Ambivalence

to

Ambition

The Eden Project: Motivating households to become energy LEAN

Max Anderson


Before we begin, lets make sure your sensor is fully charged
...Syncing, Checking Charge...
It may take a few moments for Eden to connect with your sensor
Ready to go!
11a - Laundry Setup 1 – 1
12:30
Laundry: Setup
Before we begin, lets make sure your sensor is fully charged

Abstract

Ambition always starts with a vision. Humanity's vision of a sustainable future is partly obscured by political, economic and technological barriers that seem to block progress. Australian energy usage and subsequent carbon emissions continue to rise, placing growing demand for increased and more consistently available electricity on our energy infrastructure. While industry stakeholders need to find their own solutions, individuals still need to make sizeable reductions in their electrical impact to meet the global renewable effort half-way. Individual actions can make a difference through reducing consumption and changing the timing of energy use to take greater advantage of existing and future renewable resources. However, the biggest issue for households is that their consumption is near invisible, and so they lack knowledge about where to start making adjustments. Instead of finding a traditional, efficient technology solution, there is another, and more widely accessible method of adjusting household energy usage; design for sustainable behaviour.

By utilising the sphere of smart home devices, the disconnect between appliance usage, and energy consumption can be bridged through a short-term tracking device system that monitors specific activities through the choice and interaction of the user. Instead of overwhelming the user with numerous optimisations at once, the designed product service system, Eden, takes a gradual approach. It focuses on providing energy saving feedback for individual household appliances. Eden creates more of a direct connection with how a household's usage of their appliances influences the energy consumed and the price they pay. This is possible through the portable Pebble energy tracking tool which collects motion and heat data from appliances to reveal energy consumption patterns. Teamed with the individualised, adaptive and gamified Eden interface, this product service system provides a more motivational alternative to traditional "plugged-in" energy use monitoring.

Eden can turn householder energy ambivalence into energy ambition.

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Glossary of Terms

PV	Photovoltaic
GHG	Greenhouse Gas
PEC	Primary Energy Consumption
GDP	Gross Domestic Product
IEA	International Energy Agency
MtC	Million metric tons of carbon
MtC/Yr	Million metric tons of carbon per year
RAER	Reduction in national CO2 emissions at year 10 due to the behavioral change from plasticity, expressed in MtC/yr saved and as a percentage of total US individual/household sector emissions (%I/H). Both estimates are corrected for double counting.
RES	Renewable Energy System
PE	Pro Environment
Plasticity	(Shortened from Behavioural Plasticity) A change in an organism's behavior that results from exposure to stimuli.

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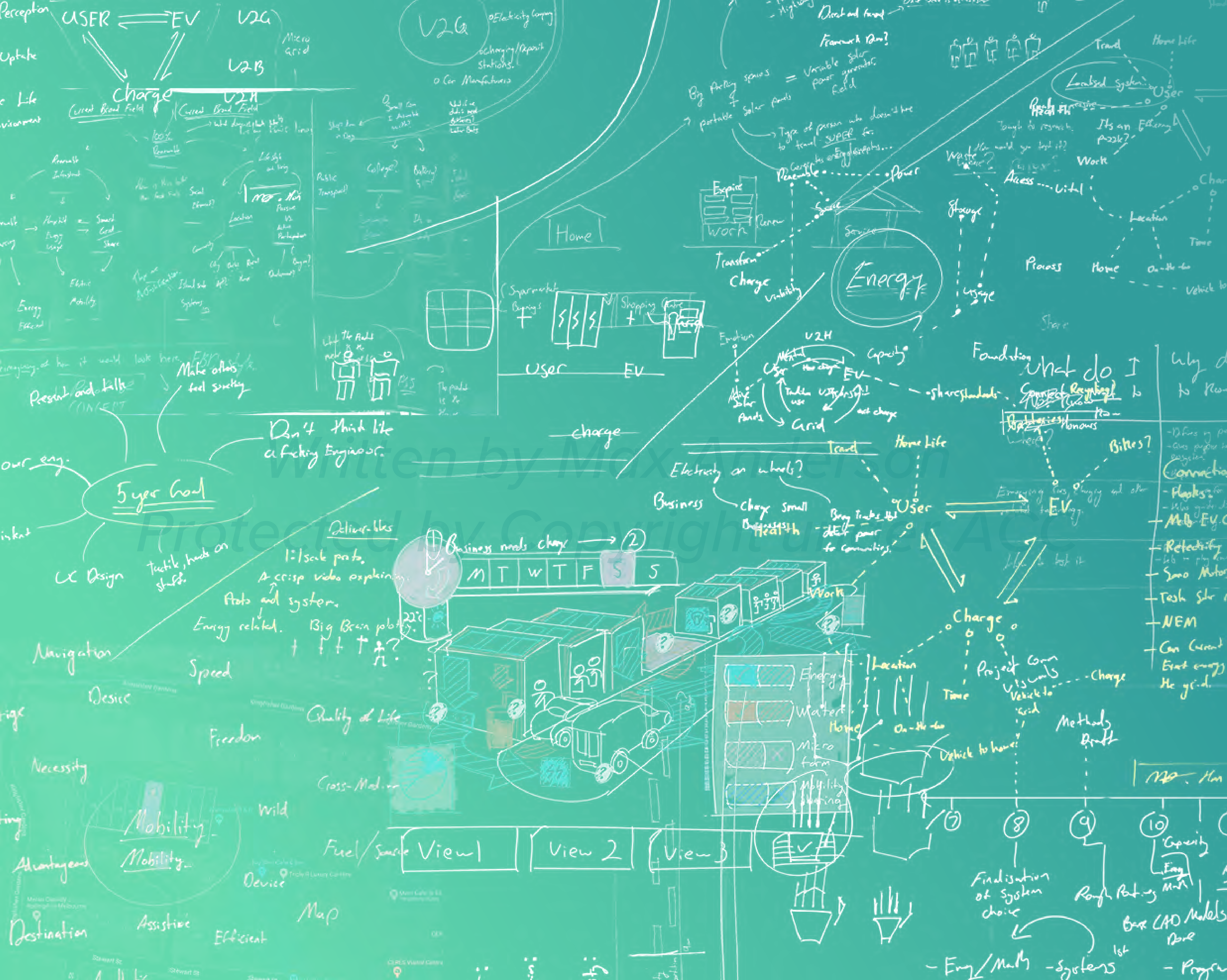
USER
EV
V2G
V2B
V2H
Charge
Home
User
EV
Energy
Don't think like a fucking Engineer.
5 year Goal
Deliverables
1:1 scale proto.
A crisp video explaining
Proto and system.
Energy related.
Big Brain policy
Business needs charge
M T W T F S S
Navigation
Speed
Desire
Quality of Life
Freedom
Necessity
Mobility
Wild
Fuel / Source
Advantageous
Device
Destination
Assistive
Efficient
Map
View 1
View 2
View 3
Energy
Water
Micro farm
Mobility sharing
Location
Time
Home
On-the-Go
Vehicle to home
Methods Draft
Finalisation of System choice
Rough Rendering
Base CAD Models Done
Eng / Math
Systems
Electricity on wheels?
Business
Charge Small Businesses
Health
Foundation
Connection
NEM
Work
Process
Power
Renewable
Storage
Usage
Grid
Capacity
Emotion
Make others feel something
Present and talk

01

FIELD OF PRACTICE

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Introduction

In accordance with the Paris Climate Agreement, Australia is expected to reduce its carbon emissions 26 to 28% below 2005 levels by 2030 (Department of the Environment and Energy, 2019). While the Australian energy department is confident they will reach this 2030 goal, 60% of Australians want immediate action (Blau, 2020).

Climate change, and climate action, has never been more at the forefront of the public eye. Yet as a country, and a global community, we are struggling to create the change we wish to see in the world. It was only 200 years ago that living efficiently was a necessity in every home. When you walked for your water, you didn't waste it.

How can we return to that level interconnectedness with our environment? This project begins with highlighting the ground work within Australia; what is the political climate of renewable energy, what are our options, and how does that mesh with our home usage.

Section 1 - Renewable energy: the political climate in Australia

By far the biggest inhibitor to transitioning Australian energy production to 100% renewables is the Australian Government. Law and policy makers in Australia have been taking several legal steps since 2013 to slow the investment in renewable energy (Prest, 2018). The most evident step of this behaviour is in the repeal of the carbon pricing legislation in July 2014 (Prest, 2018). Carbon pricing had been shown to be an effective measure in reducing electric emissions with the establishment of a three-year fixed price-per-tonne of carbon tax ($23-$28AUD) (Prest, 2018). Following its repeal, emissions from coal powered generators began to rise again (Prest, 2018).

Part of the reasoning behind this behaviour is that one of Australia's largest exports being coal. Australia is the 3rd largest exporter of Coal in the world as of 2018, with our biggest markets being in Japan, China and South Korea (Kilvert, 2019). Coal is very much rooted within energy production within Australia. Australia's National Energy Guarantee proposed by the Turnbull government in 2017 aimed to provide an electrical "Reliability Obligation", but in truth was a thinly veiled attempt to support conventional (coal powered) means of generation (Prest, 2018).

Even with many political inhibitors, renewable generation facilities have started to grow across regional Australia (Hobday & Divissi, 2019). Between July to September of 2019, 48 solar and wind farms had been connected into the grid (Hobday & Divissi, 2019). However, as new projects come online, the current electricity transmission network, built for centralised electricity generation, is approaching capacity (Hobday & Divissi, 2019). Soon enough, Australia's powerlines will begin to inhibit where (and if) more renewable projects can be built to meet capacity.

Our transmission networks (Figure 1) continue to sabotage renewable actions in different ways. Network operators employ strict regulatory tests that assist in ignoring alternatives, and promote further investment into existing methods and technology. When Kangaroo Island had an opportunity to replace their

Figure 1 - Examples of Australian Energy Transmission powerlines

aging mainland electricity connection in 2017, their plan to build a $26.9 million 66kV cable with the potential to export renewable energy back into the grid was refused (Parkinson, 2017). Instead a $25 million 33kV cable was installed that will help supply the island with energy, but not support any energy exportation (Parkinson, 2017). This action will place a heavy restriction on further renewable investment for Kangaroo Island, and is deeply upsetting to the local community when considering for many years they had plans to move towards being 100% renewably powered (Parkinson, 2017).

Within this oppressive, slow moving field, climate action often seems to be only up to combined individual action. The first, and usually logical, step many people take when taking their sustainability into their own hands is to renewably power their homes. However, there are still some issues in this endeavour.

Section 2 - System elements of home renewable energy

For any fully electric system to be 100% renewably powered, it requires three crucial elements: sufficient renewable energy generation, efficient energy storage, and a reliable communication system (Hossain et al., 2016). These three elements are modular and scalable, and is part of the reason why renewable energy can be applied on a small home scale or a large, continent wide scale (ARENA, 2017b). For energy generation sources, there are three main types of generation methods as seen in Figure 2.

Due to solar's comparably low price, location versatility and ease of installation, it is by far the most accessible form of renewable energy for home owners. This is part of the reason why solar has been so readily adopted; 20.3% of households in Australia have installed solar (Clean Energy Council, 2018). Solar simply needs to be set up in a space that receives direct sunlight, while wind and hydro require enough space to set up, and specific environmental factors for either to be a good

	Solar Electricty	Wind Electricty	Hydro Electricty
Cost to Install (5KW)	$ $5,550 AUD (Solar Choice, 2019a)	$$$$ $56,000 AUD (Australian Wind and Solar, 2020)	$$ $14,870 AUD (micro-hydro-power)
Energy Efficiency	~11-22% (Solar calculator, 2015)	~50% (University of Michigan, 2018)	~60% (micro-hydro-power)
Installation difficulty	+ Easiest to install	- Difficult to install	~ Medium difficulty
Location Factors	+ Most versatile for installation.	- Location crucial	- Location crucial
Reliability	- Not a continuous stream of energy.	+ Potential for continuous stream of energy.	+ Potential Continuous stream of energy, also supports non battery storage

Figure 2 - Home Scale Renewable Energy Generation Methods (US D.O.E, 2019)

economic investment. However, solar does not have the capacity for a continuous output, and ideally, should be offset with another source of power to nullify falloffs (US D.O.E, 2019). This is somewhat problematic, because a larger portion of our energy usage is during the night, inhibiting the base ability of solar panels to assist our energy usage. On a larger scale, continuous energy supply can be generated by mixing renewable generation methods in a "hybrid system" (US D.O.E, 2019), but for an individual home, options are either some type of grid connection, or battery storage. There are a few variations in grid connections explored in Figure 3.

