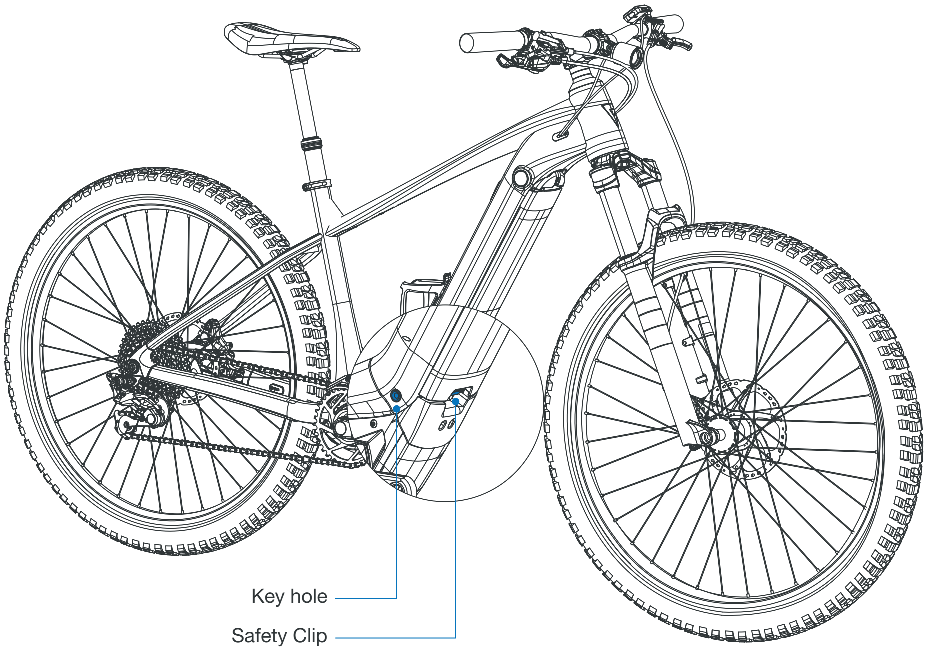


Figure 269: Push in safety clip, is more visible than the key hole so it was pressed first.

Once they had turned the key several participants did not know they needed to press in the button at the base as this was not in direct view (despite the removal lock mechanism sequence being the same as the previous battery). For 3 participants they were already pressing the button under the battery when they turned the key so were not aware of the two-part safety features.

Five of the 9 participants were pulling on the battery from the top of the frame, as this was how the battery was removed in the original Fathom. When reflecting on this after they said they did not expect the battery to pivot and slide.

When asking the participants to reflect on their task they felt the locking mechanism was challenging, and fiddly with the safety button. However once they had unlocked the battery they found the second half of the procedure a lot easier to perform since the top section of the battery is supported within the guides.

Comparing the experience to the original Fathom the participants felt that having the cover attached to the battery made the process simpler. One participant also stated that the catchment area was a nice feature as it allowed someone who was not very strong, peace of mind as the battery does not just fall into your hands immediately.

16.4.5 Uncharging the battery – inserting the battery into the frame:

When inserting the battery back into the bike 3/9 participants had a slight issue finding the catchment area, once the battery was on the catchment area, it was slid and clicked into place within 5 seconds. When asked to comment the users felt that the insertion was a lot easier and ‘so much more convenient’ several also commented on the loud click from the locking mechanism made the battery feel much more secure. Especially with the cover attached to the battery. One user also expressed that the whole process was much smoother due to the sliding of the battery and locking into place. It helps guide the battery to where it needs to go.

16.4.6 Overall operating procedure:

When looking at the overall operating procedures the users' performed there was much less variation. Due to the elimination of the adaptor, as well as the system design, the users' steps could only be performed in a sequential way leading to more clarity during to process and reduced confusion.

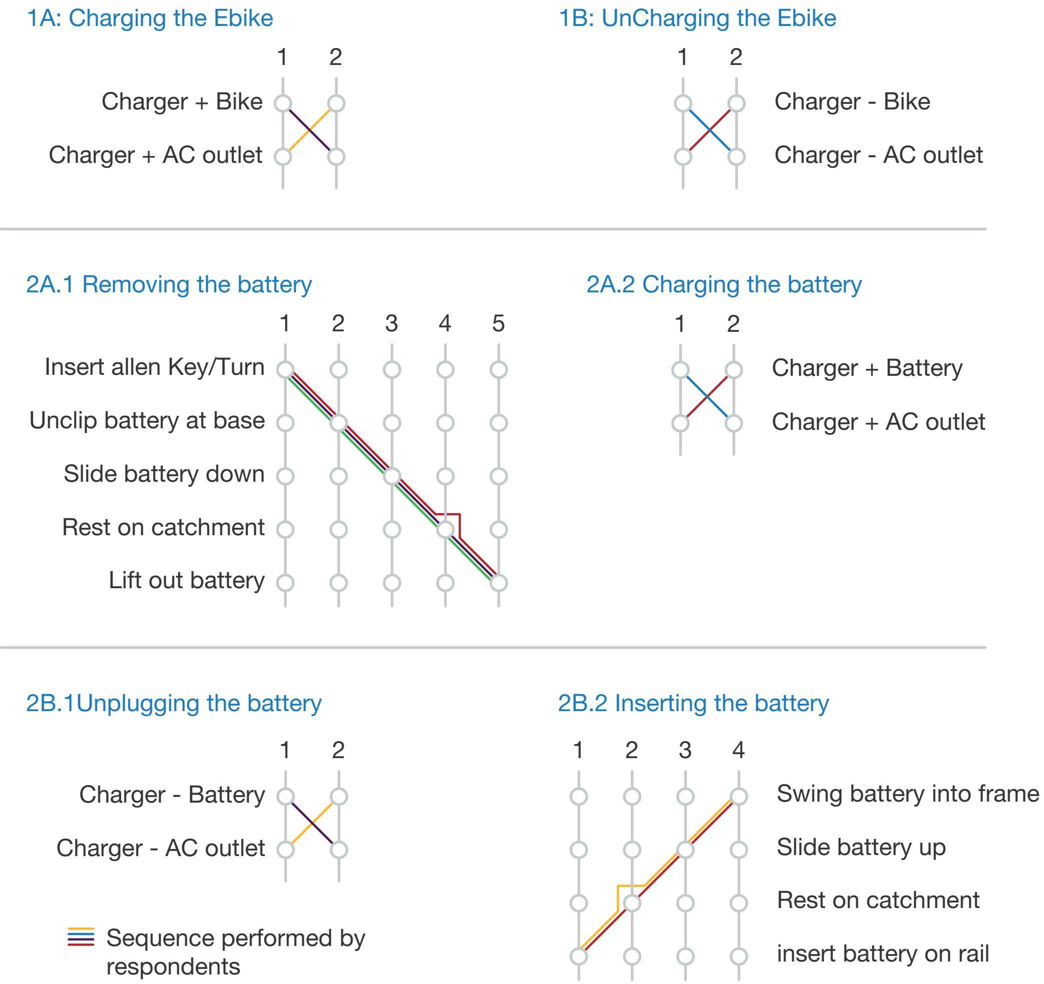


Figure 270: possible word change on the Hub display

16.4.7 Conclusion:

Based on the feedback from the participants and the observations that were made there are a few challenges which were highlighted. The alterations suggested are as follows:

- Try to reduce confusion on the location of the keyhole.
- Improve clarity on using the safety catch.
- Redesign the scheduled charging so it is easier to understand.

During the test most of the problems highlighted in this scenario are first time use problems or due to the assumption that the new design would be the same as the original.

At the end of the testing, once all the results had been collected, the participants were asked if they'd like to carry out removal and insertion of the battery into the frame again. On the second attempt, having learnt where the key and safety lock were, the task was performed faster with no problems. This observation provided confidence that the challenges are quickly overcome after the first few uses. This is not the case for the original design as the experienced Ebike users, who knew what to do, still struggled with placing the battery cover onto the frame.

16.4.8 Behaviour, emotions, and overall usability

Comparing the behaviour and emotions between the two tests that were conducted will create an overview as to whether there is a significant improvement between the user experience.

