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DE3 Design Engineering Futures, Interim Report

Maintaining Safety and Security in a Future of Widespread Publicly Swappable Batteries for Personal Electric Vehicles

Abstract

This report examines the future of batteries for electric vehicles (EVs), based on a 20 year projection from 2022. London will serve as the location for the concept's introduction, with the city showing high potential for intervention after pledges to accelerate the city's transition to zero-emission transport solutions were published[1] by the Mayor of London.

An initial STEEP analysis was conducted to identify key signals, drivers and their corresponding trends, leading to formulation of a future scenario where standardised and high efficiency swappable EV batteries are entering circulation, whilst users have shifted towards a reduction in permanent ownership, and instead are increasingly reliant on shared infrastructural services to access goods. Given that batteries are the sole component responsible for the high entry costs to EVs, it can be predicted that EVs will be sold without them in 20 years' time, with swappable batteries instead being delivered through PSS-style schemes.

After comprehensive examination of this 2042 scenario and reviewing relevant technological enablers within the prospective scope, three distinct concepts were ideated, targeting associated challenges with a focus on safety and security. These three concepts were evaluated using extensive validation methods, with the final design selected based on satisfaction of predefined user objectives. The final concept involves a Blockchain-hosted subsystem within an existing physical network of swappable batteries, digitally verifying temporary ownership of each EV battery whilst facilitating a highly secure transaction with the new owner. With the efficiency of batteries is expected to deteriorate over time, on-board IoT technology will assess performance and calculate their real-time market value in preparation for new transactions.

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1 Introduction

With the annual demand for electric vehicles hitting a record increase of 119.2% in 2021 [2], we are seeing a rapid emergence of electric vehicles replacing internal combustion engine (ICE) vehicles for personal transportation further driven by government lead net-zero goals and a growing environmental social conscience. Consequently, we are seeing excess demand for electrical power. Computer models predict a 25% increase in peak net electricity demand for 50% electric vehicle ownership in the US [3]. With current technologies, the average total monthly EV charging time is 61 hours, significantly more than the 30-minute refuel time of ICE vehicles [4]. As new demand for electric vehicles exceeds the supply of supporting infrastructure, detrimental consequences will become prevalent, forcing rapid technological innovation. This report aims to predict the future of EV support infrastructure while uncovering and addressing the social, economic, political, and environmental problems that will arise with such innovation.

2 Future Contextual Study

2.1 Foresight Practice

To define our future scenario, a futures wheel (Figure 1) was produced alongside a STEEP wheel (Figure 2). Trends were categorised and mapped to aid the prediction of corresponding consequences for various scenarios within the future of electric vehicle infrastructure. Grey fields, in Figure 1, show future scenarios that were rejected prior to project definition.

2.1.1 Social Trends

Over a short time span, we are seeing a strong increasing trend of consumers starting to prioritize convenience when making purchasing decisions. In 2021, Forbes documented that 70% of people would be willing to pay more for a service that includes an element of convenience [5]. Furthermore, when reporting on industry trends, Bringg [6] have projected food-delivery sales to grow to 40% of total restaurant sales as users continue to prioritize convenience over even taste. The fact that this trend is seen across a wide range of industries suggests it will be a strong driver for our future scenario. Also dictating our future scenario is the strong increasing trend towards a sharing economy, which is based on the principle of sharing or renting assets. IBM reported that 57% of consumers were willing to change their shopping habits to reduce environmental impact while this business practice invites environmental benefit with long-term cost efficiency [7]. Similarly, we are seeing a very strong drive from ownership to 'usership', where a recent survey from The Harris Group [8] found that 57% of people would prefer to own less stuff and this is further evidenced by the rapid emergence of subscription services across countless industries from bikes to office space. In addition, consumers are becoming ever more technology proficient. The Future Shopper Report, published in 2021, stated that we are seeing a "more technology-literate shopper base," which is spending more time online than ever". With this, however, we are also seeing an increasing trend in criminal technological proficiency. Amongst other reports, in 2022, 31 arrests were made following the development of malicious software targeting key-less vehicles [9].

2.1.2 Technological Trends

We are seeing a strong trend suggesting the increase in modularity across many fields in technology [10] as evidenced by the emergence of Computer-on-Modules driving Single Board Computer technology, modular hardware design ideology in robotics, modular software and web development, and most importantly batteries. The Modular Uninterrupted Battery Supplies (UBS) market share is predicted to grow by USD 2.11 billion from 2021 to 2026 [11] and it can be confidently stated this technology will be widespread in 2042. Uninterrupted modular batteries are energy efficient and less resource intensive as only the drained cells of a battery need to be replaced. They have become conventional in many industries, such as intricate and important medical

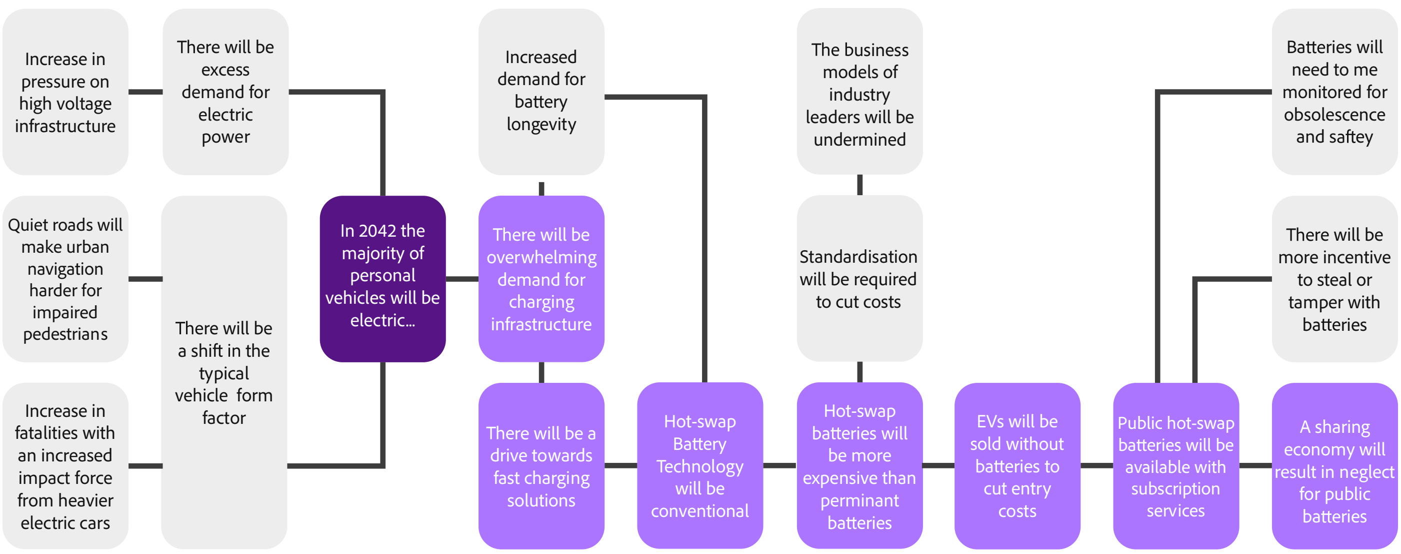

Figure 1: Futures Wheel highlighting implications based on EV adoption

instruments [12] and there are emerging applications for electric vehicles. Swappable battery technology is advancing and leading manufacturers, NIO, have already completed more than 2 million electric vehicle battery swaps in China and are planning to open 5,000 stations globally by 2025 [13] with a trend of this strength, it can be predicted that battery swapping technology will surpass alternative EV fast-charging solutions. We have also seen the emergence of, Blockchain driven, Non-Fungible Tokens that were declared the biggest investment trend of 2021 [14]. Blockchain technology is becoming increasingly more accessible. Microsoft have recently partnered with ConsenSys to provide Blockchain as a service (BaaS) to large tech companies [15], enabling access to Blockchain which was previously economically unviable.

2.1.3 Environmental Trends

With a rapid increase in electric vehicle use, we are seeing a gradual increase in strain on electric power grids and, consequently, renewable energy resources are becoming overwhelmed [16]. This trend will likely force consumers to alter their charging habits. A study from the U.S. Department of Energy highlighted that increased electrification across various technological sectors, including EV usage, could boost national consumption by as much as 38% [17] and as a result, we are seeing a shift to a more energy and resource efficient battery design. This is particularly prevalent as, at the current rate of consumption, environmental scientists predict that China alone will generate 500,000 metric tons of used Li-ion batteries with only 2–3% being collected and sent offshore for recycling [18]. Innovation in EV battery design is also being driven by the current damaging effect resource collection has on the environment. This is particularity evident in the soil degradation, water shortages, biodiversity loss and damage to ecosystem functions seen in South America's Lithium Fields [19]. The increasingly detrimental environmental impact of resource intensive batteries is a strong trend driving our future scenario.