Currently in Australia, 98% of household solar systems sold are on-grid, since they're the cheapest to set up, and provide some investment benefits (Peacock, 2009). However, if not attached to a battery for energy storage, an on-grid solar system ultimately provides most of its output during the day to the grid. If aiming to move to 100% renewable power using an on-grid solar system, you heavily rely on your energy providers choosing to provide necessary additional energy from renewable sources when your solar system is unable to reach your demand (Peacock, 2009). On such a small, household scale, solar still proves to be the most versatile option. But can solar energy keep up with the growing demand of our future homes?

On-Grid	Off-Grid	Hybrid-Grid
- Excess energy is fed back into grid	+ Excess energy is stored in high capacity batteries	* Connected to both batteries and grid.
+ Users are paid a feed-in tariff	- Expensive	+ Reliable
+ Cheapest Method	- Potential for Blackouts	+ Less expensive than off-grid
+ Reliable	* No Connection to Utility Grid	
- No storage capacity	* Best for Remote Locations	
* Requires Connection into Utility Grid		

Figure 3 - Grid Connection Variations of Renewable Energy Systems (Peacock, 2009)E, 2019)

Section 3 - Requirements for a 100% renewably powered home

Offering universal accessibility to home renewable energy is a recent area of increased interest (Prka, 2020), but adoption is still growing. For those that live in apartments, or are renters, some new apartment and housing developments are being built with pre-installed solar packages (Prka, 2020). The large, unobstructed space of apartment rooves leaves the potential for self-sufficiently powered apartment blocks, especially if the investment of installing such a system is favourable (ARENA, 2017a).

However, there is a lack of individual power to build these RESs (Renewable Energy Systems) if they aren't already in place (Olivia, 2019), and apartments and community developments need newfound interest from body corporates, developers, the local council etc to generate the funding if they want to do an "energy renovation" (Olivia, 2019).

The main people who have the individual ability to make their homes 100% renewable are those who live in seperate houses that they have ownership of. In Australia, this is quite a large demographic, with 72.9% of people living in separate houses, and in all types of housing, 65.5% of people owning their home (Australian Bureau of Statistics, 2016). Benchmarking three different houses shows how the energy usage of a 100% electric household might be powered by a renewable system (see Figure 4).

The calculations for the Benchmark Household Hybrid-Grid conversion takes the following optimal assumptions into account to comfortably power the home:

Assumptions:

- Home set up as a Hybrid Grid system only to export excess energy.
- Cannot install small scale hydro or wind turbines
- Batteries should store 1 day's worth of power usage to mitigate consistent overcast weather
- Panels receive location average summer sunshine hours, 0.5 hours of solar panel obstruction, face north at 30%

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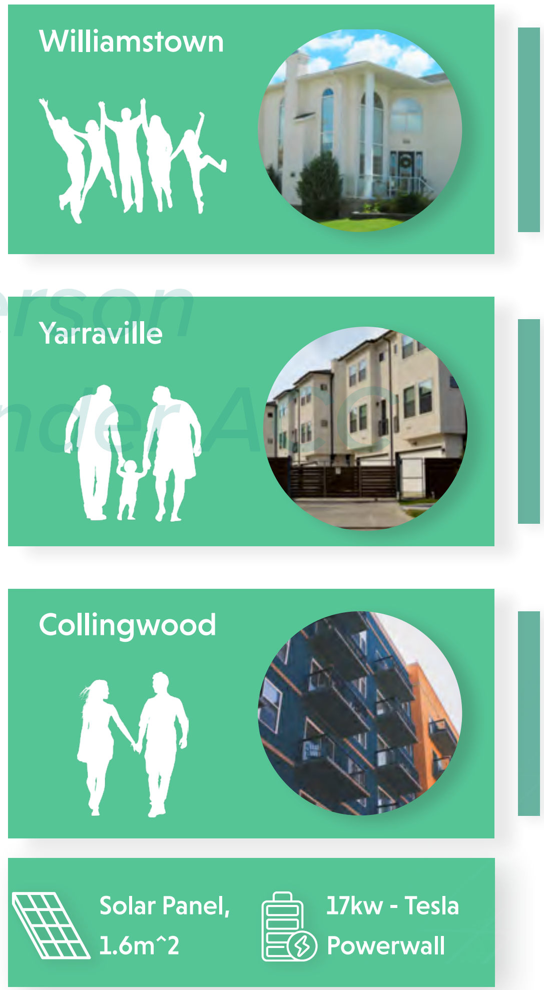
The small benchmark comparison seen in figure 4 shows that building solar and storage systems for "off grid" type powering to meet our current usage is a costly measure. Solar panels alone might be a fair investment, but the peak of their energy generation is likely to be when you are not at home. Thus, much of their benefit will only be seen by the grid that they supply.

To maximise the self-consumption of one's solar panels, they need to be paired with a set of batteries. In this benchmark, the batteries consistently are the biggest expenditure of the system, costing approximately double the price of the panels.

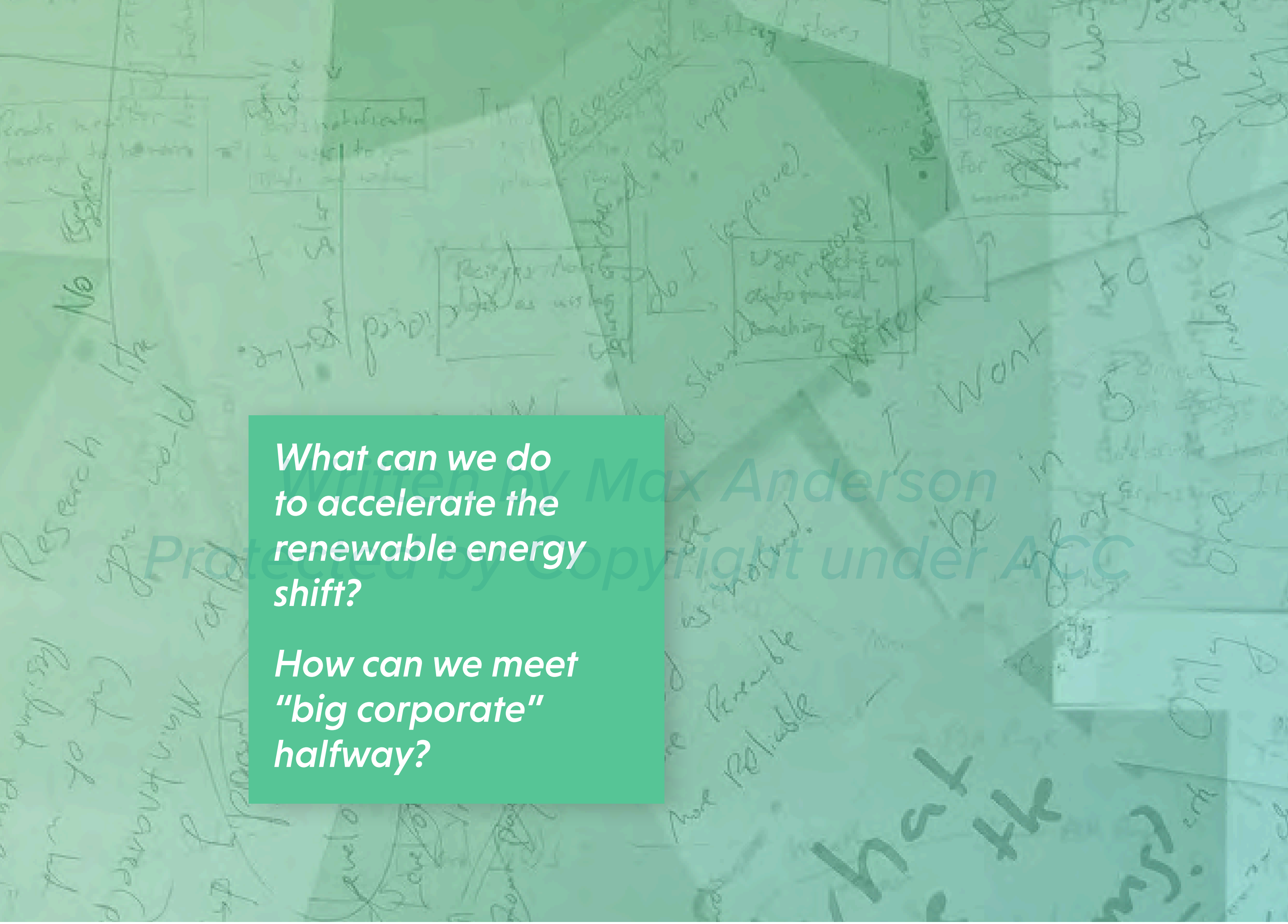
Solar energy could become more accessible (less expensive) if households were able to reliably decrease their electricity usage. Famous Australian "Sustainable House", renovated and documented by Michael Mobbs, uses a 4 kW pV system, attached to 12kWh to meet an average of 3 kWh usage a day (not including cooking) (Norris, 2016). As much as his home is renovated and optimised for this level of usage, there is something to be learnt to help reduce our electricity usage.

Type of Household



Transport	Weekday Activities	Avg Daily Energy Use	Solar System Features	Solar Production	Price
	Separate work commutes, school pickup/drop-off, afterschool activites and errands.	28.4 kwh for house 7 kwh for transport	10.5 KW 30-40 2.5	39.1 kw	$12,440 for solar system $27,000 for batteries
	Adults work from home, travel for meetings, school pickup/drop-off, afterschool activities, errands.	18.4 kwh for house 4 kwh for transport	7 KW 25-28 1.5	26.1 kw	$8,000 for solar system $16,000 for batteries
	Both use PT for work commute, electric vehicle for errands and weekend activities	12.4 kwh for house 2 kwh for transport	4.5 KW 15-20 1	16.8 kw	$5,550 for solar system $11,700 for batteries

Figure 4 -Benchmark Household Hybrid Grid Conversions (Solar Calculator, 2015) (Solar Choice, 2019a)