For both tests the most common order from the task that was easiest to perform to the hardest was consistent, however with the original Fathom charging system there was more variation with the battery charging/uncharging being the opposite way around due to the difficulties participants had with aligning/inserting the cover on to the frame.

Figure 271: The four user test tasks ranked from easiest to hardest

For both tests the participants said that they determined how easy the task was by the time to complete task, number of steps required, and the amount of movement required.

Emotions:

When analysing user’s emotion with the original Fathom charging system there was a much more distributed spread with some users finding it an unpleasant experience and other users finding it pleasant. For all tests, apart from unchanging the bike, the emotions were shown to be shifted towards unpleasant compared to their user’s expectation.

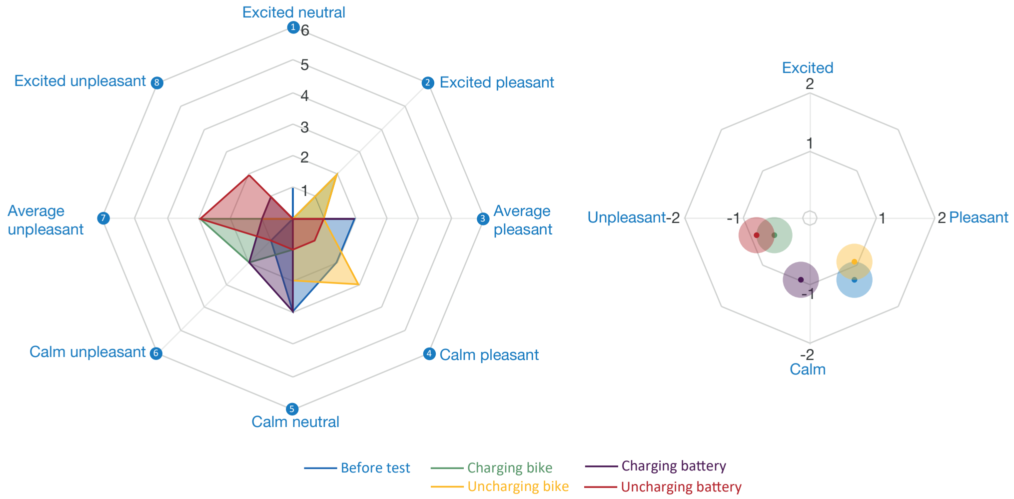


Figure 272: Emotion for each test for the original Fathom charging system

When comparing this to the emotion for the new prototype, the level of arousal was significantly higher, several of the participants stated that they were excited to be testing something new. Looking at the left diagram there is much less variation in emotion, with most of the participants’ emotion remaining similar. This is highlighted further in the right graph as the emotion for each test is tightly clustered together. The emotion for charging the battery, resulted in being less ‘pleasant’, was expressed primarily due to the initial unlocking procedure being confusing. What is also significant is how close the tests remained close to the expected user experience (shown in blue and hidden behind the yellow point).

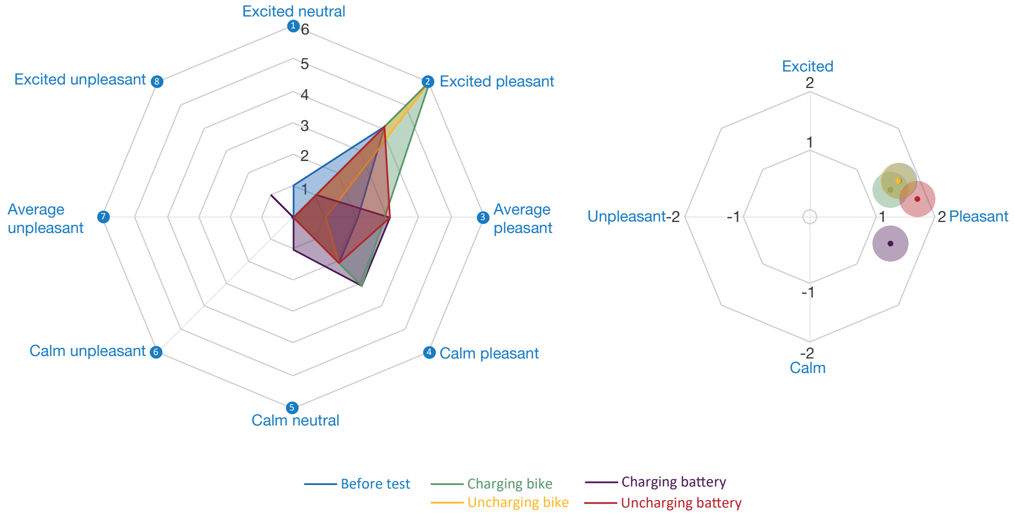


Figure 273: Emotion for each test for the new charging system prototype

Reflection on experience:
Using the four UMUX questions the user was asked to reflect on their overall experience. The figure below shows the Final UMUX score out of 100 for both the original charger system and the prototype to enable comparison between the two (the order of participants is at random for anonymity). Details on how the UMUX is calculated see section 2.2.1.

Usability component	U1	U2	U3	U4	U5	U6	U7	U8	U9
1. Effectiveness	4	5	5	4	4	2	2	6	3
2. Satisfaction	2	6	2	3	6	3	3	1	4
3. Overall	2	4	1	3	5	1	4	4	3
4. Efficiency	0	6	4	3	6	0	3	4	2
Total/24	10	21	12	13	21	6	12	15	12
Total/100	**42**	**88**	**50**	**54**	**88**	**25**	**50**	**63**	**50**

Figure 274: UMUX Score for Original charging system.

Usability component	U1	U2	U3	U4	U5	U6	U7	U8	U9
1. Effectiveness	6	6	5	5	6	5	5	6	4
2. Satisfaction	6	6	6	3	6	6	6	5	5
3. Overall	5	5	5	5	5	5	6	6	5
4. Efficiency	6	6	6	6	6	6	6	6	5
Total/24	23	23	22	19	23	22	23	23	19
Total/100	**96**	**96**	**91**	**80**	**96**	**91**	**96**	**96**	**80**

Figure 275: UMUX Score new charging system using prototype.

Looking at the UMUX values, the average score for the new charging system has a significantly higher UMUX value compared to the original Fathom and the explorer E+ UMUX testing (which was tested previously). The new charging system has a much smaller standard deviation, suggesting that there is more consistency in the experiences between the users. When calculating a T-test, to see if there is statistical difference between the means, there is a significant difference with 95% confidence interval and therefore it can be concluded that there is an improvement in the charging experience.

	Current charging system		New charging system
Usability component	Explorer E+	Fathom	Fathom
UMUX average	**78.00**	**56.66**	**91.33**
Standard Deviation	14.61	19.32	6.38

Figure 276: Comparision of the UMUX between the current charging system and the new charging system

With further alterations and a few amendments to the design as discussed in section 16.3.7 above, the small challenges the users faced during using the prototype would be eliminated or significantly reduced and the users experience would likely be elevated slightly further. If the suggested system was manufactured within a factory environment the tolerance levels would be far less and therefore should create a “better” product and improve the user experience further.

C17: REFLECTION

17.1 Guidelines

Based on the user test evaluation there has been a significant improvement in the user experience. Reflecting on the final design against the guidelines help determine which guidelines are more significant than others, what extent these guidelines contribute to 'optimise the Ebike charging Experience' and whether further refinement is necessary to obtain this optimal user experience.

G1. Reduce the number of steps to charge the bike/battery.

Reducing the number of steps within the process can improve the overall user experience however as the physical and mental workload values indicate a procedure with more steps in may result in a better user experience. This was shown in the final design of the battery integration where the additional, optional step, to rest the battery on the catchment area dramatically reduced the physical workload since the user could have a point to 'catch their breath' if they needed it - ultimately leading to a better user experience. Therefore, in conclusion, this guideline is included within G2, so will be removed from the final set of guidelines.

G2. Reduce the physical and mental workload when removing the battery.

Reducing the physical and mental workload was the focus when optimising the physical design. This proved to provide significant improvement with the design of the plug and the battery integration where there was the most user interaction. For the charger itself, since the device would be typically mounted to a wall or resting on a shelf, the interaction the user has with the device is minimal and therefore the improvements had less of an impact on the overall UX.