2.1.4 Economic Trends

Data collected in March 2022 by Morning Consult [20] indicated that consumers are prioritising service spending as elevated inflation drives up the cost of living. As inflation rises faster than incomes, household budgets are pinched, and we are seeing a rapid decline of consumer discretionary spending. This, however, is a short term signal that may not operate over the full 40 years prior to our future scenario. Furthermore, 2019 sales figures indicated that consumers are especially sensitive to the entry costs of EVs and this was backed up by a significant decline in Chinese EV sales following a cut in government subsidies [21].

2.1.5 Political Trends

Standardisation is a principal that has been pushed across all technological sectors, for instance technology companies often collaborate to produce multi-platform products [22]. Government enforced standardisation is a strong recent trend driving our future scenario. For instance, EU Parliaments and Councils have enforced that, by autumn 2024, USB Type-C will become the common charging port for all mobile phones, tablets, and cameras [23]. Our future scenario relies on leading manufactures complying with such standardisation. This compliance will be more desirable now that governments are beginning to decrease R&D tax benefits and firms will no longer be able to currently deduct their R&D expenses [24].

3 Project Definition

3.1 Future Scenario

In 2042, it is predicted that batteries will be made more energy and resource efficient by modularity

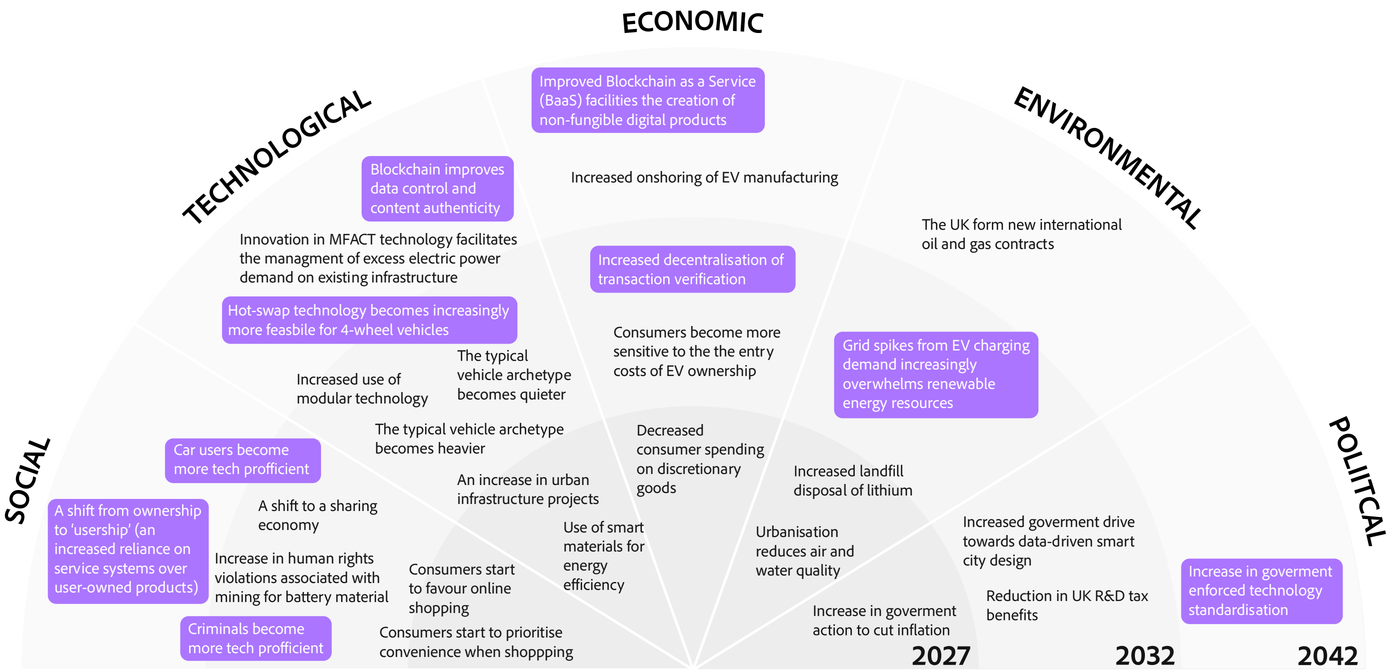

Figure 2: STEEP Wheel showing transport trends, whilst identifying those with a common theme

and standardisation. Consequently, the emergence of swappable batteries for personal electric cars is highly likely to surpass alternative fast charging solutions, due to their shorter swap times and ability to flatten spikes in power demand. As consumers are becoming more sensitive to the entry costs of personal electric vehicles whilst spending less on discretionary goods and shifting away from ownership, it can be predicted that electric vehicles will be sold without batteries, with swappable batteries provided separately through PSS schemes. However, without physical ownership and a rise in criminal technological proficiency, misconduct, associated with the battery service, is expected. This could include negligence, tampering and stealing.

3.2 Problem Definition

As an established system of rapidly swappable EV batteries is envisaged, consumers will benefit from instant access to fully charged battery modules without the constraints of permanent physical ownership.

A transition towards such a system, however, will only be feasible with secure and seamless management of this charging infrastructure, where the safety and security of individual batteries must also be closely monitored. Detailed analysis of this future scenario and its associated trends helped us to identify a number of inevitable issues for which our design opportunity will aim to target, explored in the following subsections.

3.2.1 User Safety and Misconduct

Given that the battery pack is the most valuable component of an EV [25], the potential for theft, tampering and general misuse is a particularly high concern in a society where cyber criminals are implementing increasingly sophisticated techniques in order to gain access to public infrastructure, such as IoT hacking and credential harvesting in order to gain access to public infrastructure. Due to reduced responsibility attached to temporary ownership we would see a greater amount of misuse, preventing users from trusting and using the system, presenting an opportunity for intervention.

3.2.2 Battery Health and Maintenance

With large quantities electric batteries being circulated around the swap system, degradation is expected to significantly affect their performance in the long-term, yet users will expect sufficient battery quality after each new 'swap'. Despite the improved battery performance characteristics that will have likely emerged by 2042, it is important to consider how these metrics may be tracked in order to determine their monetary value, permit servicing or diagnostic checks, and maintain the overall quality of the battery network.

3.2.3 Transaction Verification

Each time a battery is transferred or 'swapped' by a user, a formal transaction will need to be processed by the system, where each user's identity must be verified. However, with the growing risk of identity fraud, service providers must find an efficient yet highly secure method of proving a legitimate battery transaction has taken place. As a result, all parties involved should be protected, whilst a live database of previous users (temporary owners) is recorded.

3.3 Design Engineering Opportunity

Taking the identified obstacles into consideration, within the context of the future scenario detailed in section 3.1, the following opportunity statement was formulated:
"How might we incentivise users to responsibly partake in a swappable EV battery system whilst ensuring secure swapping transactions in order to prevent misconduct, tampering and theft of EV batteries?"

4 Design Definition

4.1 Tech Enablers

Key technologies were identified in order to create a secure and safe system. To maintain secure transaction verification and user trust, a robust encryption network will be required. Uniqueness and identification are two critical elements of this system, as such the introduction of new web infrastructure, such as Web 3.0 will be crucial. The system is also reliant on the introduction and widespread adoption of hot-swap batteries. These technologies were assessed further to analyse the technical feasibility of our problem.

4.1.1 Hot-swap EV Batteries

Several companies such as NIO and Ample have begun developing and rolling out swapping stations; with NIO already having approximately 1000 stations across China and Europe [26], offering a process that takes three minutes to swap a battery. Similarly, Ample's solution takes ten minutes [27], which indicates that the battery swapping process will be quick and easy for customers, which increases the likelihood of widespread adoption once mass scale is achieved.

Hot-swap battery technology promises a reliable long term life cycle for each battery due to less intensive usage. For example, stockpiled batteries inside swap stations can be maintained at 20 - 80 % charge [28], thus increasing their lifespan. This, coupled with increased longevity due to improved battery management systems [29], will result in significantly more swaps being possible per battery.