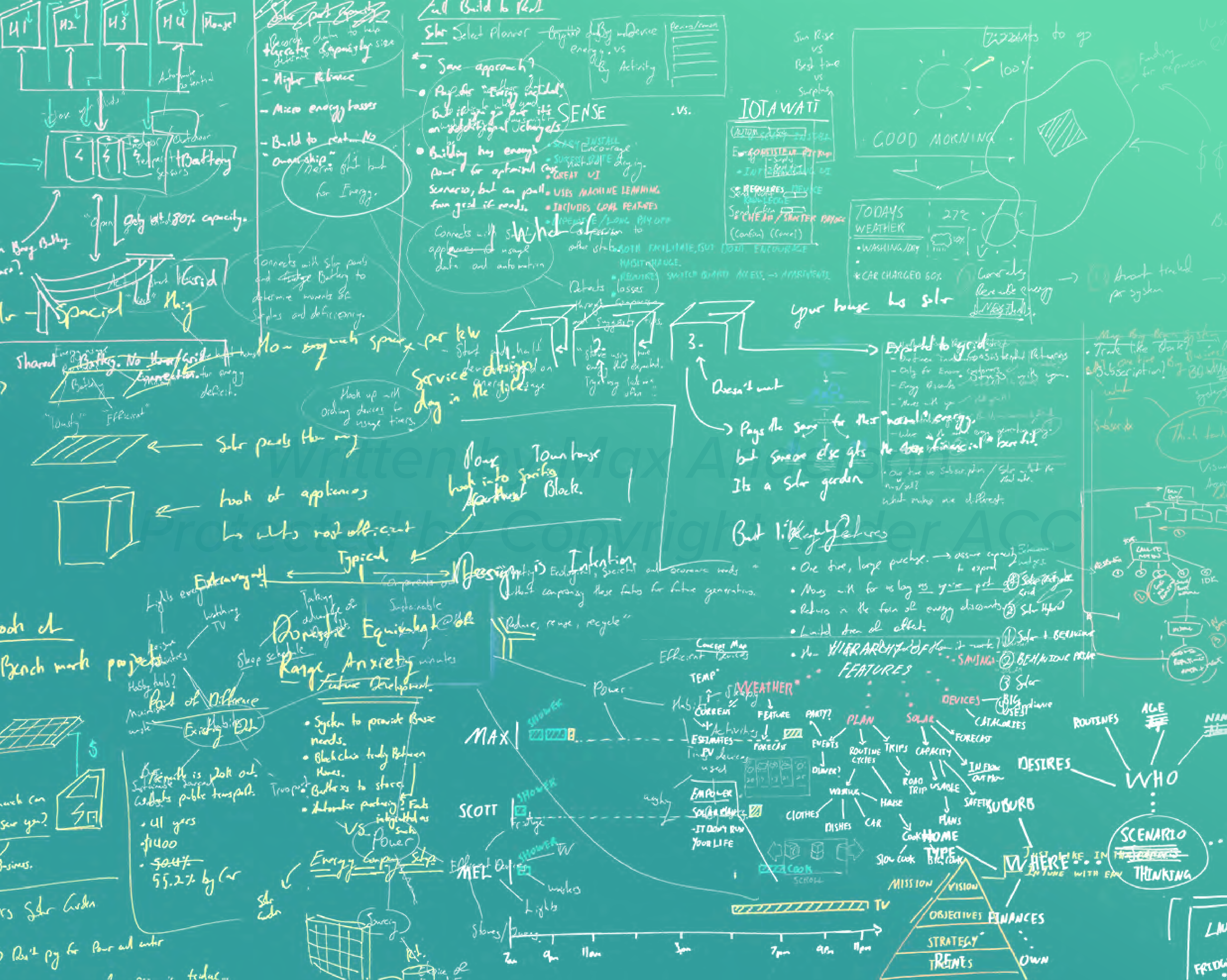
What can we do to accelerate the renewable energy shift?

How can we meet "big corporate" halfway?

Discussion and Summary

Australia appears to be moving in a positive direction towards climate action but there are still many barriers in the way of reaching this goal. Potentially, the biggest barrier is the one that we put up ourselves, with our continually increasing desire for energy. Converting our existing homes to off-grid systems is an expensive measure that many won't have access to. Yet in reducing our energy usage, and taking better advantage of solar energy, both home produced and grid sourced, we also help the system as a whole in reaching the carbon emissions reductions that many of us wish for.

We can't just expect scientists, investors etc to do all the work for us. We should be aiming to meet these renewable leaders halfway. How can we help? How can we reduce our energy consumption from the grid? How can we do this in a way that is normative and empowering?


SENSE
IOTAWATT
GOOD MORNING
TODAYS WEATHER
your house has solar
Service design
Design Intention
Domestic Equivalent
Range Anxiety
Future Development
Bench mark projects
Point of Difference
Energy Company Setup
HIERARCHY OF FEATURES
WEATHER
PLAN
SOLAR
DEVICES
MAX
SCOTT
MEL
DESIRES
WHO
SCENARIO THINKING
WHERE
SUBURB
HOME TYPE
FINANCES
MISSION
VISION
OBJECTIVES
STRATEGY
TACTICS

02

Context & Application

Context and Application

Introduction

The two core objectives highlighted at the end of Chapter 1 are reducing or shifting individual grid energy consumption and empowering the act of reduction. For a while, reducing energy consumption has been mostly relegated to the introduction of more efficient devices. The conversion to efficient devices financially makes sense; buy a slightly more expensive product, save extra down the line on energy bills. This is an area of action that has already seen good daily integration, but it is not the only part of the problem.

If the overall mission is to help the migration to renewable energy, what are other, potentially more accessible, areas of difference. Base load and our transmissions network play a crucial part in our energy generation habits, and understanding how we interact with them through our appliances and our behaviour is crucial in finding new ways to address our objectives.

Section 1 - Understanding base load

When looking into our energy consumption, it is important to understand the network that it is being provided over. Typically, our energy usage over time can be characterised by two main terms: "peaks" and "base/averages" (Platt, 2018). Base/averages typically refers to the consistent, general energy usage, while peaks describe surges in demand that occur for a sustained period (Platt, 2018).

Traditionally, our base is handled by conventional generation methods such as coal plants, which take days to reach full output, but can cheaply output consistent power once operational. This continued baseload generation stems from a conservative desire for a constant, reliable source of power in the background for when the sun goes down and wind stops (Kilvert, 2017).

This does however lead to the functional issue of the inability to easily modify output when demand slumps during off peak usage (Kilvert, 2017). In some cases, when supplemented with other methods of energy (wind, solar, oil etc), coal generators have to dispatch the generated electricity at a negative price due to excessive output (Kilvert, 2017).

Conventional electricity generation typically aims to reach or exceed peak demand (during the morning and evening) (Kilvert, 2017), but unfortunately this can often mean up to double the amount of energy provided during off peak periods (Platt, 2018). Our existing energy usage is leading to greater and more frequent peaks (see Figure 5), posing greater strain on our transmission networks, and encouraging poor production practices (Platt, 2018). If energy usage increases, we are likely to see more emphasis in meeting the growing demand by investing in additional forms of generation, instead of investing in increasing the efficiency/ sustainability of our existing systems.

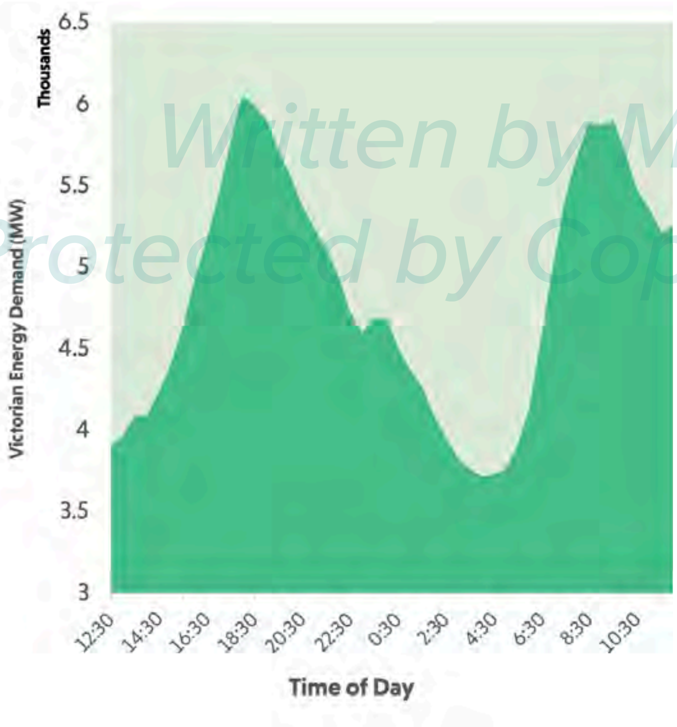


Figure 5 - Victorian Energy Demand (MW) 14/6/20

This is especially problematic when the IEA (International Energy Agency) has shown that the greatest wedge for reducing CO2 emissions in our energy networks is in increasing the efficiency of our transmissions systems (IEA, 2019a) (see Figure 6). Within Australia, our energy sector is already the third highest sector for energy consumption (26.3%) (Figure 7), and could continue to grow from increased fuel input (coal, gas, etc) and transmission losses (Australian Government Department of the Environment and Energy, 2019).

Context and Application

Figure 6 - CO2 emissions (Gigatons) reductions by measure in the Sustainable Development Scenario relative to the Stated Policies Scenario, 2010-2050 [IEA (direct from source)]

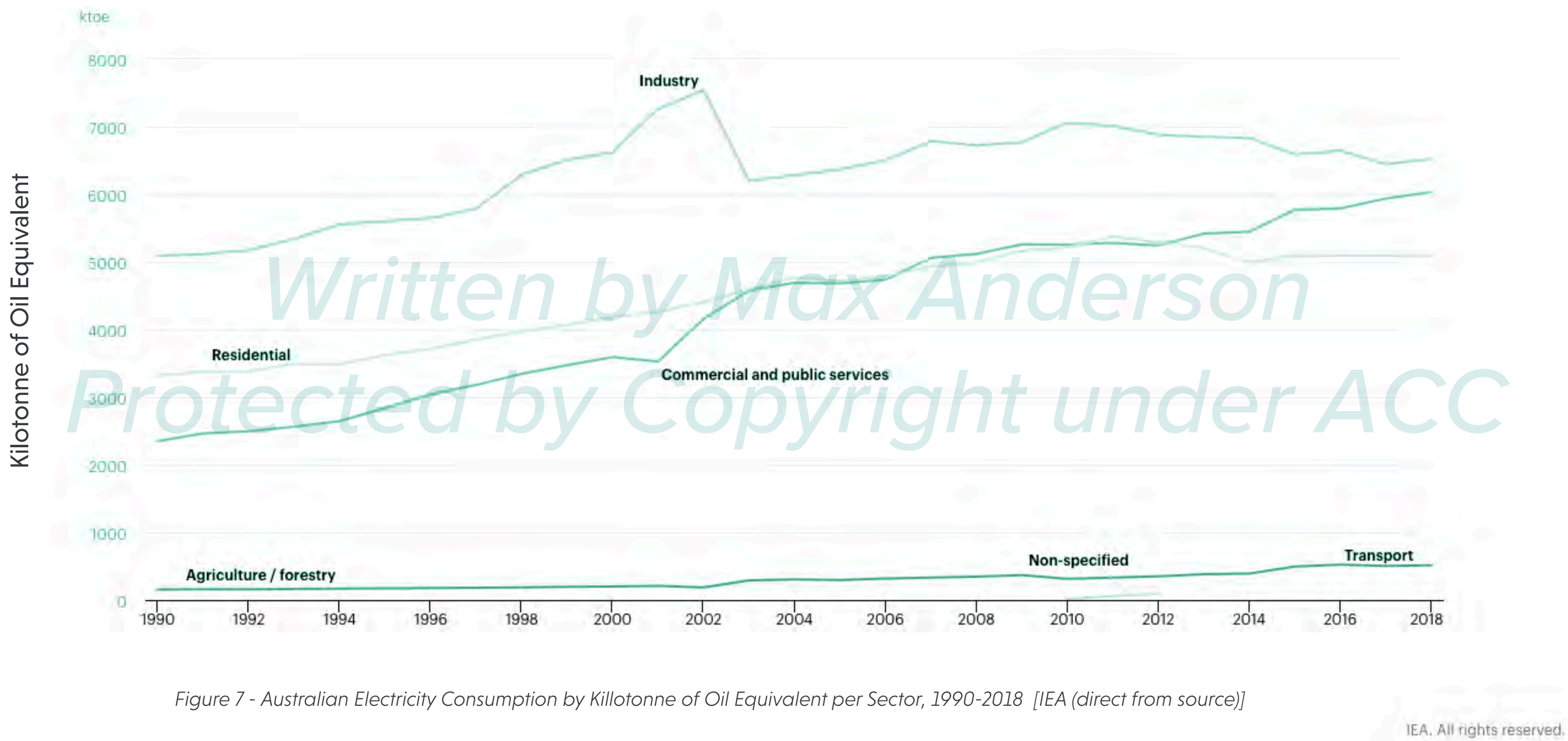


Figure 7 - Australian Electricity Consumption by Killotonne of Oil Equivalent per Sector, 1990-2018 [IEA (direct from source)]

Figure 8 - Collection of smart home appliances; (From left to right, top to bottom) Phillips Hue Bulb, Google Nest Hub,Simplisafe, Google home mini, Amazon Echo plus, Phillips Hue smart plug, Nest smart thermostat, August Smart Lock Pro + Connect, Roomba, Apple Homepod, Google Home, Teckin Smart Plug

Section 2 - The smart home and the risk of convenient ignorance

Overall, our energy usage continues to grow every year (see Figure 9) and is expected to continue to rise 1.3% each year towards 2040 (IEA, 2019a). Our increasing demand in energy is driven by (in order of magnitude) industrial motors, household appliances, cooling and electric vehicles (IEA, 2019a). Decidedly, technological innovation is a shared, core element of our increase in energy consumption, both in the short term and in the long term (Jin et al., 2018).