Reducing the physical and mental workload for an Ebike charging system is desirable, however under stimulation can also result in a poor product performance and engagement from the user leading to a negative user experience [98]. Therefore, the decision to reduce the mental and physical workload cannot be applied to all applications. That said there is a very wide broad range of industries this guideline could be applied especially for products that involve a series of steps, where performing the task both efficiently and effectively is of high priority, these could include medical applications, kitchen appliances or within the construction industry.

This guideline will be updated to "Reduce the physical and mental workload when charging and uncharging the bike/battery" while the battery charging was the main priority for this guideline the reduction in workload for the other procedures also added significant benefit to improving the overall UX.

G3. Provide fast feedback that charger is setup correctly.

The feedback to the user will be shown through the display on the charger, to confirm that the connection has been made. The prototype could not provide the charge confirmation and charging the battery could not be properly tested. However, within all the developed products the feedback the user receives provides a big contributor to the overall experience, improving the effectiveness of the task [47]. This was highlighted during the user testing as users were seeking a 'satisfying click' that rewards them once they have completed a task and so they know that they have not made any errors. Based on this, to make the guideline more applicable to further applications, it will be changed to "Provide feedback to the user as a task is fulfilled"

G4. Assist the user to better manage their battery health.

This assistance was provided through the app & the displays on the charger. To determine whether this solution would help the user better manage their battery health further testing needs to be conducted. However, within the framework of an app the users who want to manage their battery health can while the users who do not want to manage their battery health can still perform their charging procedure in the same manner they did before. This is a very important element which has become apparent during the design phase, therefore a new guideline has been generated to "ensure the addition of new features does not reduce the performance for the users who do not want them"

G5. Eliminate need to monitor the battery during charging when user does not want 100% charge.

This feature was incorporated in both the app and will be on the Ridedash Evo, Ride Control dash and future models to ensure that this feature remains accessible for users who are not accustomed to using apps. This guideline is also applicable to the new guideline mentioned above, because there will be a high proportion of bike users who only ever want to charge their battery to 100%, where increasing the longevity of their battery is low priority.

G6. Provide better feedback on the battery charge status and other data when required.

Within the final concept, feedback is now provided on the charger, bike display and app. This means that feedback is easily accessible for different user groups. This relates to guideline G7. Other data includes the charge scheduling, time till charged and the range – an important feature for making the battery percentage more tangible. Since 'better' is an ambiguous word, this guideline will be merged with guideline 7.

G7. Ensure that feedback can quickly be obtained.

To ensure that feedback could be quickly obtained the digital information is provided on multiple displays with few steps required for the user to see the feedback. Based on the feedback from the user testing the addition of the display on the charger was very well received and significantly increased the charging clarity. To determine whether the app is as successful further testing is required. It is important to ensure that any new features do not overcomplicate the charging experience and if the feedback is displayed on multiple devices they must be seamlessly in sync ensuring the displayed information is consistent to eliminate confusion.

G8. Ensure that the charging system usability is not hindered in different usage contexts.

To ensure that this guideline is fulfilled, the different contexts were established. The research highlights lots of different potential usage scenarios within multiple contexts. Designing one product to meet the needs of every scenario can result in a product which lacks personality, as evident from Giant's current charger, which cannot provide the optimum experience for every user. To address these three different chargers were designed to create a family of products suitable for different contexts of use. Based on this the guideline was refined further to 'Design a charging system that offers flexibility to cater for different usage contexts.' This guideline still needs to be tested further to ensure that good user experience is still obtained during a wider range of conditions such as, removing the battery when the bike is muddy or in low light.

G9. Design the charging system so that it can be performed by any user based on their experience.

This final guideline addresses the user's capability (knowledge). As supported in literature over time the user's confidence will improve, as well as their understanding, leading to improved usability [98]. However the first engagement with a product is important and the charging system needs to be easily understandable for the first time users. In the final design this was achieved by the battery only being able to be removed in one sequential way, reducing confusion of the user. Another feature was the catchment on the battery integration, which could be employed to assist the first-time users when removing the battery, but for the more experienced users they could 'by pass' resting the battery on the catchment area, making the process more efficient. Based on these findings the guideline is altered to 'Design the charging system so it is easy to perform for first time users without compromising the efficiency for experienced users.'

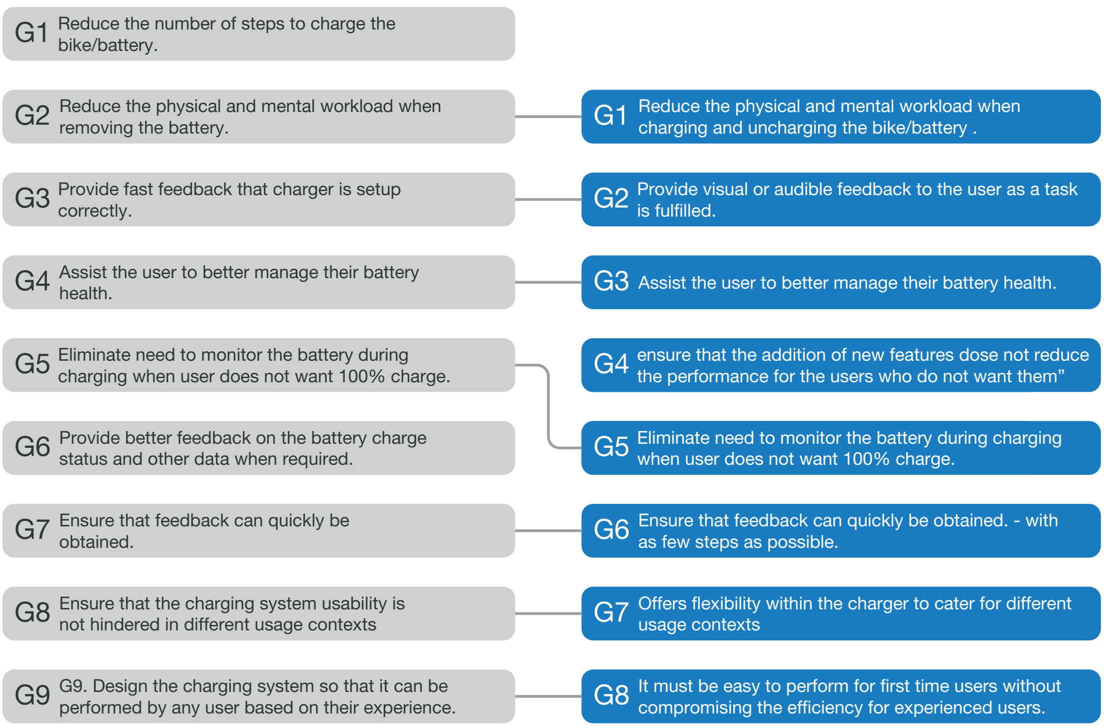


Figure 279: old guidelines converted to new guidelines.

17.2 Discussion

The revised 8 guidelines have been proposed in section 17.1. If Giant was to apply these to the redesign of their charging system, as seen with the final proposed design, there would be an improvement in the user experience, as supported by the testing which was conducted. However, as shown, throughout this thesis, user experience is a complex topic that is difficult to define. Every user's experience will differ and generalising it is a difficult task. As a result, the usefulness of these guidelines, if they were used directly for other projects, are relatively limited. To achieve an improved user experiences the components discussed in section 2.1 would be useful to act as a starting point. By exploring these contributing factors of user experience, in conjunction with an in-depth user evaluation, and using the methods within this thesis such as Emo-cards and UMUX metric to evaluate a current product, provides an insight into what components within the user experience should be focused on.

Quantifying the components of user experience was challenging to achieve, which is confirmed by the absence of a predictive approach being seen in literature. Using the PWV and MWV as a basis to refine and develop concepts led to an improved design, however the greatest limitation to this method was to be confident that the scales to quantify each value are comparative. It is important to note that different evaluators or the same product would obtain different scores, since their perception is different; however the 'best' product chosen would likely still be the same. Therefore, the next stages in developing these values would be to create a more detailed definition of what score should be assigned to each element through evaluating lots of different products. For example, defining what each score out of ten is associated to a certain scenario ie. the difference between a 5/10 and 6/10 for the physical exertion component which is used in the PWV.