In order to achieve the mass adoption of this technology by 2042, a significant area for development lies in standardisation of battery technology. Battery connectors must be consistent across brands, as well as ensuring that module shapes and sizes are interchangeable. There are signals that car manufactures are shifting to a more open-source approach, with Tesla opening their proprietary charge connector for other manufactures to use for their own vehicles [30]. To further this, policy makers will be required to intervene: EUROBAT, a European battery standards initiative, are developing a set of battery standards and regulations for the automotive industry [31]. This will result in a similar position as today, with current ICE vehicles all running on the same type of fuel.

As adoption of this technology increases over the next twenty years, hot-swap infrastructure will grow to meet demand. Ample claims that their swap stations are cheaper to build than charging stations, which confirms the financial viability of this change. Therefore, due to the convenience and sustainability benefits alongside already validated technology of hot-swap batteries, we can confidently assume that this method of charging will be the norm in 2042.

4.1.2 Web-Driven Technology
The introduction of Web 3.0 will see a transition from an internet era being controlled by "Big Tech" [32] to a focus on decentralisation, Blockchain and token-based economics [33]. This will provide increased security, scalability, and privacy to users.

The use of Digital Twins is growing rapidly and they have already been trialled in the automotive industry [34], in order to evaluate driving patterns. Through the improvement of product modelling, physical sensing, and high-speed data transfer, the adoption of digital twins will increase from major systems to sub-systems such as individual batteries. This will create a wealth of opportunities such as real-time data visualisation by drivers which can be used to provide information, as well as monitoring capabilities to identify and address a potential fault [35].

Distributed ledger technology (DLT), more specifically Blockchain, provides a set of decentralised and synchronised data presented as a list of records [36]. This creates a chain and provides complete traceability of a battery. Therefore, the use of this secure transaction tracking system could ensure that security and trust is maintained with every battery swap.

Some Web 3.0 technologies are already prevalent today, with DLTs successfully being used in cryptocurrency [37] and NFTs. It can be assumed that as the technology matures, adoption will spread to other industries that require security and data visibility. Therefore, we can assume that it is likely this will be a likely enabler for systems in 2042.

4.2 Initial Product Service System
In order to specify the scope for the project, a high-level diagram was first produced to broadly represent the system as a whole. This is shown in Figure 3. In doing so, various aspects associated with the implementation of the system were considered. However, system logistics, manufacturing and distribution, scalability and end-of-life were not considered in the scope of this project.

As batteries cycle from being charged to being swapped to being discharged and to being swapped again, there are two key direct interactions with users. This would form our primary focus for the project. In particular, how ownership of the physical assets will be verified and transactions between users be made secure and trustworthy.

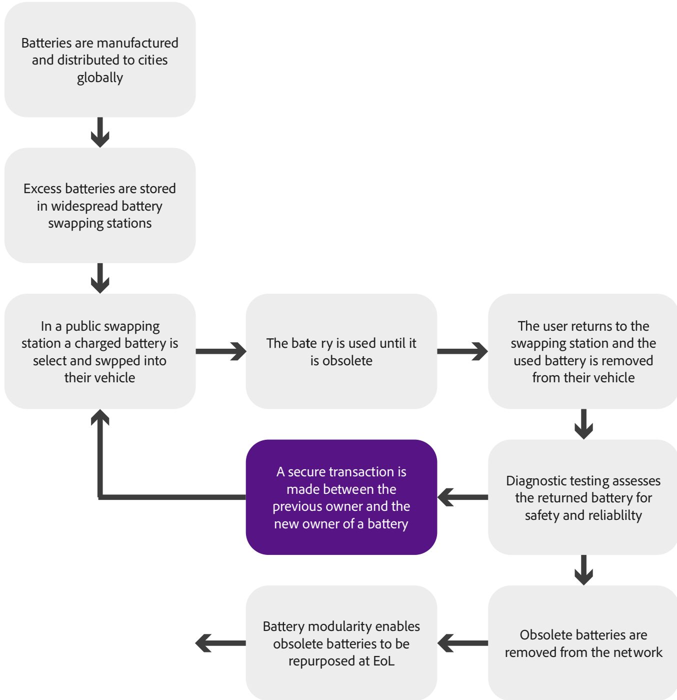

Figure 3: High level system diagram of hot-swap battery PSS

4.3 Design Specification
To further define and validate the project definition, key user needs and objectives, within the domain of EV charging and cyber-physical systems, were considered and evaluated using a pairwise comparison matrix shown in Table 1. Primary data collected from surveys and interviews with EV vehicle users [38] was used to aid the prediction of consumer needs of the future.

Table 1: Pairwise Comparison of User Objectives

Needs		A	B	C	D	E	F	G	Score	Weight
Reduced Cost	A		B	C	A	E	F	G	1	0.05
Reduced Ownership	B			C	B	E	B	B	4	0.2
Safety	C				C	E	C	C	5	0.24
Intuition	D					E	D	G	1	0.05
Security	E						E	E	6	0.29
Trust	F							G	1	0.05
Automation	G								3	0.14

This analysis highlighted that the key needs and objectives of EV vehicle users of the future are: Reduced ownership, safety, and security. These findings were taken forward into the design definition.

4.4 Design Statement

Following broad analysis of the problem, the following design definition was formulated: to create a subsystem within a network of swappable batteries for personal EVs. This subsystem aims to digitally verify temporary ownership of the physical battery while ensuring security when making a transaction with a new owner. The solution will need to ensure a battery is safe and reliable for a user with an intuitive, trustworthy, and data-driven solution that provides a seamless and insightful UX, allowing more informed driving decisions to be made.

5 Concept Discovery

5.1 Diagnostic smart docking system

This concept would oversee the secure docking and removal of hot-swap batteries from a docking station, where each station is capable of running rapid diagnostic tests on the battery. To remove a battery from a dock, the user must scan a membership card. This would permanently tie a battery to a user, meaning that the battery cannot be returned without being rescanned. A second software-enabled authentication step then verifies the user's identity, before unlocking a new battery for swapping. By incorporating an advanced IoT system, a record of the battery health is kept alongside a record of previous users, while also enabling live tracking of the battery's location. Integrated tamper detection sensors are designed to deter users from interfering with individual battery packs. This concept is demonstrated in Figure 4.

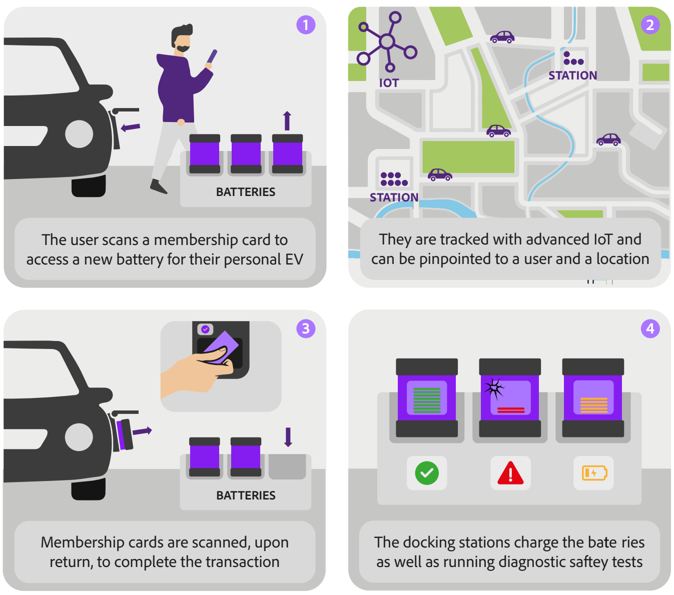

Figure 4: User journey of Concept 1

5.2 Battery-vehicle locking system

A proprietary physical and digital locking mechanism ensures that batteries remain difficult to steal. This concept makes use of Digital Twin technology and flags a stolen battery's location. This, coupled with an advanced, location based physical lock, ensures that batteries can only be swapped at designated swapping stations. The use of a proprietary physical connector to the battery, renders it unusable for other purposes outside of EVs. Combined, this provides an increased level of security for the user. This concept is demonstrated in Figure 5.