Within the long term, energy efficiency is improved by technological innovation, but actually acts as an enabler of increased consumption, since users are more willing to use their devices, and for longer periods of time (Jin et al., 2018). This has been coined as the "rebound effect"; a short term decrease in energy usage followed by a return to or a small increase in usage.

Technological innovation has had a serious recent effect on growing "smart-home" culture and appliances (examples seen in Figure 8). A smart home utilizes multiple interlinked devices and sensors with the key ambitions to create easy access to media, control over space mood and automated/simplified actions, to create feelings of luxury, ambience, and convenience (Strengers & Nicholls, 2017). Unlike other fields of smart development (smart grids, cities, meters etc), energy saving is not at the foreground of its technological improvement (Strengers & Nicholls, 2017).

In fact, the idea of a fully-integrated smart home using off the shelf additive products is likely to increase passive energy usage, and potentially encourage more active energy usage too. While your system might automatically turn off your lights for you, it also encourages you to use them in new ways (Strengers & Nicholls, 2017).

Studies founded in the UK, US and Netherlands show that 26% - 36% of home energy usage is due to user behaviour decisions (Lockton et al., 2010), and smart homes have the potential to further increase that. This narrative of a simplified, luxurious "good life"

Context and Application

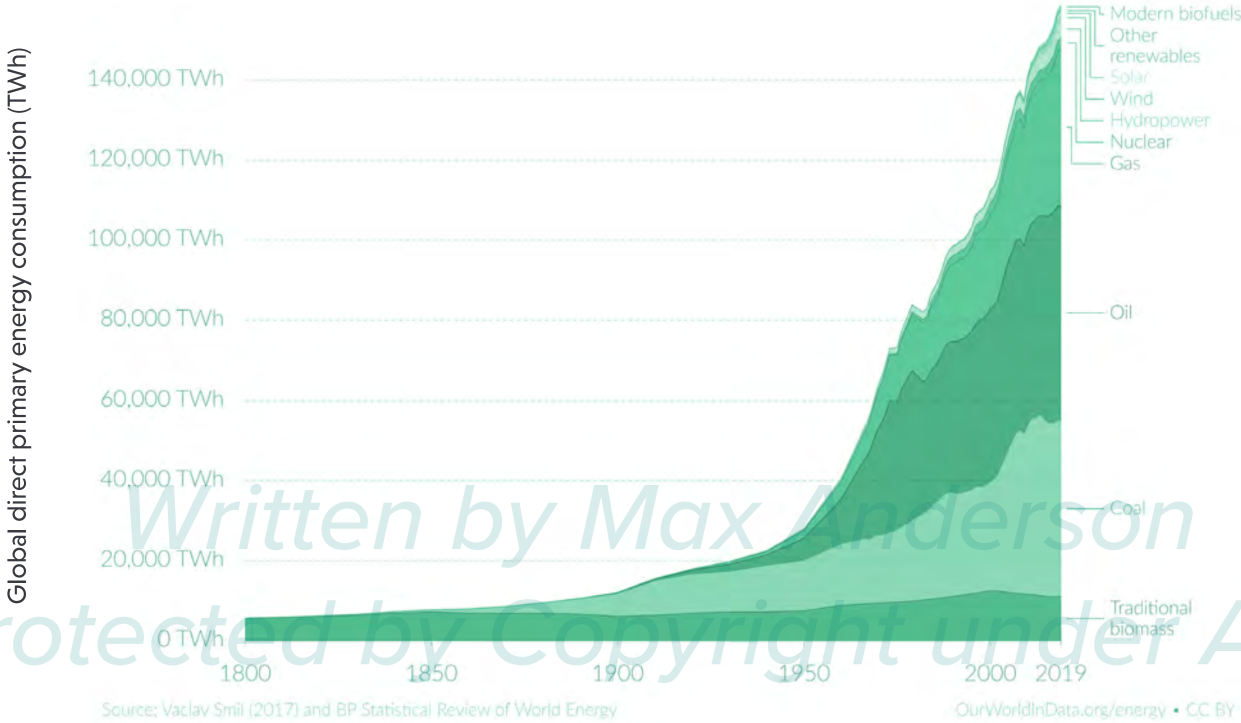


Figure 9 - Global Direct Primary Energy Consumption, 1800-2019 [OurWouldinData (direct from source)]

is fundamentally shaping the social practices people perform, and may become a new social norm that encourages increased passive and active energy usage (Strengers & Nicholls, 2017).

In the same way that past home automation technology (e.g automated washing and laundry machines) were once new and exciting, but now commonplace, smart home devices pose the risk of also becoming mainstream/ common place, where it is more noticeable to be without them than with them (Strengers & Nicholls, 2017). However, there is potential to generate or re-approach "lower energy visions for everyday life" using the same technology to create better behavior in the home.

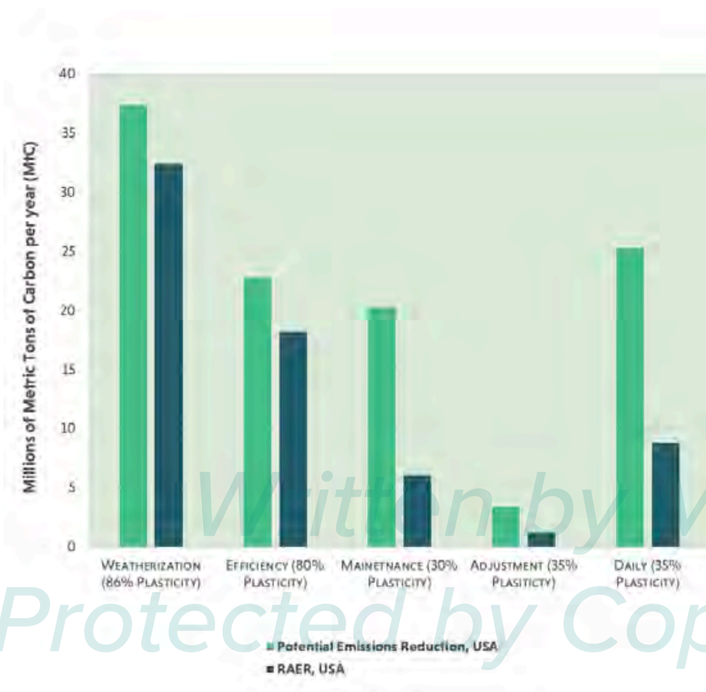


Figure 10 - Achievable Carbon Emission Reductions in the USA from Household Actions, 2009 [Dietz et al. (Summarised, excluding transportation Actions)]

RAER stands for Reduction in national CO2 emissions at year 10 due to the behavioral change from plasticity, expressed in MtC/yr saved and as a percentage of total US individual/household sector emissions (%I/H). Both estimates are corrected for double counting.

Section 3 - Behaviour change versus current practices

Studies have shown positive improvement (decrease) in household emissions from utilizing behavior change to re-approach how people view their consumption. A behavior change study conducted in the united states in 2009 (Dietz et al,. 2009) showed that there was a 20% reduction in direct household emissions with little to no reduction in the perceived well-being of the household (Dietz et al,. 2009). In fact, behaviour change was credited as a short term option with the potential for swift, substantial reduction in carbon emissions (Dietz et al., 2009).

As seen in Figure 10, changes that fell under Maintenance, Adjustment and Daily together would have high total potential reductions, but all suffer from low plasticity (Dietz et al., 2009) (see Appendix A for more). However, plasticity, and overall reductions, were increased by the usage of daily/continuous energy-use feedback (5-12%), and further increased by "Multi-Pronged Interventions" (15% or more) (Dietz et al., 2009).

Context and Application

Currently, households don't receive nearly enough feedback on their energy usage, which helps us to perpetuate uninformed and wasteful habits. Typically, the only information we receive about our energy usage is in our quarterly energy bills, revealing our total usage, an average daily usage, and comparing those figures to other households in the neighborhood (refered to as average home energy). It creates very little moment to moment accountability for our usage, unless we are overwhelmed by the figures we see in the bill (perhaps in comparison to other households).

Contented average users (seen in Figure 11), are debatably the most problematic type of home energy persona. This persona is the type of person that sees that they are perfectly average, or slightly below average home usage, and are content to remain where they are, not changing their routines. Over time, as our general energy usage increases, the average energy usage seen on electricity bills will also increase, and is likely to create more contented average users. Succinctly, content median users create an unintentional cycle of increasingly wasteful energy use habits (see Figure 12).

On the other hand, the ideal persona for reducing home energy usage is the one that continually searches for new ways to decrease their energy usage, whether for financial or sustainable incentives. As illustrated in the 2009 US study (Dietz et al., 2009) though, personas as such are hard to adopt and maintain, meaning many of them are likely to become contented average users without continual support, guidance and incentive.