Reflecting on the final design the family of three chargers have the potential to provide an improved user experience. Taking this forward, from Giant's perspective it comes down to business feasibility and whether the additional cost of the new charger, with intelligent system and digital display, would provide enough improvement in the user experience to justify the development and production costs as well as the increased sale cost. Within the Ebike industry there are a lot of unknowns, the industry is still rapidly developing, and this makes it particularly challenging to develop a future-proof product. Over the next several years the rate of Ebike technology development is likely to slow down and the distinction between Ebikes will become increasingly challenging. As this happens new unique selling points will arise, convenience and user experience will likely be one. For the case of chargers it is predicted that these may not always be a 'must-be requirement' but may eventually be a 'one-dimensional; or even 'attractive requirement' that will create pressure to develop a new Ebike charger.

Evaluating the battery integration concept, this design has potential to improve the ease of removing the battery. A prototype needs to be fully built around a complete bike to determine the exact user interaction it creates as having a front wheel, cranks and handlebars will change how the user interacts with the battery and will allow more significant testing conditions. In addition, further work is required to find the optimal amount of constraints, which was used with the guide rail. The benefit of adding constraints is that it prevents the user from making mistakes by preventing the users from 'cutting corners', making the process more efficient for new users, however it is important that it does not reduce efficiency for experienced users.

17.3 Conclusion

This thesis focused on providing guidelines to optimise the Ebike charging experience. Traditionally, evaluating success of a product, and its associated user experience, relies on user testing after a physical prototype is developed; as there is a lack of tools to predict and optimize the user experience during the early stages of design. The thesis identified the burden experienced by users through research of other technologies and user testing of the current Giant Ebike charging system. From this research, initial guidelines were generated focussing on the different elements of user experience such as effectiveness, satisfaction, and efficiency. These guidelines were quantified and resulted in a focus on reducing the physical and mental workload through a proposed evaluation method, which involved calculating the physical and mental workload value to compare different concepts formulated in flow diagrams. Based on selection of the lowest workload values an optimised ideated concept was created and the Ebike charging system redesigned.

The final prototype of the redesigned charging system was produced and evaluated using measurable components such as Usability Metric for UX (UMUX) and emo-cards. Based on these results the new system demonstrated a significant improvement in the overall UX, with a reduced variance in results.

The results suggest if these guidelines are applied to develop Giant's Ebike charging system they would address the issues of the current system and potentially revolutionise the way chargers are perceived. A fully integrated system where the user experience is optimised can ensure a better Ebike charging system that remains superior to Giant's competitors.

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APPENDIX

APPENDIX A:

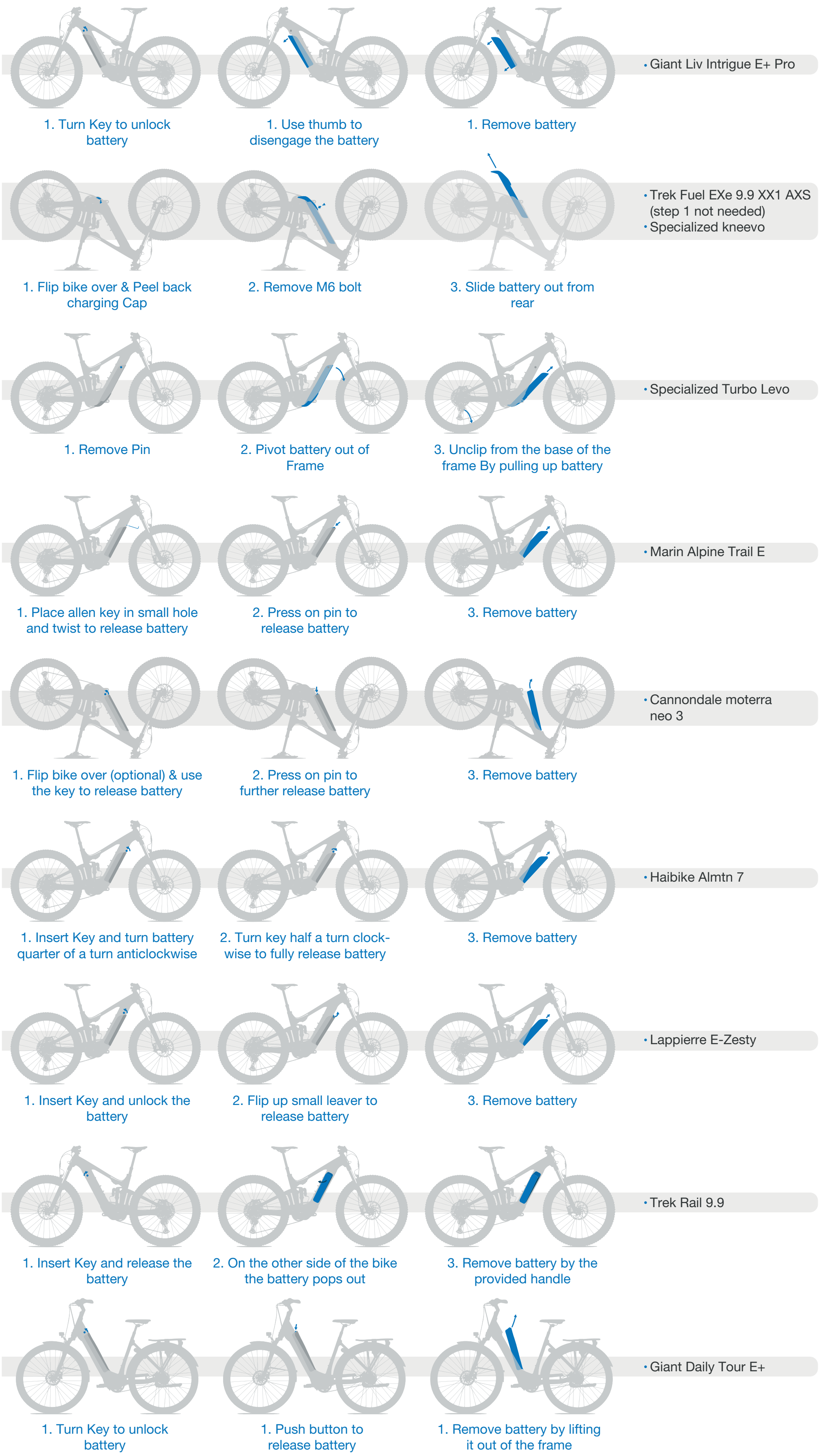

Figure A1: Battery removal types for some of Giant's Ebikes and their competitors.

APPENDIX B:

Optimised Uncharging Bike and Uncharging Battery flow diagrams. To see the optimisation flow diagrams for charging the Bike/Battery refer to section 6.1