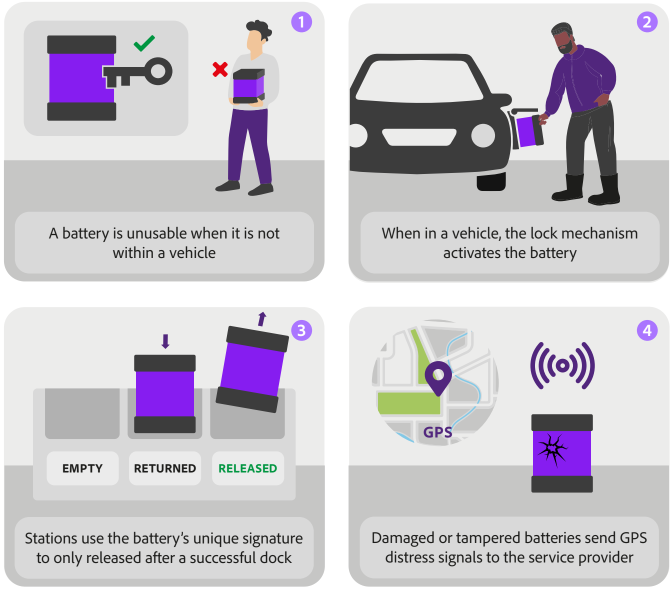

Figure 5: User journey of Concept 2

5.3 NFT EV Batteries

Through a cyberphysical unique identifier every battery will be linked to a non-fungible digital token, often referred to as a battery passport [39]. Ownership of such token and the corresponding physical battery will be verified with Blockchain driven technology. Consequently, smart contracts can verify transactions between users through use of a battery swap station. The value of the digital asset is calculated using battery metrics and is made available to the user. Consequently users are made conscious of how their driving behaviour affects the physical battery. This concept is demonstrated in Figure 6.

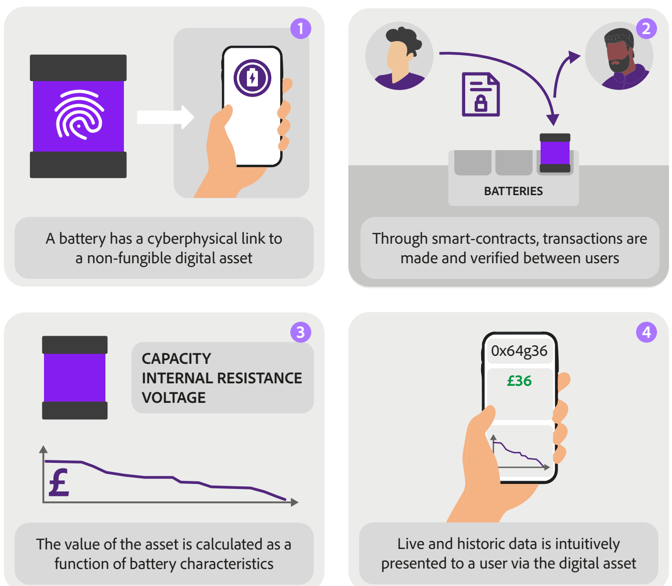

Figure 6: User journey of Concept 3

5.4 Concept Evaluation

Figure 7 evaluates the concepts against our system requirements. Concept 3 scored higher than the other concepts overall and as a result it was selected for further development. This would focus on refining the system's technical elements and user interaction.

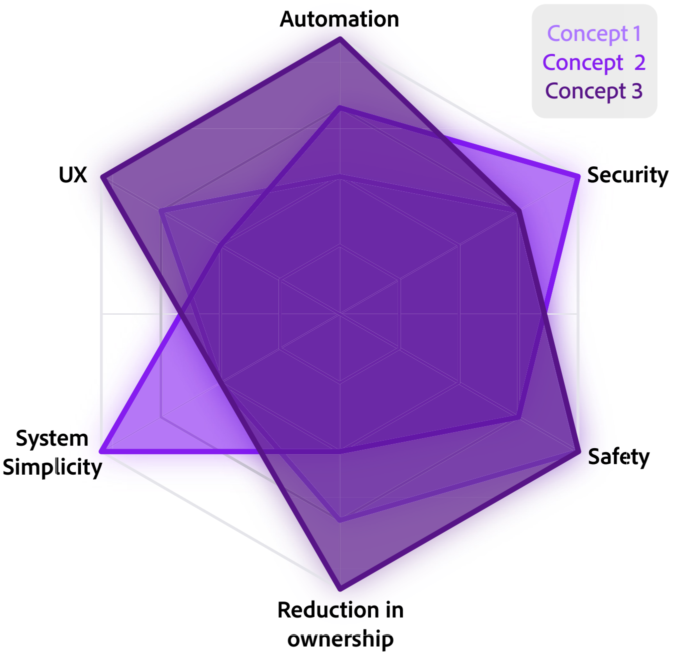

Figure 7: Radar comparison of initial concepts

6 Concept Development

6.1 Feature Specification

For the proposed concept, Table 2 details a number of design features that were produced based on the top objectives defined in the pairwise comparison, with each feature allocated two scores based on their relative importance (C) and certainty (K). After combining the respective scores for each feature, they were ranked and evaluated, with the top four highest scoring features being selected to lead further concept development.

6.1.1 Transaction verification

To ensure that each individual EV battery transaction can be verified across the Blockchain, the concept must be able to confirm a user's identity. To do so, the concept will utilise smart contracts. These are programs stored on the Blockchain, which automatically execute when predetermined conditions are met, in this case, the user's identity serves as the criteria for execution.

A zero-knowledge proof (ZKP) algorithm works by a prover showcasing to a verifier that they have an identifying piece of data without disclosing the data on-chain itself. For instance, a prover might be holding an asymmetric key pair and using the identifying data as a private key to respond to the statement sent with the public key [40].

In the instance of individual battery transactions,

Table 2: Assumption Mapping Against Key Concept Features

Feature Specification	K	C	Explanation
Link digital twin to physical asset	4	5	A core element of this concept relies on a secure, unreproducible marker, which allows each physical battery to be linked to its Digital Twin. There are a range of methods being investigated, so further analysis is required to determine the optimal solution.
Transaction verification between previous and new owner	4	5	The battery swap process will require secure transactions to protect users against fraudulent activity, therefore a robust method of verification must be researched before the concept can be confidently validated.
Display battery performance information to the user.	4	4	By including users in the concept's technology at a high level and providing transparency in the health state of each battery, they will be more comfortable using the system, so a means of gaining their trust is essential.
Battery performance assessment	3	4	A high level of accuracy will be required to ensure that the performance index value(s) can be reliably calculated, in addition to the monitoring of degradation state for EoL procedures.
Scalability of the system	3	3	Although the concept will target the swap system from a unique perspective, the recent surge in Blockchain implementation suggests that the concept is feasible to achieve on a high scale within its associated future scenario.
Battery swapping	1	5	Despite the proposed subsystem being designed on the basis of a hot-swap system already existing, the success of current implementations such as NIO's, where over 4 million swaps have already taken place globally [13], indicate that the systems will be mass rolled out across cities in years to come.
Regulations to guarantee safety	2	3	The UK government has already announced pledges [1] to support mass transition to EVs, as a result we will likely see strict policies put in place to protect consumers, and ensure manufacturers are complying with safety procedures.
Prevention of stockpiling of batteries	3	1	Users will be permitted to access only one battery for each electric vehicle that they own at any given time, hence the system should feasibly deter the possibility of stockpiling and maintain a fair battery distribution amongst all users.
Battery Embodiment	1	3	As new EV manufacturing standards are introduced, the overall form and size of battery packs may change to support optimisation of the swapping procedure, however as we are relying on car manufacturers to produce batteries, its physical embodiment is not crucial.

the Blockchain service provider will fulfil zero knowledge-powered smart contracts, where an authentication process is used to verify each party's identity and thus prove ownership – the ZKP is generated with user input data and revealed to the smart contract program, which results in the battery swap transaction. A transaction commission fee is collected for the ZKP to be processed on the Blockchain. This is how the service provider will gain value from the proposed system.

Recent developments in ZKP applications indicate that ZKP programmability can be accessed from other blockchains and ultimately even end user devices such as smartphones, such that the service provider can securely interact with their customers at the tap of a button. Figure 8 demonstrates how the zero-knowledge proof would play a role in facilitating a safe and secure battery swap transaction.

To verify that this technology will be feasible, a works-like prototype will be programmed in phase 2 to mimic transaction verification digitally between two users. Existing development tools, such as Blockchain APIs, will create a secure but basic network of transactions. As such, the system can be simulated to a test group of individuals. If the test users determine the system to be trustworthy and secure we can validate this process on a small-scale, providing sufficient evidence for this technology to be widely implemented in 2042.