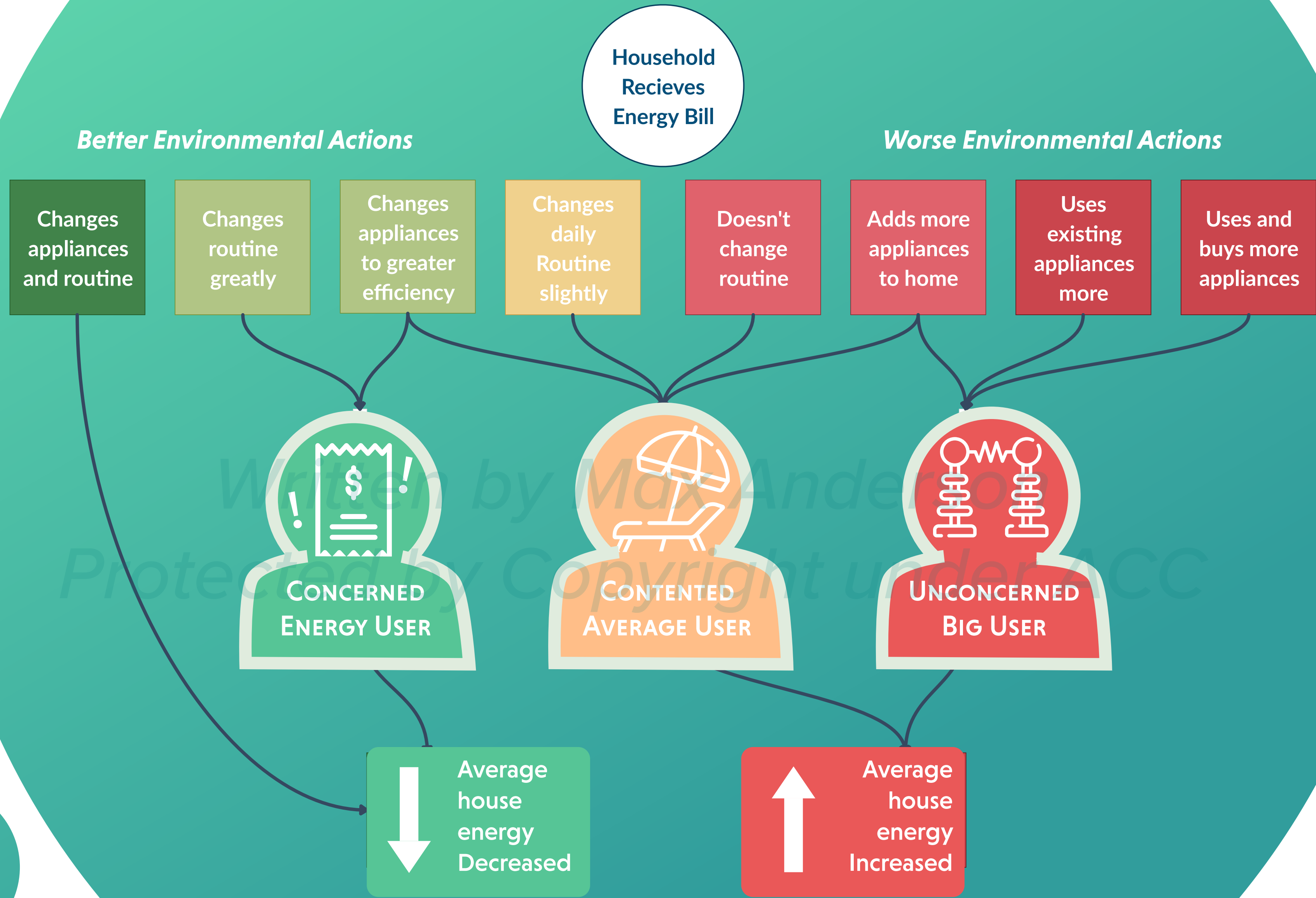
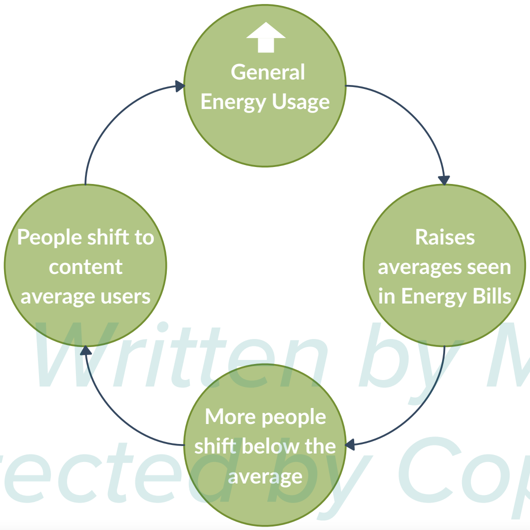
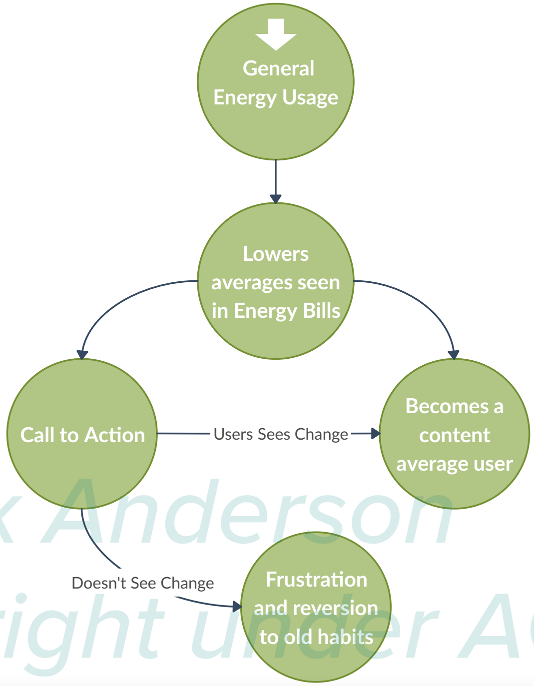


Figure 11 - Current State User Journey Map of Receiving Energy Bill (singular method of tracking)





Energy bill response with an increased average energy usage

- Lack of consistent feedback
- Lack of incentive for habit change
- Concerned consumers become content with their below average usage when comparing to increased average energy use

Energy bill response with a decreased average energy usage

- Motivation for change is difficult to maintain between bills (1 to 3 months)
- Difficulty in evaluating if routine changes have had an effect
- Yields frustration and/or complacency

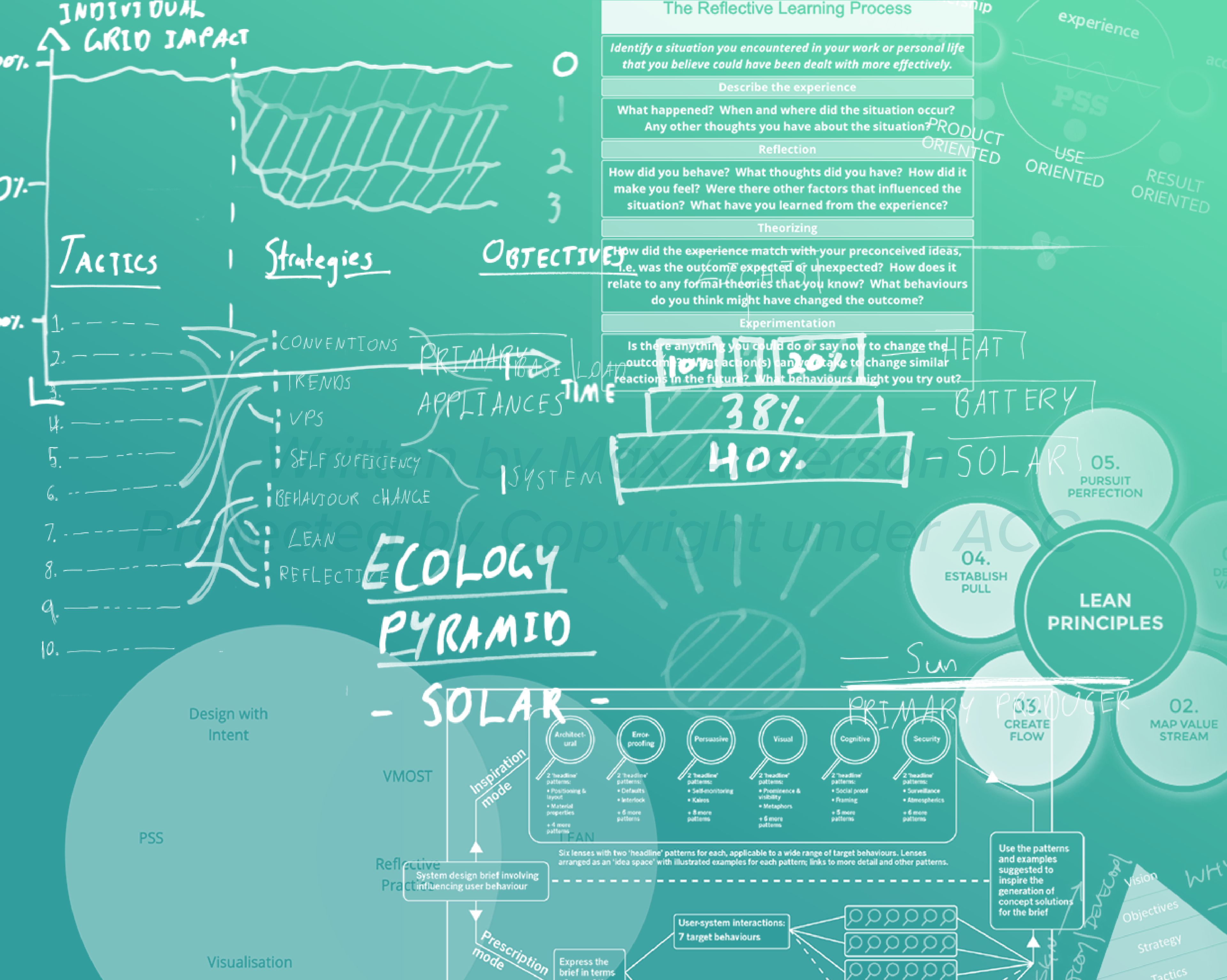
Figure 12 - Current state energy bill responses with households in increased and decreased average energy climates.

Discussion and summary

Globally our energy usage is steadily increasing from our actions. As this consumption continues to rise, so too will the strain on the networks delivering that power to us (Platt, 2018). The construction of new renewable resources takes time, and will not have a rapid change on our carbon emissions. However, changing our own practices can. It's been shown that there are a great deal of energy savings in our behaviors, but behavior change trials in the past have struggled with getting and keeping people on board with these programs.

The smart home technology that traditionally empowers our increased usage, could be re-interpreted to empower a different perspective on our energy. A smart home that makes its inhabitants smarter, and connects them closer with their home. Behavior change seems like a concept ripe with potential to assist in rapid change to help our communities, networks, and ecosystems.

"As consumption continues to rise, so too will the strain on the networks delivering that power to us."


INDIVIDUAL GRID IMPACT
TACTICS
Strategies
OBJECTIVES
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
CONVENTIONS
TRENDS
VPS
SELF SUFFICIENCY
BEHAVIOUR CHANGE
LEAN
REFLECTIVE
PRIMARY
APPLIANCES
TIME
SYSTEM
ECOLOGY PYRAMID
- SOLAR -
The Reflective Learning Process
Identify a situation you encountered in your work or personal life that you believe could have been dealt with more effectively.
Describe the experience
What happened? When and where did the situation occur? Any other thoughts you have about the situation?
Reflection
How did you behave? What thoughts did you have? How did it make you feel? Were there other factors that influenced the situation? What have you learned from the experience?
Theorizing
How did the experience match with your preconceived ideas, i.e. was the outcome expected or unexpected? How does it relate to any formal theories that you know? What behaviours do you think might have changed the outcome?
Experimentation
Is there anything you could do or say now to change the outcome? What action(s) can you take to change similar reactions in the future? What behaviours might you try out?
10%
20%
38%
40%
HEAT
BATTERY
SOLAR
Sun
PRIMARY PRODUCER
experience
PSS
PRODUCT ORIENTED
USE ORIENTED
RESULT ORIENTED
05. PURSUIT PERFECTION
04. ESTABLISH PULL
LEAN PRINCIPLES
03. CREATE FLOW
02. MAP VALUE STREAM
Design with Intent
VMOST
PSS
Reflective Practice
Visualisation
Inspiration mode
Prescription mode
Architectural
Error-proofing
Persuasive
Visual
Cognitive
Security
Six lenses with two 'headline' patterns for each, applicable to a wide range of target behaviours. Lenses arranged as an 'idea space' with illustrated examples for each pattern; links to more detail and other patterns.
System design brief involving influencing user behaviour
User-system interactions: 7 target behaviours
Express the brief in terms
Use the patterns and examples suggested to inspire the generation of concept solutions for the brief
Vision
Objectives
Strategy
Tactics
Written by Max Anderson
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03

Methods

Methods

Introduction

It is evident, that while technology has become smarter and more efficient, we are still utilising it in the same way as before. Homes have more devices than ever before, which is accounting for more energy usage. If we change the habits with which we use our devices, we are liable to see significant reductions with electricity consumption (Dietz et al., 2009).

In navigating towards a design solution, a variety of methods from two different disciplines will be used (Figure 13). A strong direction is fulfilled by the project's primary guiding methods of VMOST and Design with Intent, which brought focus and accountability to the deliverables of the project.

In addition, research through design was also assisted by the secondary exploratory methods of LEAN, Reflective Practice, PSS and Scenario Thinking. Through the application of these frame works and mindsets, the knowledge gained in previous chapters is tested, and further explored.