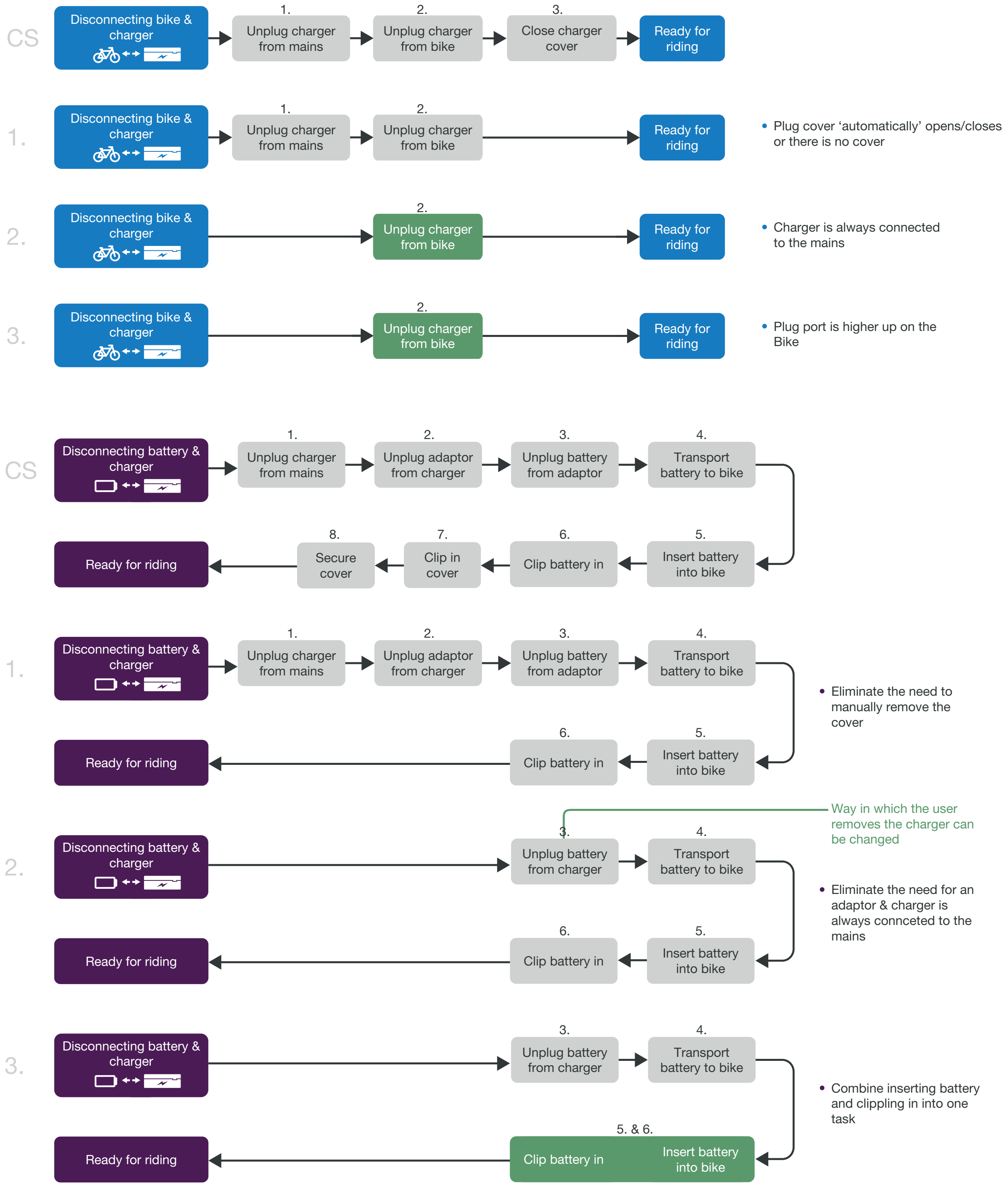

Figure A2: Uncharging Bike and Uncharging Battery flow diagrams

Note: The numbers above each flow chart box refers to the working method: Task number for calculating the PWVs and MWVs.

APPENDIX C:

Original System PWV & MWV

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Bike Charging											
Level of movement	3	3	3								
Physical exertion	2	3	2								
Duration of task (sec)/10	0.4	0.5	0.4								
Physical Workload	2.4	4.5	2.4								**9.3**
Battery Charging											
Level of movement	3	4	2	2	4	6	6	2	2	3	
Physical exertion	2	2	2	2	4	6	4	1	1	2	
Duration of task (sec)/10	2	1.3	0.5	0.3	1.2	2	3	0.3	1	0.4	
Physical Workload	12	10.4	2	1.2	19.2	72	72	0.6	2	2.4	**193.8**
Bike Uncharging											
Level of movement	3	3	3								
Physical exertion	2	2	2								
Duration of task (sec)/10	0.4	0.5	0.4								
Physical Workload	2.4	3	2.4								**7.8**
Battery Uncharging											
Level of movement	4	3	4	6	5	4	4	3			
Physical exertion	2	2	1	4	6	3	2	2			
Duration of task (sec)/10	0.2	0.2	0.2	3	1.5	0.1	2.3	2.5			
Physical Workload	1.6	1.2	0.8	72	45	2.4	18.4	15			**156.4**

Figure A3: PWVs for the original system

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Bike Charging											
Decision complexity	2	4	2								
Decision severity	3	4	3								
Decision Feedback	2	4	2								
Mental Workload	12	64	12								**88**
Battery Charging											
Decision complexity	3	3	3	3	4	2	1	3	1	1	
Decision severity	1	1	1	2	2	3	1	2	3	2	
Decision Feedback	3	4	2	6	2	2	1	4	4	3	
Mental Workload	9	12	6	36	16	12	1	24	12	6	**134**
Bike Uncharging											
Decision complexity	1	1	1								
Decision severity	1	3	2								
Decision Feedback	2	1	3								
Mental Workload	2	3	6								**11**
Battery Uncharging											
Decision complexity	1	1	1	1	4	3	4	4			
Decision severity	1	1	1	1	2	2	1	1			
Decision Feedback	1	1	1	1	3	1	3	4			
Mental Workload	1	1	1	1	24	6	12	16			**62**

Figure A4: MWVs for the 1st original system

Note: The yellow highlighted sections show where tasks have been eliminated due to the optimisation process.

1st Optimisation System PWV & MWV

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Bike Charging											
Level of movement		3	3								
Physical exertion		3	2								
Duration of task (sec)/10		0.5	0.4								
Physical Workload		4.5	2.4								**6.9**
Battery Charging											
Level of movement			2	2	4	6	6	2	2	3	
Physical exertion			2	2	4	6	4	1	1	2	
Duration of task (sec)/10			0.5	0.3	1.2	2	3	0.3	1	0.4	
Physical Workload			2	1.2	19.2	72	72	0.6	2	2.4	**171.4**
Bike Uncharging											
Level of movement		3	3								
Physical exertion		2	2								
Duration of task (sec)/10		0.5	0.4								
Physical Workload		3	2.4								**5.4**
Battery Uncharging											
Level of movement	4	3	4	6	5	4					
Physical exertion	2	2	1	4	6	3					
Duration of task (sec)/10	0.2	0.2	0.2	3	1.5	0.2					
Physical Workload	1.6	1.2	0.8	72	45	2.4					**123**

Figure A5: PWVs for the 1st optimised system

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Bike Charging											
Decision complexity		4	2								
Decision severity		4	3								
Decision Feedback		4	2								
Mental Workload		64	12								**76**
Battery Charging											
Decision complexity			3	3	4	2	1	3	1	1	
Decision severity			1	2	2	3	1	2	3	2	
Decision Feedback			2	6	2	2	1	4	4	3	
Mental Workload			6	36	16	12	1	24	12	6	**113**
Bike Uncharging											
Decision complexity		1	1								
Decision severity		3	2								
Decision Feedback		1	3								
Mental Workload		3	6								**9**
Battery Uncharging											
Decision complexity	1	1	1	1	4	3					
Decision severity	1	1	1	1	2	2					
Decision Feedback	1	1	1	1	3	1					
Mental Workload	1	1	1	1	24	6					**34**

Figure A6: MWVs for the 1st optimised system

2nd Optimisation System PWV & MWV

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Bike Charging											
Level of movement		3									
Physical exertion		3									
Duration of task (sec)/10		0.5									
Physical Workload		4.5									**4.5**
Battery Charging											
Level of movement			2	2	4	6	6	2			
Physical exertion			2	2	4	6	4	1			
Duration of task (sec)/10			0.5	0.3	1.2	2	3	0.3			
Physical Workload			2	1.2	19.2	72	72	0.6			**167**
Bike Uncharging											
Level of movement		3									
Physical exertion		2									
Duration of task (sec)/10		0.5									
Physical Workload		3									**3**
Battery Uncharging											
Level of movement			4	6	5	4					
Physical exertion			1	4	6	3					
Duration of task (sec)/10			0.2	3	1.5	0.2					
Physical Workload			0.8	72	45	2.4					**120.2**

Figure A7: PWVs for the 2nd optimised system

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Bike Charging											
Decision complexity		2									
Decision severity		4									
Decision Feedback		2									
Mental Workload		64									**16**
Battery Charging											
Decision complexity			3	3	4	2	1	3			
Decision severity			1	2	2	3	1	2			
Decision Feedback			2	6	2	2	1	4			
Mental Workload			6	36	16	12	1	24			**95**
Bike Uncharging											
Decision complexity		1									
Decision severity		3									
Decision Feedback		1									
Mental Workload		3									**3**
Battery Uncharging											
Decision complexity			1	1	4	3					
Decision severity			1	1	2	2					
Decision Feedback			1	1	3	1					
Mental Workload			1	1	24	6					**32**