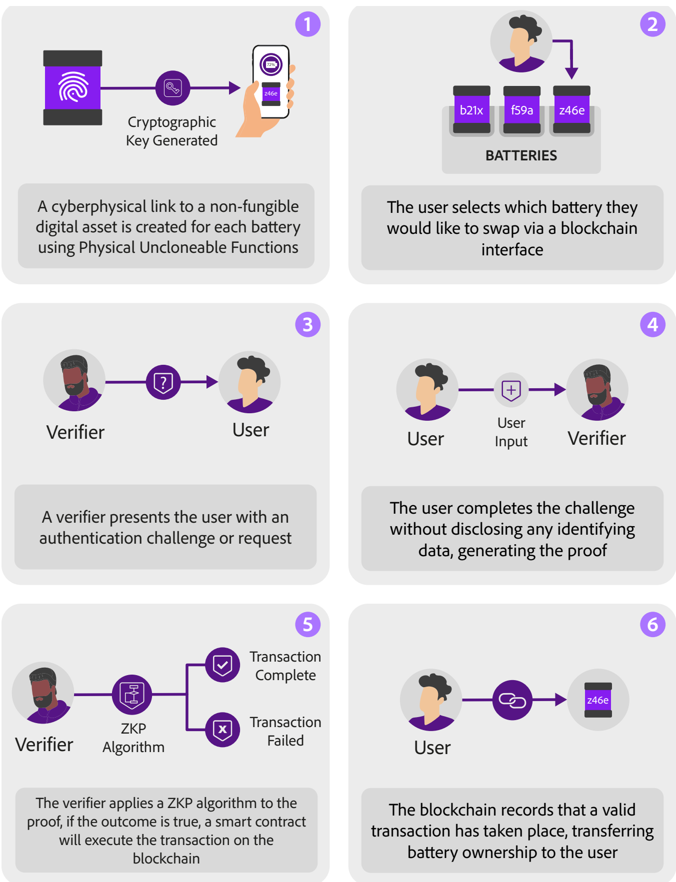

Figure 8: User Journey of Transaction Verification

6.1.2 Cyberphysical Link

In order to introduce the EV batteries into the Blockchain, they must be protected and monitored using Physical Unclonable Functions (PUFs) [41] which create a secure link between a battery and it's Digital Twin. PUFs depend on the uniqueness of their physical microstructure which depends on random physical factors introduced during manufacturing. These factors are unpredictable but controllable, which makes it almost impossible to duplicate. However, all PUFs are subject to environmental variations such as temperature, supply voltage or electromagnetic interference, which can affect their performance. Different types of PUFs were explored to establish which one would most adequately fit our requirements, as shown in Table 3.

Research published in Nature Communications [42] explores the idea of using silk as a lens-free optical PUF as it offers high entropy, an exponential number of Challenge-Response-Pairs and high security against cloning due to a difficult reverse-engineering process. The researchers introduced a system which is based on stochastically manifested diffraction using silk fibres. A light is shone through the fibres which results in a unique image appearing, creating the cyberphysical link. This method is not only extremely secure but also low-cost, eco-friendly and does not require pre-/post-processing for PUF-tag creation. Therefore, it was decided that optical PUFs will be embedded into battery casing in our final concept.

To embody this in a lo-fi format, a prototype will be developed to test a unique unclonable battery identifier. Through rapid prototyping techniques such as 3D printing and laser cutting, a section of the battery casing will be produced. Due to the expensive accurate manufacturing techniques needed to implement an optical PUF, a looks-like model, using a piece of silk and an LED, will be used to demonstrate how the technology would work. Furthermore, a works-like model will be produced through CAD visualisation and animations, to more clearly convey the intended functionality. This will allow us to assess the user interaction and affordances associated with the technology, in order to assess to the viability and implications for full functionality by 2042.

Table 3: Comparison of different PUFs

Metrics	Bio PUF	Optical PUF	DRAM PUF
PUF Strength	Strong	Strong	Weak
Cost	Low	High	High
Volatile	No	No	Yes
Reverse Engineering	Very Difficult	Very Difficult	Possible
Energy Consumption	Low	Low	High

6.1.3 Visualising Battery Information

Through the use of a Digital Twin, battery passport information [43] will be passed to the user, to enable greater understanding of battery origin, performance and value, which aims to passively ensure greater compliance and care towards batteries, resulting in a more sustainable system.

Through a survey conducted to understand EV driver preferences [38], it was concluded that this information will be relayed through a mobile app. Drivers will also have access to key driving insights such as: predicted distance remaining based on driving habits. This will be displayed predominantly in the form of graphs, with numerical values also available to provide greater detail. Figure 9 shows a mock-up of how this information will be presented. In-line with user preferences, drivers will also be alerted if battery sensors detect misuse, in order to encourage improving driving habits.

Due to vast amounts of information being shared, privacy is a key concern. To address this, information available to future users of that battery will be anonymised and aggregated. Live location tracking will also only be visible for the current owner of the battery.

We plan to create a looks-like mobile app prototype to mimic battery information visualisation for users. The prototype will be created in Figma, and the entire UX will be mapped out. Following this, a web-app will be produced, using JavaScript and Firebase to manage battery data. If test individuals conclude that the displayed data is sufficiently private, intuitive and would actively alter their driving habits, full implementation of a digital battery mobile app in 2042 will be validated.

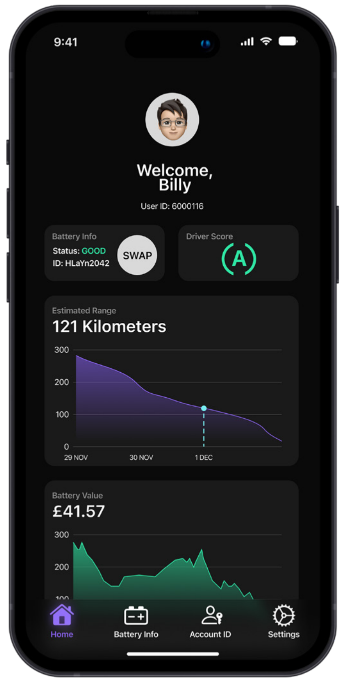

Figure 9: Mock-up of Battery Information available to the user

6.1.4 Battery Performance Index (BPI)

As frequent digital transactions are made with batteries of varying quality, the assigned monetary value of these batteries becomes crucial. Energy storage capacity, represented by the vehicle range and recorded in Kilowatt-hours, and power capacity, represented by acceleration,