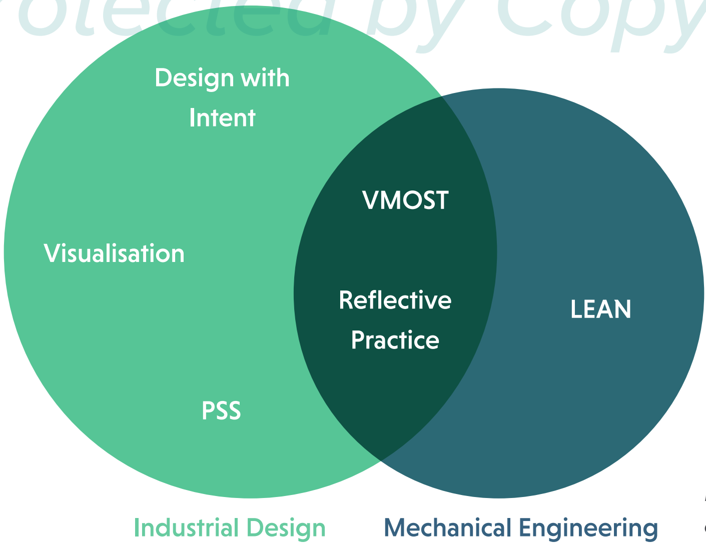


Figure 13 - Venn diagram of intersection between disciplines, and associated methods

Primary method - VMOST

VMOST is a strategy/analysis tool that aims to create focus by reinforcing a tangible and clear direction of a project (BAD Toolkit Ltd., 2019). VMOST breaks the bigger picture into actionable strategies and tactics that have been critical in finding and maintaining a steady direction for the project (BAD Toolkit Ltd., 2019). When establishing and enacting a new tactic, it helps to answer questions such as "should I be designing this thing" or "is there a place for this outcome in the strategy/objective/vision of my project".

VMOST is relevant to this project because it succinctly records objectives of the project, and keeps them visible within the hierarchy of the pyramid. This helps to influence lower elements of the pyramid addressing "how" the design meets the vision and objectives.

The strategies and tactics of the project is where VMOST shines the most. While there may be only one objective for this project, multiple strategies were used to achieve it (BAD Toolkit Ltd., 2019).

The strategies and tactics element of VMOST has been a good tool in organising the other primary method, Design with Intent, and the secondary methods. Figure 14 shows the organisation and layout of these elements in reaching the objective, with Figure 15 breaking down the specifics of each part.

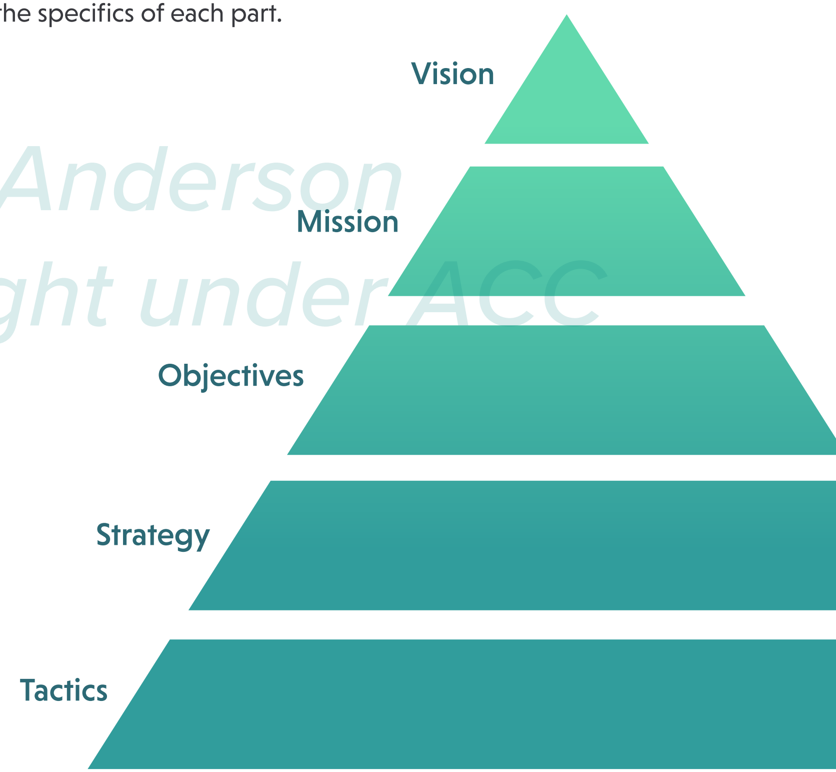


Figure 14 - VMOST Pyramid

Methods

Tactics

Review existing research literature

Investigate existing application design

Determine points of intervention

Characterise Personas

Develop attractive design and rewards

Test prototypes consistently

Solidify design objectives

Determine ideal features

Consider price, manufacture and budget

Seek guidance from others

Strategies

PSS

MVP

Behaviour Change

LEAN

Reflective Practice

Design with Intent

Visualisation

Scenario Thinking

Objectives

Design a system that supports energy efficiency through technical innovation and behaviour change

Decrease and equalise electricity grid load

Mission

Support and empower sustainable behaviour changes that reduce energy usage and carbon emissions

Vision

A return to less wasteful and more environmentally attuned living

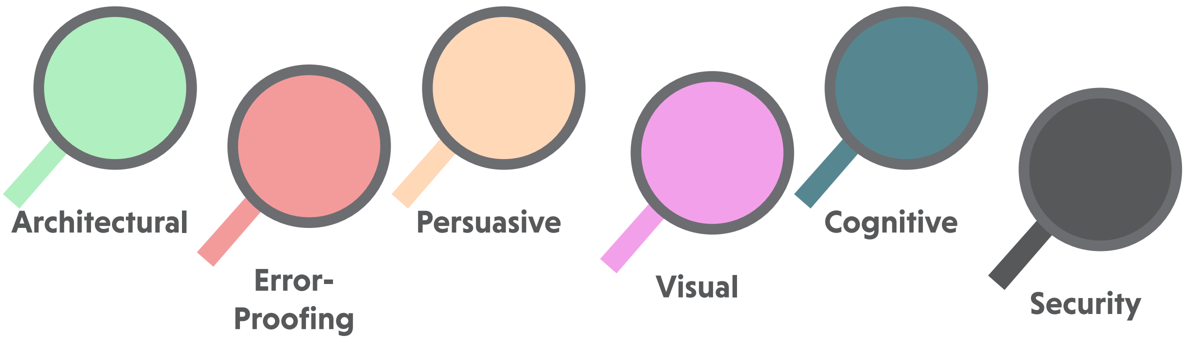
Figure 15 - Full VMOST Map (see figure 14 for reference)

Primary method - Design with Intent

Design with Intent can be defined as a conscious act of design intended to influence behaviour of those who use your product/system (Lockton et al., 2010). Generally, this method of design begins with a target behaviour, that is directed through informed, cyclic, "trial and error" design (Lockton et al., 2010) (shown in figure 16). However, where target behaviour can be reached through error proofing a product/system, Design with Intent also aims to provoke attitude change (Lockton et al., 2010).

Design with Intent applies to this project in terms of finding effective ways of rewarding and motivating a change in behaviour. It can be applied in one of two modes; Prescription (Figure 16) or Inspiration. This is especially effective because it allows for a designer to explore and test different techniques.

This method will be applied in tri-weekly tests to help determine the plasticity of different methods, and how people respond to different methods of behaviour change.



Six lenses, applicable to a wide range of target behaviours. Lenses arrange as an 'idea space' with illustrated examples for each pattern; links to more detail and other pattern.

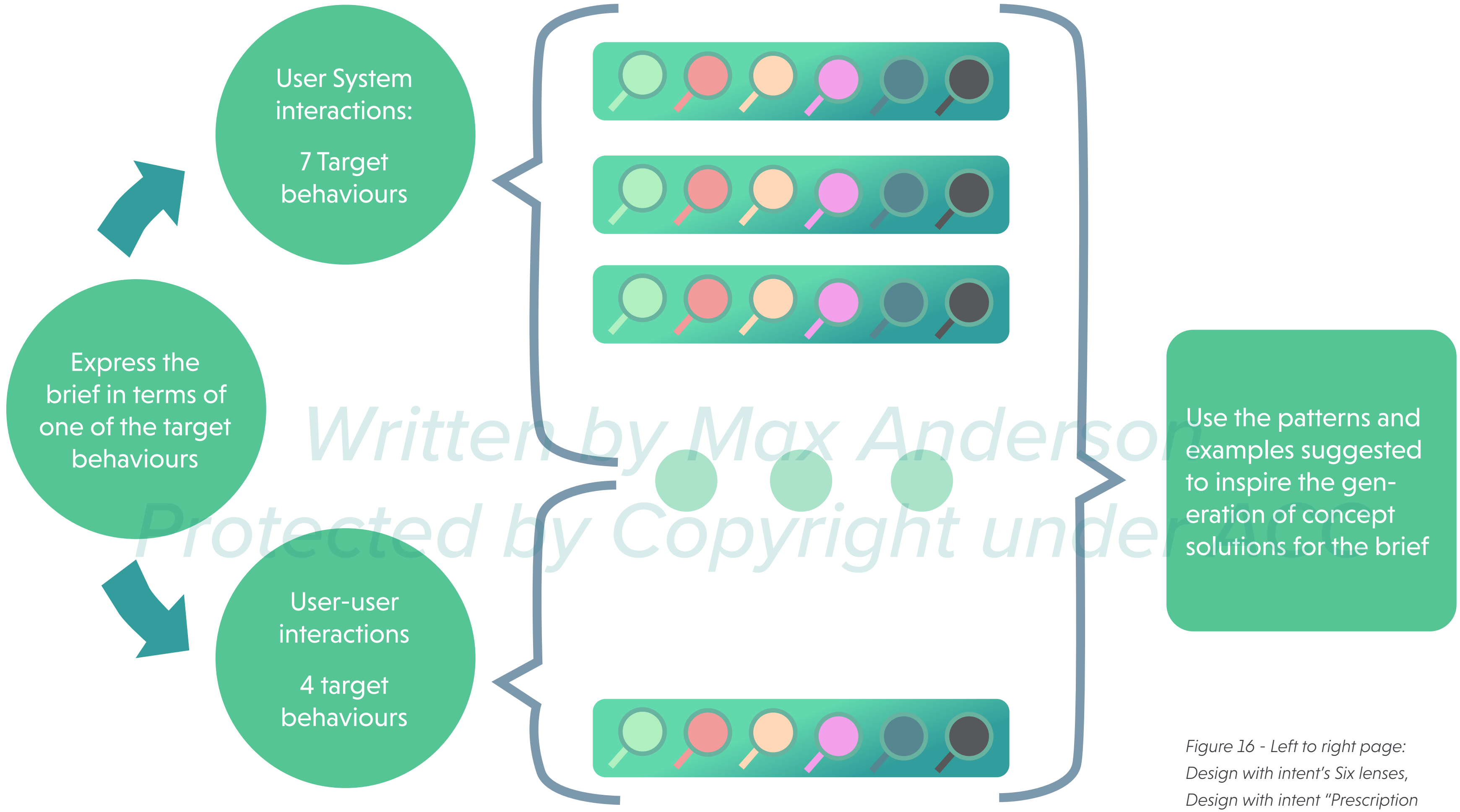


Figure 16 - Left to right page: Design with intent's Six lenses, Design with intent "Prescription Mode" (Lockton et al., 2010)

For each target behaviour, a subset of the most applicable design patterns from the six lenses (see left) is suggested, with illustrated examples. Typically there may be 15-25 patterns applicable to each target behaviour.