Figure A8: MWVs for the 2nd optimised system

3rd Optimisation System PWV & MWV

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Bike Charging											
Level of movement		3									
Physical exertion		2									
Duration of task (sec)/10		0.5									
Physical Workload		3									**3**
Battery Charging											
Level of movement			2	2	6		6	2			
Physical exertion			2	2	5		4	1			
Duration of task (sec)/10			0.5	0.3	1.8		3	0.3			
Physical Workload			2	1.2	54		72	0.6			**129.8**
Bike Uncharging											
Level of movement		3									
Physical exertion		1									
Duration of task (sec)/10		0.5									
Physical Workload		3									**1.5**
Battery Uncharging											
Level of movement			4	6	5						
Physical exertion			1	4	4						
Duration of task (sec)/10			0.2	3	2						
Physical Workload			0.8	72	40						**112.8**

Figure A9: PWVs for the 3rd optimised system

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Bike Charging											
Decision complexity		4									
Decision severity		4									
Decision Feedback		4									
Mental Workload		64									**64**
Battery Charging											
Decision complexity			3	3	4		1	3			
Decision severity			1	2	2		1	2			
Decision Feedback			2	6	2		1	4			
Mental Workload			6	36	16		1	24			**83**
Bike Uncharging											
Decision complexity		1									
Decision severity		3									
Decision Feedback		1									
Mental Workload		3									**3**
Battery Uncharging											
Decision complexity			1	1	4						
Decision severity			1	1	3						
Decision Feedback			1	1	2						
Mental Workload			1	1	20						**22**

Figure A10: MWVs for the 3rd optimised system

Final Concept PWVs & MWV

Working Method: task	1	2	3	4	5	6	7	8	9	10	PWV
Bike Charging											
Level of movement	3										
Physical exertion	2										
Duration of task (sec)/10	0.3										
Physical Workload	3										**1.8**
Battery Charging											
Level of movement	3	3		6	2		6	2			
Physical exertion	2	2		4	4		3	1			
Duration of task (sec)/10	0.5	0.3		1	0.4		3	0.3			
Physical Workload	3	1.8		24	3.2		54	0.6			**86.6**
Bike Uncharging											
Level of movement	2										
Physical exertion	1										
Duration of task (sec)/10	0.5										
Physical Workload	1										**1**
Battery Uncharging											
Level of movement	2	6	2	3							
Physical exertion	1	3	4	3							
Duration of task (sec)/10	0.2	3	0.6	2							
Physical Workload	0.4	54	4.8	18							**77.2**

Figure A11: PWVs for the final concept

Working Method: task	1	2	3	4	5	6	7	8	9	10	MWV
Bike Charging											
Decision complexity	1										
Decision severity	4										
Decision Feedback	3										
Mental Workload	12										**12**
Battery Charging											
Decision complexity	3	3		3	1	3					
Decision severity	1	2		2	1	2					
Decision Feedback	2	2		2	1	2					
Mental Workload	6	12		12	1	12					**43**
Bike Uncharging											
Decision complexity	1										
Decision severity	3										
Decision Feedback	1										
Mental Workload	3										**3**
Battery Uncharging											
Decision complexity	1	1	4	2							
Decision severity	1	1	2	2							
Decision Feedback	1	1	2	1							
Mental Workload	1	1	16	4							**23**

Figure A12: MWVs for the final concept

APPENDIX D:

Ideation: Plug with cover PWV & MWV

Physical Workload			
Working Method: task	1	2	PWV
Idea 1			
Level of movement	3	3	
Physical exertion	3	4	
Duration of task (sec)/10	0.2	0.3	
Physical Workload	1.8	3.6	**5.4**
Idea 2			
Level of movement	3	3	
Physical exertion	3	4	
Duration of task (sec)/10	0.2	0.3	
Physical Workload	1.8	3.6	**5.4**
Idea 3			
Level of movement	3	3	
Physical exertion	2	4	
Duration of task (sec)/10	0.2	0.3	
Physical Workload	1.2	3.6	**4.8**
Idea 4			
Level of movement	2	3	
Physical exertion	2	4	
Duration of task (sec)/10	0.3	0.3	
Physical Workload	1.2	3.6	**4.8**
Idea 5			
Level of movement	4	3	
Physical exertion	3	4	
Duration of task (sec)/10	0.5	0.3	
Physical Workload	6	3.6	**9.6**
Idea 6			
Level of movement	3	3	
Physical exertion	3.5	4	
Duration of task (sec)/10	0.3	0.3	
Physical Workload	3.15	3.6	**6.75**
Idea 7			
Level of movement	2	3	
Physical exertion	2	4	
Duration of task (sec)/10	0.2	0.3	
Physical Workload	0.8	3.6	**4.4**

Mental Workload			
Working Method: task	1	2	MWV
Idea 1			
Decision complexity	3	3	
Decision severity	1	3	
Decision Feedback	2	3	
Mental Workload	6	27	**33**
Idea 2			
Decision complexity	3	3	
Decision severity	1	3	
Decision Feedback	2	3	
Mental Workload	6	27	**33**
Idea 3			
Decision complexity	2.5	3	
Decision severity	1	3	
Decision Feedback	2	3	
Mental Workload	5	27	**32**
Idea 4			
Decision complexity	4	3	
Decision severity	2	3	
Decision Feedback	2	3	
Mental Workload	16	27	**43**
Idea 5			
Decision complexity	4	3	
Decision severity	2	3	
Decision Feedback	3	3	
Mental Workload	24	27	**51**
Idea 6			
Decision complexity	4	3	
Decision severity	1	3	
Decision Feedback	2	3	
Mental Workload	8	27	**35**
Idea 7			
Decision complexity	3	3	
Decision severity	1	3	
Decision Feedback	1	3	
Mental Workload	3	27	**30**

Figure A13: PWVs and MWVs for the plug (with a cover) ideation

Ideation: Plug without cover PWV & MWV

Physical Workload			
Working Method: task	1	2	**PWV**
Idea 8			
Level of movement		2	
Physical exertion		2	
Duration of task (sec)/10		0.2	
Physical Workload		0.8	**0.8**
Idea 9			
Level of movement		3	
Physical exertion		3	
Duration of task (sec)/10		0.4	
Physical Workload		3.6	**3.6**
Idea 10			
Level of movement		3	
Physical exertion		3	
Duration of task (sec)/10		0.3	
Physical Workload		2.7	**2.7**
Idea 11			
Level of movement		3	
Physical exertion		2	
Duration of task (sec)/10		0.4	
Physical Workload		2.4	**2.4**
Idea 12			
Level of movement		3	
Physical exertion		3	
Duration of task (sec)/10		0.3	
Physical Workload		2.7	**2.7**

Mental Workload			
Working Method: task	1	2	**MWV**
Idea 8			
Decision complexity		2	
Decision severity		3	
Decision Feedback		2	
Mental Workload		12	**12**
Idea 9			
Decision complexity		3	
Decision severity		3	
Decision Feedback		2	
Mental Workload		18	**18**
Idea 10			
Decision complexity		3	
Decision severity		3	
Decision Feedback		2	
Mental Workload		18	**18**
Idea 11			
Decision complexity		4	
Decision severity		3	
Decision Feedback		2	
Mental Workload		24	**24**
Idea 12			
Decision complexity		3	
Decision severity		3	
Decision Feedback		3	
Mental Workload		27	**27**