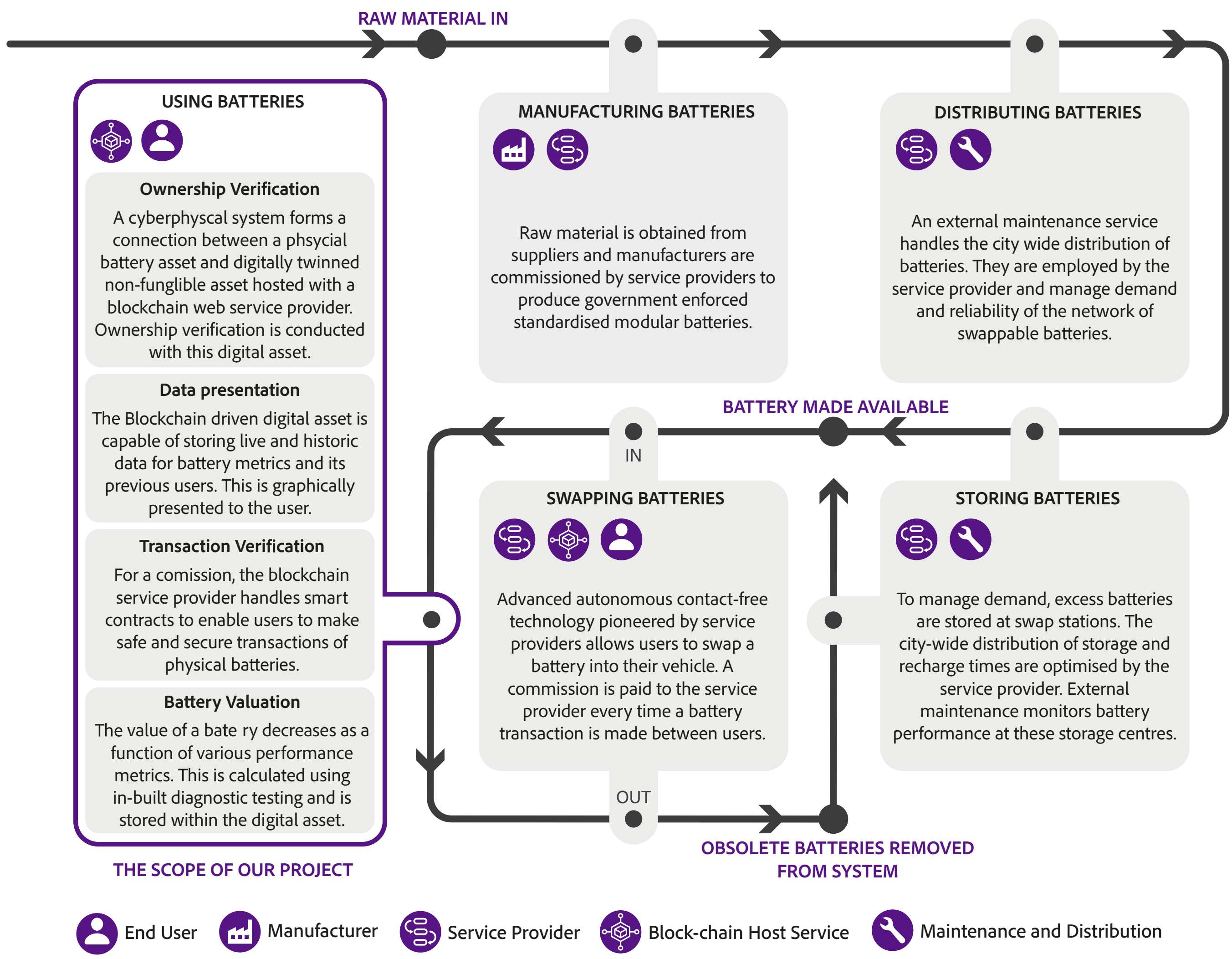

Figure 10: System Diagram of Selected Concept

gradeability and regenerative braking capabilities [44], are the two leading factors in determining the value of a battery. At a surface level, the value of a battery could be derived with the following performance index:

$$\text{Performance index} = \text{storage capacity index} \times \text{power capacity index}$$

A performance spectrum could be generated to map a given battery within the range from brand-new to a threshold that defines when a battery is no longer suitable for the system. For instance, when the storage capacity index drops below a value that results in less than an hour of usage; as users believe that a single charge should last them no less than an hour. With the average drive efficiency of modern electric cars, the lower bound for the storage capacity performance spectrum would, therefore, be 24 kWh[45]. Importantly, the performance index can also depend on several factors including resistance and open-circuit voltage [46]. Consequently, we propose to design and manufacture hardware to instantaneously measure several characteristics of Lithium-Ion batteries, as decreasing production costs indicate that they will remain the material of choice in 2042 [47]. After batteries are sampled, linear regression will be implemented and tuned to generate an appropriate performance index function. If the linear model can predict the degradation of a battery with a sufficient R-squared value, the technology will be assumed to be feasible within the proposed system in 2042.

During phase 2, a program to simulate battery performance over time will be developed. This will take battery data as inputs, and calculate value, allowing us to verify the BPI function. As a lo-fi prototype, this algorithm will run completely digitally, taking different conditions into account. Validating this is the first and most critical step to realising a physical BPI device, hence our focus. Future stages of development would involve embedding sensors into the battery, but this has already been deemed feasible, thus isn't part of the required development program.

6.2 Full System Diagram

The refined system diagram, shown in Figure 10, highlights how the proposed subsystem operates within the whole system of resources and stakeholders. Consequently, the scope of the project could be better defined.

7 Conclusion

To conclude, trends of various strengths were analysed and combined to establish a future scenario of externally supplied widespread swappable batteries for personal electric vehicles driven by an increasing demand for convenience and decreasing demand for ownership. A problem space and corresponding opportunity was identified to target the safety and security associated with the user interaction with such system. Various solutions were explored and evaluated before selecting a concept to develop further.

The simplified concept roadmap shown in Figure 11 outlines how user needs will evolve over the 20-year timespan, how the product service system offering will develop to meet those needs and what technological development will be required to facilitate.

Importantly, the chosen concept was broken down into several key aspects that are required for its success within our future scenario. These aspects were ranked by their importance and certainty to select four key components for the scope of the further stages of the project. A concept embodiment plan was considered for each of the four most critical elements of the system, in order to best demonstrate the feasibility of the concept overall. Additionally, further UX research will be conducted, to identify how drivers will perceive our system. If those goals are achieved, it can be assumed that the concept will be feasible in 2042.

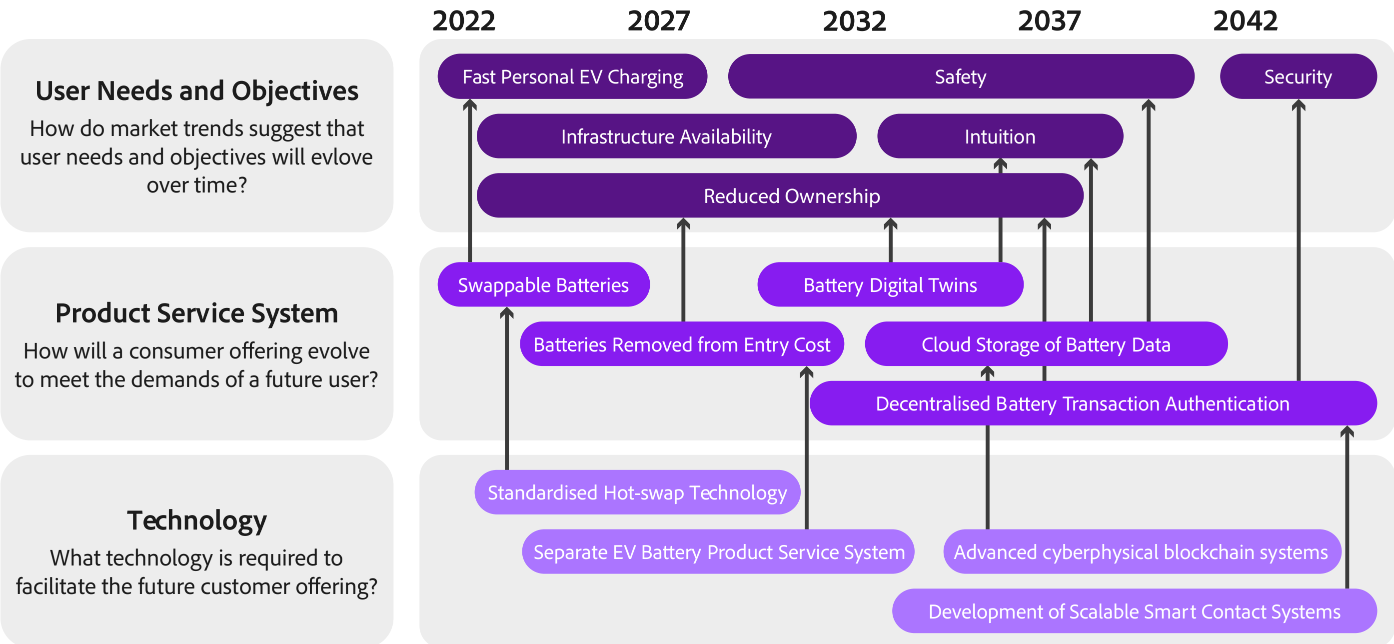

Figure 11: Future Roadmap for Concept Viability

8 Brief Review on Project Management and Documentation

8.1 Project Management

The following links can be used to access team management documentation:

Meeting Minutes (Can also be found on Group 16 Teams)
Microsoft Planner
Miro

8.2 Approach & Planning

The Gantt chart shown in Figure 12 outlines our planning for this project. The report was broken down into 4 sections, with each team member being allocated tasks for those sections, according to strengths and weaknesses. We worked in an efficient, iterative manner, setting internal deadlines, which allowed time at the end of each section for review and mitigations. There was effective communication between all members of the group, and weekly meeting with our supervisor

8.3 Self Reflection

Neil: My strengths are in design and visualisation; however before this project I lacked technical report writing experience. So, my aim was to use this opportunity to build on my ability to coherently synthesise information. Next term I would like to also work on my design skills.

Harris: Prior to starting this project I lacked the skills required to comprehensively argue and justify technical concept proposals. I used this opportunity to develop my ability to collate convincing and credible data to support my claims and I will develop this further next term.