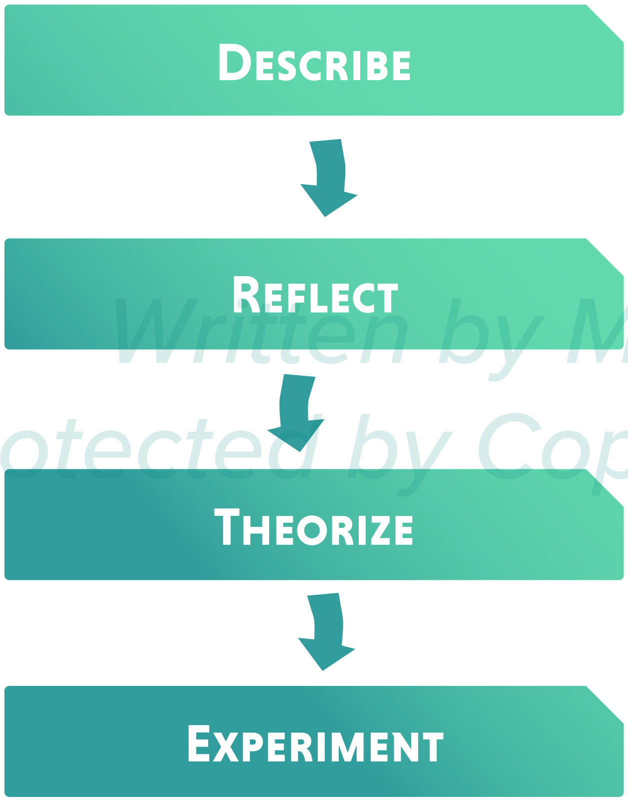


Figure 17 - 4 step process of Reflective Practice

Secondary method - Reflective Practice

Part of the process of striving towards behaviour change through design is the necessity for continual reflection on the various elements of design of this project. Reflective Practice isn't as much of a solidified toolset like Design with Intent is, but is a skill which can be learned and honed (Skillsyouneed, 2011) It is both the passive act of being aware and present, while also taking active steps to record and contemplate one's findings (Skillsyouneed, 2011). Figure 17 shows the process of reflection undertaken at the end of every week to record the experience of the goals fulfilled that week, but also to act as a method of quality control.

Reflective Practice works hand in hand with VMOST by bringing in habits and processes to look back on the what has already been recorded/done, and work from there. It has also assisted with generating more benefit than methods that framework don't explicitly use cyclic action and reflection, such as LEAN.

Secondary method - Lean

Lean is a Framework that aims to maximize customer value while reducing or eliminating waste (Lean Enterprise Institute, 2019). Lean aims to increase value and reduce waste by utilising 5 directed principles (see Figure 18). As described by the Institute of Lean (Lean Enterprise Institute, 2019) the Principles of Lean are the "Five-step thought process for guiding the implementation of lean techniques".

Since the project is about maximizing value of weather, timing and energy usage to minimize waste, Lean is the perfect method in searching for areas of improvement. Traditionally, Lean is seen as a tool used for optimizing manufacturing processes of a manufacturing cell (Lean Enterprise Institute, 2019). In the context of this project, a household that collects, stores and processes various resources could also be compared to a manufacturing cell. Utilising Lean has established clear and sustainable pathways that the user is encouraged to perform through the use of the Product Service System.

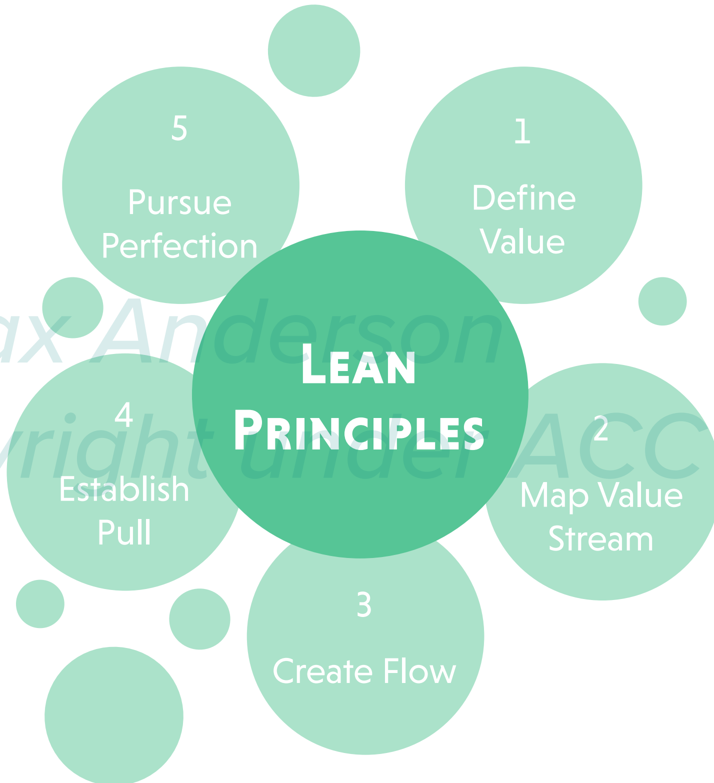


Figure 18 - Principles of LEAN (Lean Enterprise Institute, 2019)

Methods

Secondary method - Product Service System

A Product Service System (PSS) (see Figure 19) is a broadly defined design method that provides a combination of products and services that work together to satisfy a particular demand (Vezzoli et al., 2018). There are a wide variety of factors to consider, such as product ownership, financial schemes etc, that influence how the PSS looks (Vezzoli et al., 2018).

In the case of this project, a PSS acts as the method of delivery for behaviour change, incorporating external databases of user data with the internal system of the users household appliances/inhabitants. The Product element of the PSS is essential in giving the user a tangible way of accessing and interacting with all of the interconnected systems. Providing a service system enables the ability for these systems to change as new information comes to light. In many ways, this method of communication/ delivery is very similar to other smart home products such as Google Home or Nest, but the interaction will be more system led than user led.

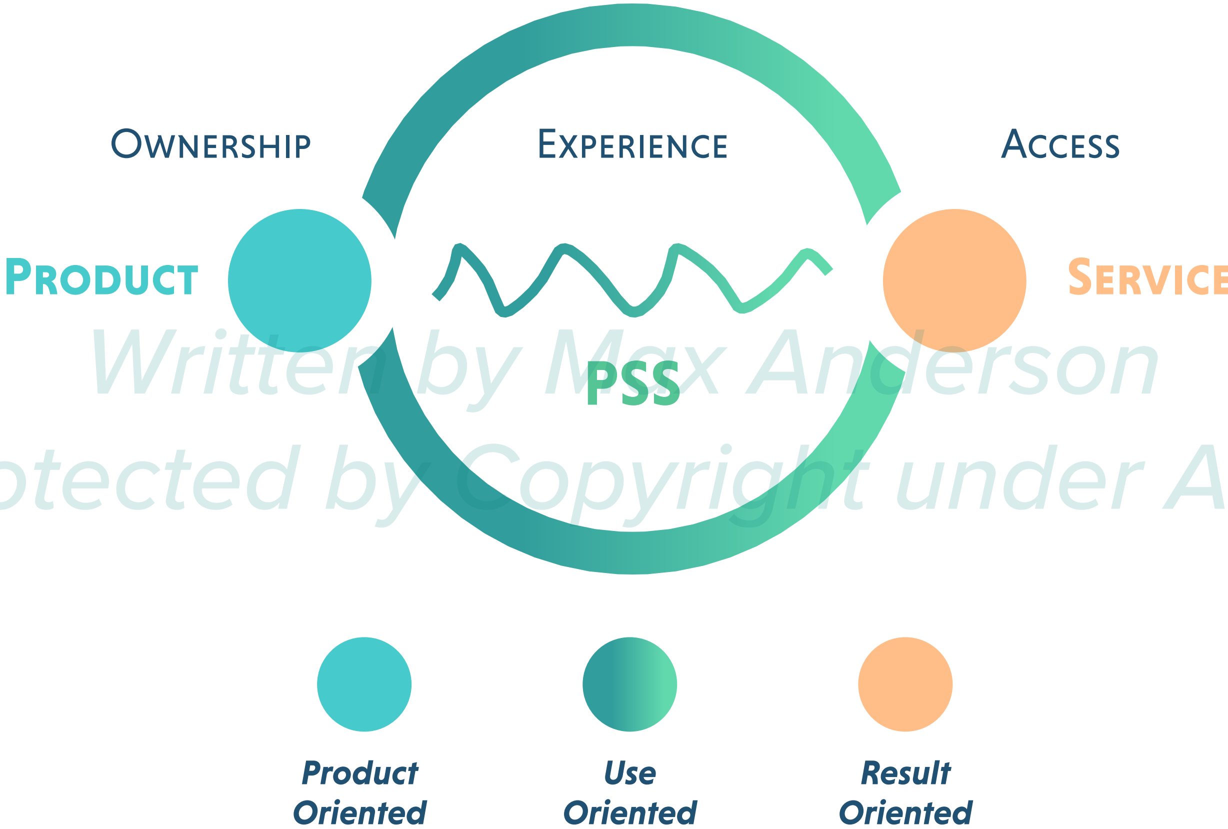


Figure 19 - Product Service Systems Diagram Explanation (Tonus, 2014)

Methods

Secondary method - Scenario thinking

Scenario Thinking is building and utilising believable narratives to visualise existing behaviours and future cast change via the designed intent (Martin & Hanington, 2018). Scenario Thinking is both a design method and a communication method that can be used further down the line.

In the context of this project, there are three main scenarios of living that have to be taken into account: houses, villas and apartment blocks. All of these places have been characterised with electricity related information such as; what is the home's existing usage, what appliances do they have in their home, what are the inhabitants' core routines etc.

Scenario Thinking throughout this project has enabled the broadening of designer field of practice and allowed for the testing of ideas in different environments. This has proved to be a useful tool in both gaining better user access, or building empathy for a specific use case.

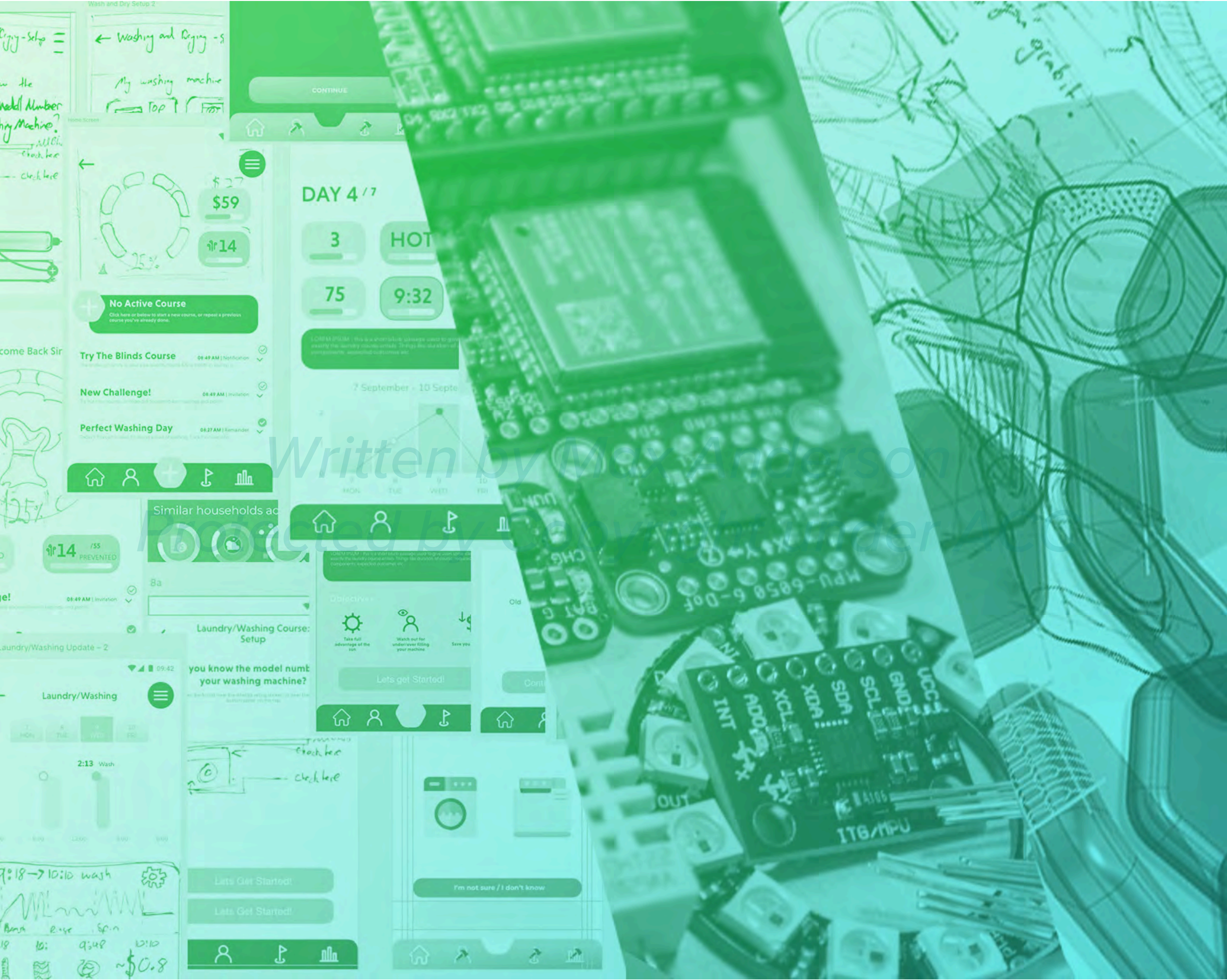
Secondary method - Visualisation

Visualisation, in this context, is showing an intangible or invisible element in a communicative and expressive form. Using Visualisation will help a designer to better *see things*, and also communicate to stakeholders. Visualisation is an especially broad method, but for the context of this project, it has been more thoughtfully applied to the communication of data, interface and integration to the user.