Figure A14: PWVs and MWVs for the plug (without a cover) ideation

Ideation: Battery Integration PWV & MWV

Physical Workload

Working Method: task	1	2	3	4	PWV
Idea 1					
Level of movement	2	2	3	5	
Physical exertion	2	2	2	5	
Duration of task (sec)/10	0.5	0.3	0.3	0.5	
Physical Workload	2	1.2	1.8	12.5	**17.5**
Idea 2					
Level of movement	2	2	4	5	
Physical exertion	2	2	3	6	
Duration of task (sec)/10	0.5	0.3	0.2	0.5	
Physical Workload	2	1.2	2.4	15	**20.6**
Idea 3					
Level of movement	2	2	5	5	
Physical exertion	2	2	2	5	
Duration of task (sec)/10	0.5	0.3	0.2	0.5	
Physical Workload	2	1.2	2	12.5	**17.7**
Idea 4					
Level of movement	2	2	2	6	
Physical exertion	2	2	3	7	
Duration of task (sec)/10	0.5	0.3	0.3	0.5	
Physical Workload	2	1.2	1.8	21	**26**
Idea 5					
Level of movement	2	2	6	6	
Physical exertion	2	2	2	7	
Duration of task (sec)/10	0.5	0.3	0.3	0.5	
Physical Workload	2	1.2	3.6	21	**27.8**
Idea 6					
Level of movement	2	2	5		
Physical exertion	2	2	5		
Duration of task (sec)/10	0.5	0.3	0.5		
Physical Workload	2	1.2	12.5		**15.7**
Idea 7					
Level of movement		2	5		
Physical exertion		4	5		
Duration of task (sec)/10		1	0.5		
Physical Workload		8	12.5		**20.5**
Idea 8					
Level of movement	2	2	4	4	
Physical exertion	2	2	3	6	
Duration of task (sec)/10	0.5	0.3	0.3	0.5	
Physical Workload	2	1.2	3.6	12	**18.8**

Mental Workload

Working Method: task	1	2	3	4	MWV
Idea 1					
Decision complexity	3	3	2	2	
Decision severity	1	2	2	2	
Decision Feedback	2	6	2	3	
Mental Workload	6	36	8	12	**62**
Idea 2					
Decision complexity	3	3	3	4	
Decision severity	1	2	2	2	
Decision Feedback	2	6	3	2	
Mental Workload	6	36	18	16	**76**
Idea 3					
Decision complexity	3	3	2	3	
Decision severity	1	2	2	2	
Decision Feedback	2	6	2	2	
Mental Workload	6	36	8	12	**62**
Idea 4					
Decision complexity	3	3	4	2	
Decision severity	1	2	2	2	
Decision Feedback	2	6	3	2	
Mental Workload	6	36	24	8	**74**
Idea 5					
Decision complexity	3	3	3	3	
Decision severity	1	2	2	2	
Decision Feedback	2	6	2	3	
Mental Workload	6	36	12	18	**72**
Idea 6					
Decision complexity	3	3	3		
Decision severity	1	2	2		
Decision Feedback	2	3	2		
Mental Workload	6	18	12		**36**
Idea 7					
Decision complexity		3	3		
Decision severity		2	2		
Decision Feedback		3	3		
Mental Workload		18	18		**36**
Idea 8					
Decision complexity	3	3	2	3	
Decision severity	1	2	2	2	
Decision Feedback	2	5	2	2	
Mental Workload	6	30	8	12	**56**

Figure A15a: PWVs and MWVs for the battery integration ideation

Physical Workload

Working Method: task	1	2	3	4	PWV
Idea 9					
Level of movement	2	2	4	4	
Physical exertion	2	2	4	5	
Duration of task (sec)/10	0.5	0.3	0.4	0.4	
Physical Workload	2	1.2	6.4	8	**17.6**
Idea 10					
Level of movement	2	2	4	4	
Physical exertion	2	2	4	5	
Duration of task (sec)/10	0.5	0.3	0.4	0.6	
Physical Workload	2	1.2	6.4	12	**21.6**

Mental Workload

Working Method: task	1	2	3	4	MWV
Idea 9					
Decision complexity	3	3	2	3	
Decision severity	1	2	2	2	
Decision Feedback	2	3	2	3	
Mental Workload	6	18	8	18	**50**
Idea 10					
Decision complexity	3	3	3	2	
Decision severity	1	2	2	2	
Decision Feedback	2	6	3	2	
Mental Workload	6	36	18	8	**68**

Figure A15b: PWVs and MWVs for the battery integration ideation

APPENDIX E:

Battery removal types for some of Giant's Ebikes and their competitors.

Figure A16: Digital displays mood board

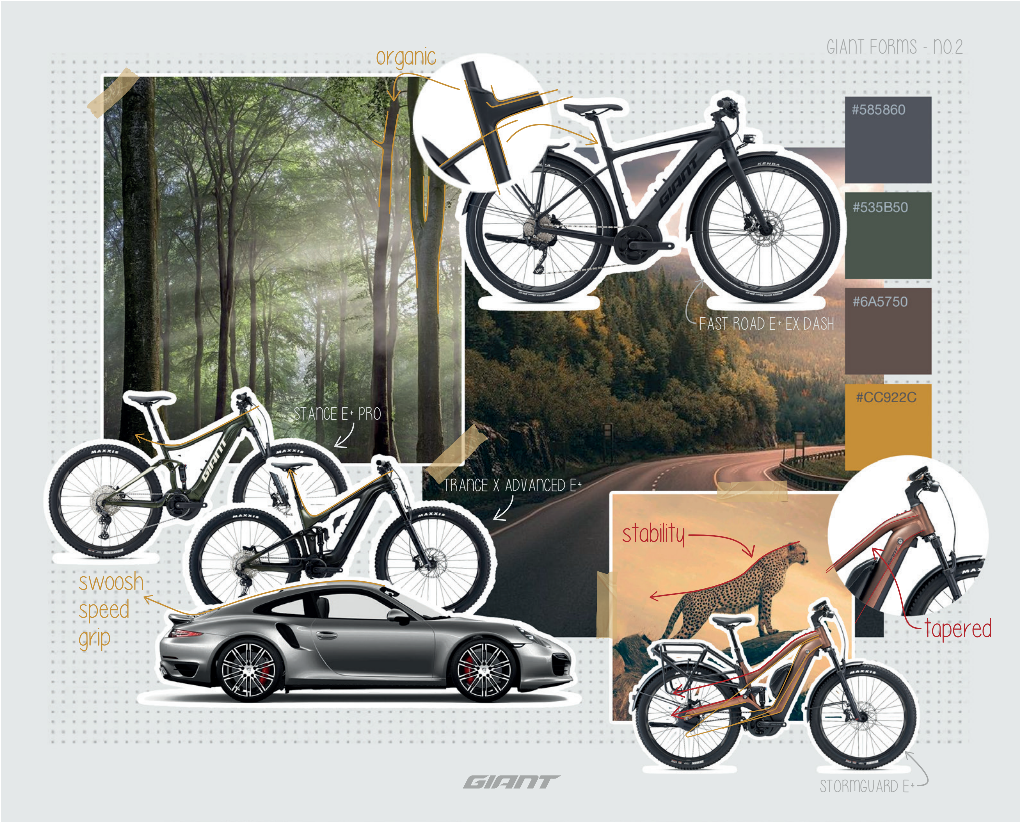

Figure A17: Giant forms N0.2 mood board

Figure A18: Momentum forms N0.1 mood board

APPENDIX F:

Below shows some of the different screens which would be displayed on the Hub and Hub+. The Go charger would display similar information, but with a slightly different layout.

Connecting the Hub to the bike or battery:

During this display the user is directed to 'connect the plug to the bike or battery'. As soon as the plug is connected a loading bar would show for 3 seconds followed by a confirmation screen. If charging begins immediately a small animation will show that the bike is being charged before going to the home screen with an overview of the charging information.

Figure A19: Digital displays mood board

Charging Issue:

If there is a charging issue, a screen will display on the charger informing the user to go to the app or display on their Ebike. Here a full diagnostic will be run from the charger to diagnose why the battery is not charging, depending on the problem the charger and device used will identify it to the user.

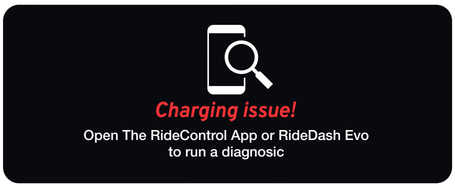

Figure A20: Charging issue displayed on the Hub

Just finished a ride:

If the user wants to charge their bike straight after a ride, a warning message on the Hub charger will show. This will delay charging to allow the cells to balance. A count down will be displayed on the screen so the user knows when charging will begin.