Arturo: The team divided the work efficiently, which allowed me to improve my research skills. I found Microsoft Planner to be effective at handling due tasks.

Lily: Initially, some of the technical concept components were difficult to interpret, however after conducting industry research I found that these became clearer, allowing me to develop a greater understanding of blockchain systems and advanced verification techniques.

Yang: Personally, I concentrated on investigating numerical-based concept requirements, as this is my strength. This project has made me realise that my abilities in producing technical reports and doing literature reviews still need some improvement, which I plan on developing further next term.

8.4 Risk Mitigation

Table 4: Comparison of different PUFs

Risk	Mitigation	Trigger
Team member not up to date on group's progress (S: 2, L:4)	Produce debrief notes to pass onto absent team members	Team member absent from meeting(s)
Prototyping method is unfeasible (S: 5, L:2)	Seek advice from project super-visor or departmental staff who may be able to offer expertise	Nature of future concept re-quires complex technology that is difficult to validate at present
Internal deadline missed by group member (S: 2, L:3)	Offer member support for task completion, reassigning or splitting task up if necessary	No work showing on collaborative report document
Group member(s) in disagreement (S: 2, L:3)	Evaluate pros and cons of each idea without bias	One or more team members flags a concern to the group
Group member producing irrelevant content (S: 4, L:2)	Discuss individual goals with each member to clarify uncertainties	Poor content noticed in collaborative document

8.5 Moving Forward

Next term, we will contact experts within the field such as Bob Shorten, to refine the concept. We will then begin prototyping. None of the budget has been used, so it will be used for embodiment development.

The team will continue to use the same teamworking methods and tolls next term as the project was managed effectively. Table 4 highlights potential risks, evaluated by their severity (S) and likelihood (L).

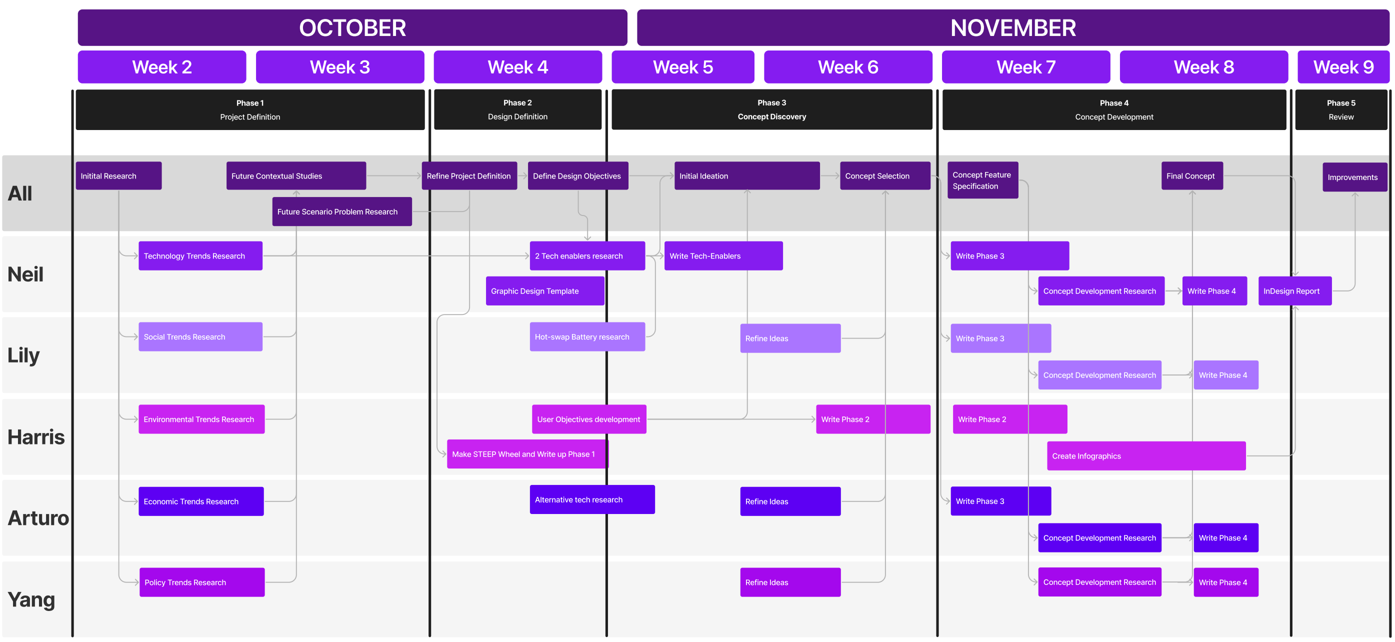

Figure 12: Comparison of different PUFs

9 References

[1] Greater London Authority, "Mayor sets out plans for London's electric vehicle future," gov.uk, 17 June 2019. [Online]. Available: https://www.london.gov.uk/press-releases/mayoral/mayor-sets-out-londons-electric-vehicle-future. [Accessed 30 November 2022].

[2] D. Powell, "Electric car statistics - data and projections," heycar, 3 September 2022. [Online]. Available: https://heycar.co.uk/blog/electric-cars-statistics-and-projections. [Accessed 30 November 2022].

[3] J. Hsu, "Too many electric cars charging at night may overload electrical grid," NewScientist, 22 September 2022. [Online]. Available: https://www.newscientist.com/article/2339237-too-many-electric-cars-charging-at-night-may-overload-electrical-grid/. [Accessed 30 November 2022].

[4] D. Oreizi, "EV Charging vs Gas Refueling Comparison: EVs Take Less of Your Time!," ChargedFuture, 8 June 2020. [Online]. Available: https://www.chargedfuture.com/ev-charging-vs-gas-refueling/#:~:text=Regardless%2C%20if%20you%20were%20to,to%2010%20hours%20(electric). [Accessed 30 November 2022].

[5] S. Hyken, "Customers Will Pay More For This," Forbes, 29 August 2021. [Online]. Available: https://www.forbes.com/sites/shephyken/2021/08/29/customers-will-pay-more-for-this/?sh=7c00b54216c6. [Accessed 30 November 2022].

[6] Z. Dalin-Kaptzan, "Food Delivery: Industry Trends for 2022 and beyond," Brigg, 2021. [Online]. Available: https://www.bringg.com/blog/delivery/food-delivery-industry-trends/. [Accessed 30 November 2021].

[7] RetialBanker, "Sharing Economy: Macroeconomic trends," RetailBanker, 20 May 2022. [Online]. Available: https://www.retailbankerinternational.com/comment/sharing-economy-macroeconomic-trends/. [Accessed 30 November 2022].

[8] V. Afshar, "5 trends driving end of ownership and growth of subscription economy," ZDNET, 22 July 2019. [Online]. Available: https://www.zdnet.com/article/5-trends-driving-the-end-of-ownership-and-the-growth-of-the-subscription-economy/. [Accessed 2022 November 2022].

[9] europol, "31 arrested for stealing cars by hacking keyless tech," europol, 17 October 2022. [Online]. Available: https://www.europol.europa.eu/media-press/newsroom/news/31-arrested-for-stealing-cars-hacking-keyless-tech. [Accessed 30 November 2022].

[10] Z. Peterson, "Product Design Trends in 2020: Modular Hardware vs. Modular Software," Altrium, 30 March 2021. [Online]. Available: https://resources.altium.com/p/product-design-trends-in-2020-modular-hardware-vs-modular-software. [Accessed 30 November 2022].

[11] technavio, "UPS Battery Market Size for Data Center Industry Market to grow," Cision, 3 August 2022. [Online]. Available: https://www.prnewswire.com/news-releases/ups-battery-market-size-for-data-center-industry-market-to-grow-by-usd-2-11-billion-driven-by-increase-in-adoption-of-modular-ups-systems---technavio-301598162.html. [Accessed 30 November 2022].

[12] Scott-Clark Medical, "Hot Swap Batteries," Scott-Clark Medical, 2022. [Online]. Available: https://www.scott-clark.com/power-systems/hot-swap-batteries/#:~:text=Hot%20swap%20batteries%20are%20batteries,as%20in%20a%20medical%20emergency. [Accessed 30 November 2022].

[13] N. Winton, "Battery-Swapping," WintonsWorld, 6 October 2022. [Online]. Available: https://www.wintonsworld.com/battery-swapping-unlikely-to-pose-threat-to-ev-chargers/#:~:text=NIO%20has%20completed%20more%20than,2025%2C%20up%20from%20800%20now.. [Accessed 30 November 2022].

[14] T. Sharma, "5 Biggest Blockchain Trends In 2022," Blockchain Council, 25 August 2022. [Online]. Available: https://www.blockchain-council.org/blockchain/5-biggest-blockchain-trends/. [Accessed 30 November 2022].

[15] J. Frankenfield, "Blockchain-as-a-Service (BaaS) Meaning and Major Players," Investopedia, 31 March 2021. [Online]. Available: https://www.investopedia.com/terms/b/blockchainasaservice-baas.asp. [Accessed 30 November 2022].

[16] Nature, "Electric cars could break the grid if future drivers stick to today's routines," Nature, 27 September 2022. [Online]. Available: https://www.nature.com/articles/d41586-022-03052-5. [Accessed 20 November 2022].

[17] A. Brown, "Electric Cars Will Challenge State Power Grids," PEW, 9 January 2020. [Online]. Available: https://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2020/01/09/electric-cars-will-challenge-state-power-grids. [Accessed 30 November 2022].

[18] M. Jacoby, "It's time to get serious about recycling lithium-ion batteries," C&EN, 14 July 2019. [Online]. Available: https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28. [Accessed 30 November 2022].

[19] M. Campbell, “In pictures: South America’s ‘lithium fields’ reveal the dark side of our electric future,” EuroNews, 21 November 2022. [Online]. Available: https://www.euronews.com/green/2022/02/01/south-america-s-lithium-fields-reveal-the-dark-side-of-our-electric-future. [Accessed 30 November 2022].

[20] K. Bruun, “Consumers’ Discretionary Spending Tumbled in March,” MorningConsult, 26 April 2022. [Online]. Available: https://morningconsult.com/2022/04/26/consumers-discretionary-spending-tumbled-in-march/. [Accessed 30 November 2022].

[21] M. Woodward, B. Walton and J. Hamilton, “Electric vehicles,” Deloitte, 28 July 2020. [Online]. Available: https://www2.deloitte.com/us/en/insights/focus/future-of-mobility/electric-vehicle-trends-2030.html. [Accessed 30 November 2022].

[22] CFI, “Standardization,” CFI, 28 April 2022. [Online]. Available: https://corporatefinanceinstitute.com/resources/economics/standardization/. [Accessed 30 November 2022].

[23] europarl, “ Deal on Common Charger,” europarl, 07 June 2022. [Online]. Available: https://www.europarl.europa.eu/news/en/press-room/20220603IPR32196/deal-on-common-charger-reducing-hassle-for-consumers-and-curbing-e-waste. [Accessed 30 November 2022].

[24] Bloomberg, “R&D Tax Credit and Deductions,” Bloomberg, 23 August 2022. [Online]. Available: https://pro.bloombergtax.com/brief/rd-tax-credit-and-deducting-rd-expenditures/. [Accessed 30 November 2022].

[25] AheadOfTheHerd, “EV Affordability Confronted By Rising Component Costs,” AheadOfTheHerd, 2 April 2022. [Online]. Available: https://aheadoftheherd.com/ev-affordability-confronted-by-rising-component-costs/. [Accessed 30 November 2022].

[26] N. Gibbs, “Could battery swapping replace EV charging?,” AutoCar, 4 April 2022. [Online]. Available: https://www.autocar.co.uk/car-news/business-tech%2C-development-and-manufacturing/could-battery-swapping-replace-ev-charging. [Accessed 30 November 2022].

[27] Ample, “Let’s get one billion electric vehicles on the road,” Ample, 2022. [Online]. Available: https://ample.com/. [Accessed 30 November 2022].

[28] RAC, “How long do electric car batteries last? EV battery recycling,” RAC, 21 October 2021. [Online]. Available: https://www.rac.co.uk/drive/electric-cars/charging/how-long-do-electric-car-batteries-last/. [Accessed 30 November 2022].

[29] e-motec, “New i-BMS Battery Management System,” e-motec, 24 November 2021. [Online]. Available: https://www.e-motec.net/new-i-bms-battery-management. [Accessed 30 November 2022].

[30] Tesla, “Opening the North American Charging Standard,” Tesla, 2022. [Online]. Available: https://www.tesla.com/blog/opening-north-american-charging-standard. [Accessed 30 November 2022].

[31] EUROBAT, “Standardisation,” EUROBAT, 2022. [Online]. Available: https://www.eurobat.org/what-we-do/topics-we-cover/standardisation/. [Accessed 30 November 2022].

[32] Wikipedia, “Web 2.0,” Wikipedia, 28 November 2022. [Online]. Available: https://en.wikipedia.org/wiki/Web_2.0#Technologies. [Accessed 30 November 2022].

[33] Wikipedia, “Web3,” Wikipedia, 27 November 2022. [Online]. Available: https://en.wikipedia.org/wiki/Web3. [Accessed 30 November 2022].

[34] Wikipedia, “DigitaL Twin,” Wikipedia, 30 November 2022. [Online]. Available: https://en.wikipedia.org/wiki/Digital_twin. [Accessed 30 November 2022].

[35] M. Armstrong, “Cheat sheet: What is Digital Twin?,” IBM, 4 December 2020. [Online]. Available: https://www.ibm.com/blogs/internet-of-things/iot-cheat-sheet-digital-twin/. [Accessed 30 November 2022].

[36] Wikipedia, “Blockchain,” Wikipedia, 20 November 2022. [Online]. Available: https://en.wikipedia.org/wiki/Blockchain. [Accessed 30 November 2022].

[37] A. Hayes, “Blockchain Facts,” Investopedia, 27 September 2022. [Online]. Available: https://www.investopedia.com/terms/b/blockchain.asp. [Accessed 30 November 2022].

[38] N. Patel, “EV Battery NFTs - Responses,” MS Forms, 20 October 2022. [Online]. Available: https://forms.office.com/Pages/DesignPageV2.aspx?subpage=design&token=9d9ecbc8c6144f9ca78f5ecc5c59b291&id=B3WJK4zudUWDC0-CZ8PTB3_7RLKN42FNkhDHzDqywY5UM0hXNlA4RjNUUUlKWkxYMzNRSURENkRHUy4u&analysis=true. [Accessed 30 November 2022].

[39] Y. Tay, “Battery Passports: How traceability enables responsible,” November 2022. [Online]. [Accessed 30 November 2022].

[40] Ethereum.org, “What are zero-knowledge proofs?,” Ethereum.org, 29 November 2022. [Online]. Available: https://ethereum.org/en/zero-knowledge-proofs/. [Accessed 30 November 2022].

[41] Wikipedia, “Types of physical unclonable function - SRAM PUF,” Wikipedia, 10 November 2022. [Online]. Available: https://en.wikipedia.org/wiki/Types_of_physical_unclonable_function#SRAM_PUF. [Accessed 30 November 2022].

[42] M. Kim, J. Leem, S. Choi, Y. Kim and Y. Song, “Revisiting silk: a lens-free optical physical unclonable function,” Nature Communications, vol. 13, no. 247, 2022.

[43] GBA, “BATTERY PASSPORT,” GBA, 2022. [Online]. Available: https://www.globalbattery.org/battery-passport/. [Accessed 30 November 2022].

[44] S. Saxena, C. Le Floch, J. MacDonald and S. Moura, “Quantifying EV battery end-of-life through analysis of travel needs with vehicle powertrain models,” Journal of Power Sources, vol. 282, no. 0378-7753, pp. 265-276, 2015.

[45] C. Boyd, “How much power does an electric car battery hold?,” Jerry, 13 May 2022. [Online]. Available: https://getjerry.com/questions/how-much-power-does-an-electric-car-battery-hold. [Accessed 13 November 2022].

[46] J. Harmon, “Assessing battery performance: Compared to what?,” Argonne, May 2019. [Online]. Available: https://www.anl.gov/article/assessing-battery-performance-compared-to-what#:~:text=Typically%2C%20battery%20researchers%20use%20three,%2Dcircuit%20voltage%2C%20and%20resistance. [Accessed 30 November 2022].

[47] G. Donnelly, “5 charts explaining the future of EV batteries,” EmergingTechBrew, 28 October 2021. [Online]. Available: https://www.emergingtechbrew.com/stories/2021/10/28/5-charts-explaining-the-future-of-ev-batteries-the-backbone-of-the-electric-transition. [Accessed 30 November 2022].