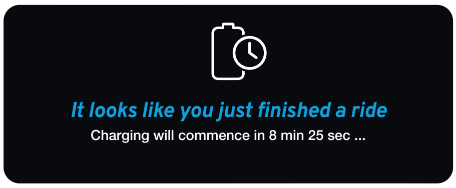

Figure A22: Delay charging just after a ride, displayed on the Hub

Battery Temperature:

Based on the information from the BMS, the charger will delay charging if the battery is too warm or cold to prevent damage to the battery cells. Once the battery has reached a temperature just below 40°C or just above 0°C the display will go green with a 10 second count down until charging will begin.

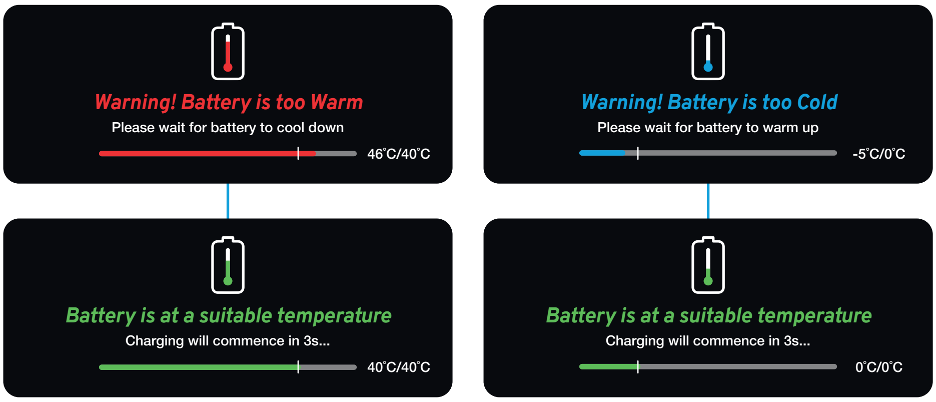

Figure A21: Temperature warning displayed on the Hub

Phone notifications:

If the user has their phone notifications enabled, they will receive notifications to remind them to charge their battery and give them the option to override charging if they need to charge their battery as soon as possible. These notifications will also be used to educate the user in looking after their battery, see research conducted in section 4.3.

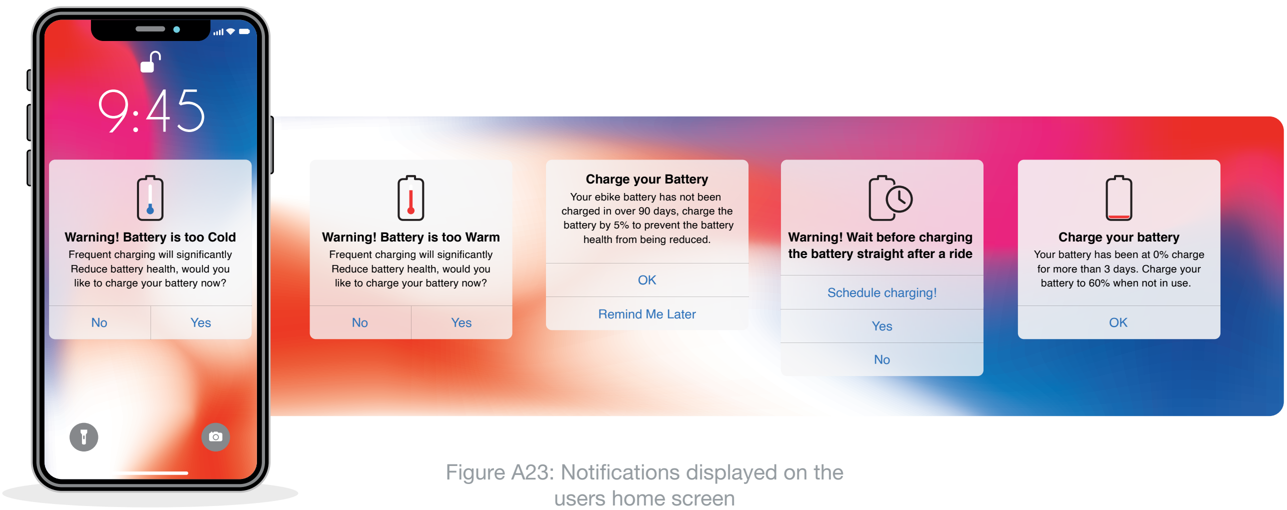

Figure A23: Notifications displayed on the users home screen

APPENDIX G:

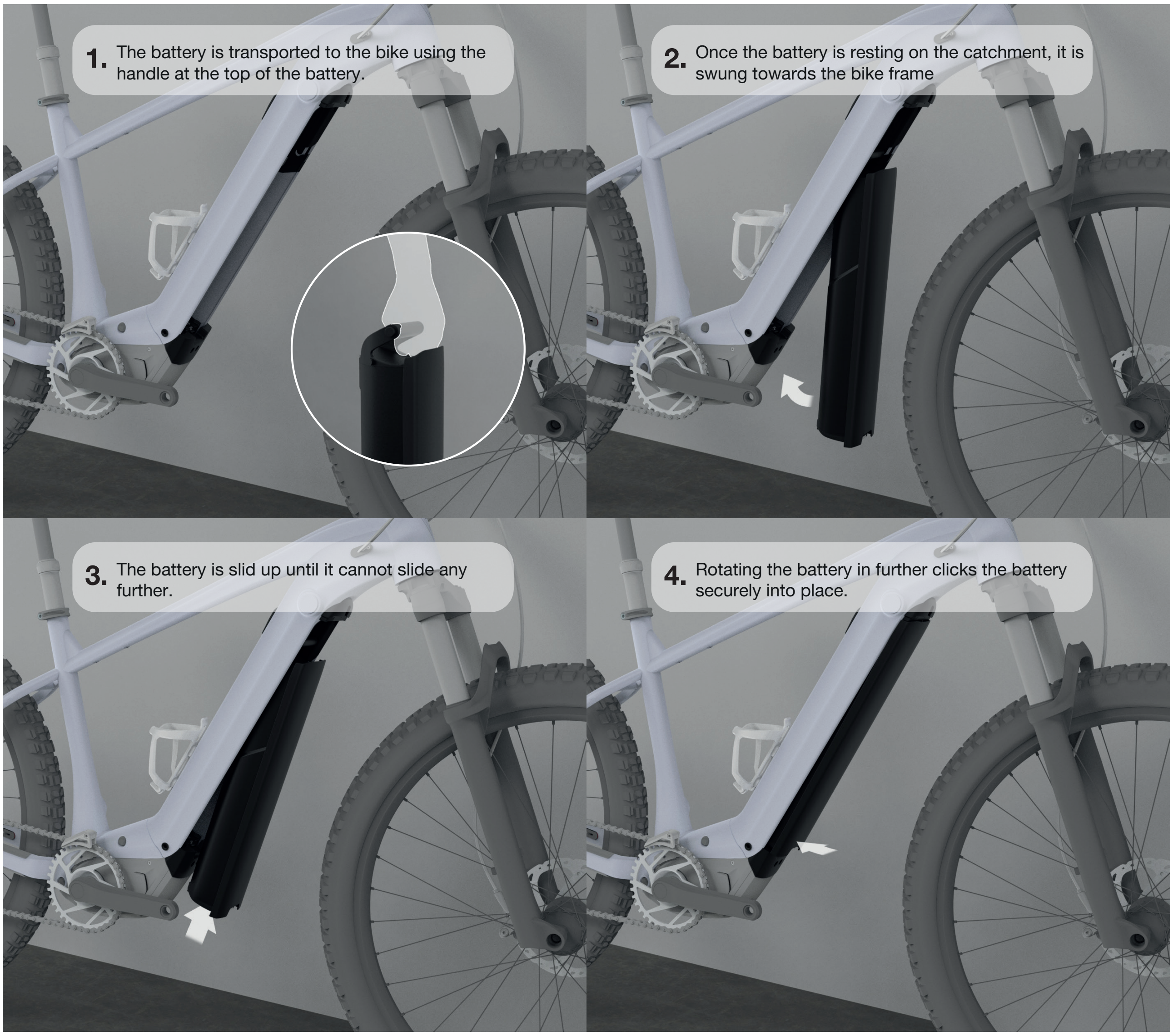

Figure A24: Battery insertion procedure