An example is the way that the Fit Bit visualises a wearer's exercise and habits, quickly communicates outcomes, and compares it to their intended goals. It is used as a method to visualise and motivate behaviour. Visualisation will be applied in the forms of Home Life Mapping, User Data and Recontextualising sensor data

Discussion and summary

Through these methods, this project will be targeting an empathetic, on the ground solution that will generate needed behaviour change in appliance usage. Primary method Design with Intent, combined with LEAN and PSS, can create a system that helps to reduce energy waste from the house. Coupled with Scenario Thinking and Visualisation, events in day to day life can be formulated into opportunities to maximize the utility of energy you have, and save for a later date. Finally, VMOST acts as the "North Star" of the project, to guide and direct all of the research through design towards a vision. VMOST will be acting as a "LEAN enabler" to ideally make up for lost time, and to propel the project quickly into the next phase of development.


CONTINUE
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75
9:32
No Active Course
Try The Blinds Course
New Challenge!
Perfect Washing Day
Similar households ac
14 /55 PREVENTED
Laundry/Washing Course: Setup
you know the model numb
your washing machine?
Laundry/Washing
2:13 Wash
Lets get Started!
I'm not sure / I don't know
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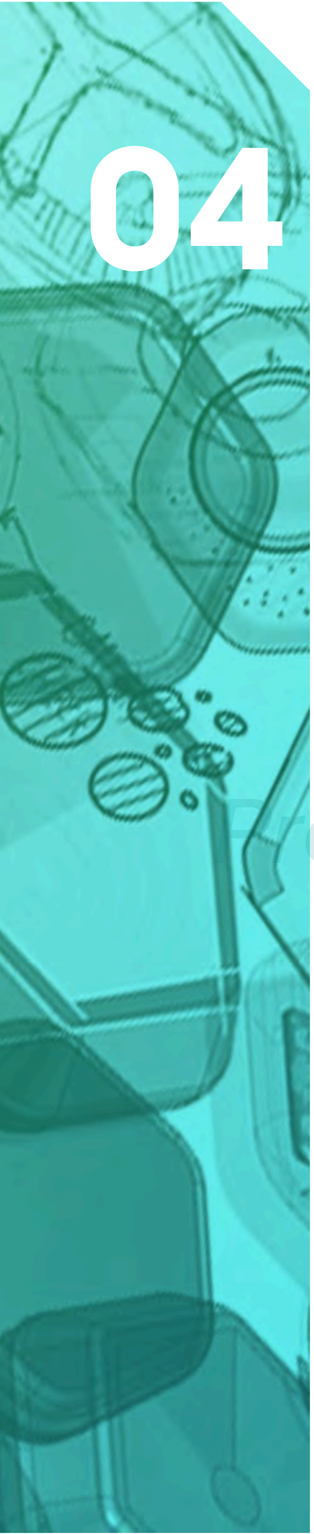


Design Development

Design Development

Introduction

After background research and consideration, the idea being developed was to reinterpret smart home technology to provide a different, more environmentally positive perspective on home energy usage. Following through with the methods highlighted in the prior chapter, the development journey began with building an understanding of relevant existing solutions, before moving to do further research, and finally, using classic design iteration.

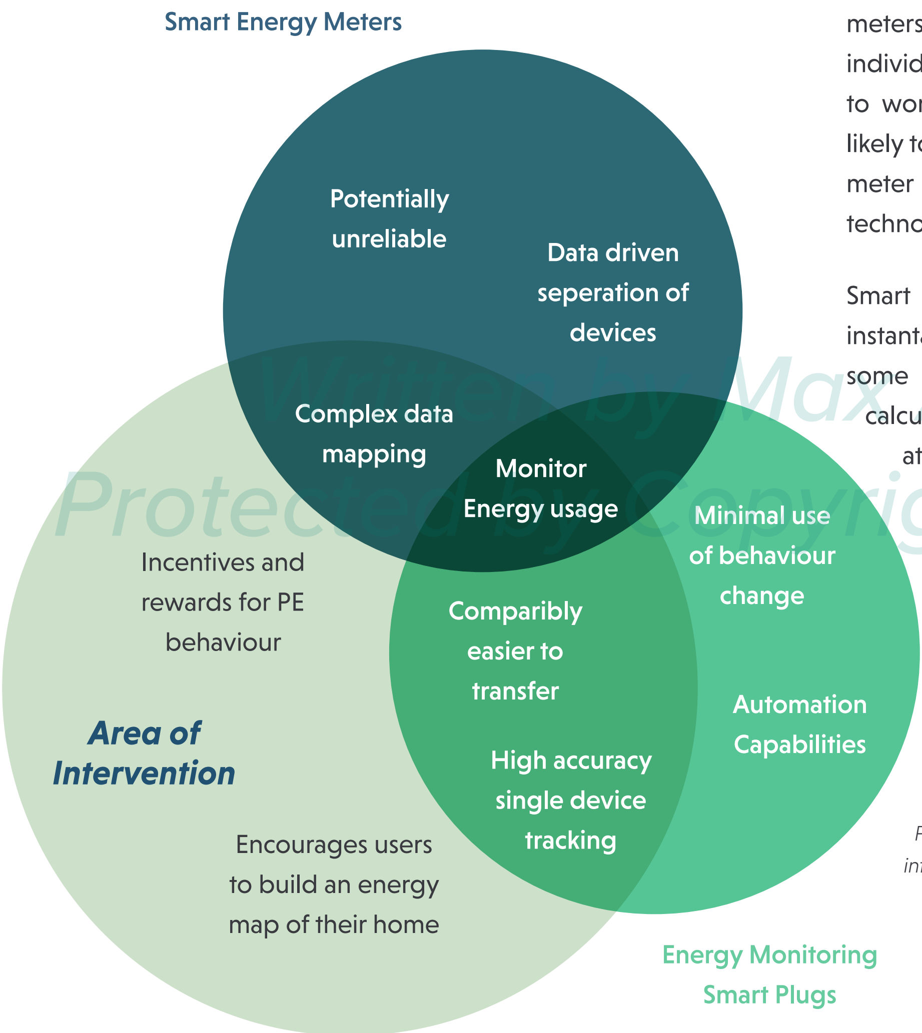
Preface - Continued research: Market and justification

This stage began by looking into existing smart home solutions that were promoting a different message to the traditional connotations of luxury and leisure. More specifically, smart energy meters and smart energy plugs (examples seen in Figure 20). Numerous devices were viewed and analysed, and various conclusions and comparisons were made.

It was found that there are a variety of smart home energy meters that take a household wide approach to measuring energy consumption. Devices like these have been in the market place for quite some time, though recently, newer products are able to determine and track individual home appliances based on their energy signals (Wollerton, 2017). The Sense Energy Monitor has this feature, and while the technology sounds great in theory, in practice it takes time to find new appliances, and doesn't work accurately all the time (Wollerton, 2017).

Figure 20 - Collection of smart home appliances; (From left to right, top to bottom) Sense Home Energy Monitor, Tp-Link Smart Plugs, Power- pal, Reduction Revolution, Kill A Watt, Wemo, Power-

Design Development



An additional issue with these smart energy meters is that they require access to your individual energy meter/sub meter for them to work. People who live in apartments are likely to not have easy, or secure access to their meter and will generally be unable to use this technology.

Smart energy meters are great at visualising instantaneous and long term energy usage, some incorporating live tariff features to calculate how much you're paying for energy at an instant (Wattcost, 2017). Products like Powerpal and Wattcost include some element of investment calculation, and Wattcost includes direct, data centric strategies for finding savings around the home (Wattcost, 2017).

Figure 21 -Venn diagram of starting established area of intervention

These products give you the tools, but in general leave the process of bettering behaviour up to the user. Smart plugs are very similar in this regard. Most smart plugs simply enable automation capabilities on non-smart devices, but some also include energy monitoring services (TP-Link, 2017). Even then, the energy monitoring services are generally minimal, only offering data on instantaneous consumption, and consumption over predetermined periods such as a week, month or since connected. For research purposes in tracking individual appliance energy usage, a 3rd party software had to be run on a separate machine to intercept, and log the instantaneous consumption over time.

Smart plugs do have three main advantages. They can be used in practically any household; are the most reliable way of finding individual appliance consumption; and can be moved around the house from device to device. These features are an ideal basis for a device that looks into device usage behaviour, but since the current utilisation lacks clear data mapping, and ease of transfer between devices, is not being utilised in such a way.

This posed an excellent query that matched with this projects' goals. This led to thinking about combining the more complex data mapping seen in energy meters, with a sensor that is far easier to transfer between home appliances. By combining traits of the existing solutions, a potential idea for an easily transferable energy usage device could be a new technology to provide energy tracking to a new or broader demographic of people (see Figure 21).

This would make mapping home energy usage more accessible to those who don't have easy access to their energy meter. Ideally, something that could be mounted onto a home appliance, instead of at the power socket. These ideas led to consideration of the potential of measuring the forms of energy an electric appliance gives off when it is being used (e.g heat, vibration, light etc) and using that to accurately estimate appliance consumption, based on some metrics specific to the appliance being measured.

Design Development

Section 1 - Design development plan; Designed artifacts

Following the conclusions highlighted in the preface, the direction that this honours project would pursue became clear:

"Develop a Multi Sensor Tool that accurately converts measurement of waste energy emitted from an appliance (such as vibration or heat) into data on electricity consumption. The multi sensor tool will be paired with a visual interface that presents this data to the user, and intelligently uses this data to propose specific methods of how to reduce/shift their usage to save money and utilise more renewable resources. The visual interface will use a variety of emotionally motivating techniques that aim to keep users interested, and solidify long term habits. Thus, the Multi Sensor Tool and the Visual Interface together create a Product Service System (PSS) focusing on generating interest in energy usage behaviour and changing it"

The targeted design outcomes were split into three artifacts seen on the following page to build the one product service system:

Interface Prototype

The interface is the key element in driving the behaviour change this project has set out to accomplish. It is what links the multi sensor tool to the user, so that its data has much more meaning. For this design artifact, this project will construct an interactive prototype app interface using Adobe XD, or similar interactive interface program. The interface prototype should show the breadth of its intended capacities, and should speak for itself.

Multi Sensor Tool Model

As the second half of the PSS, the Sensor is what collects the data to be interpreted by the app and the user. As such, it is an important part of the product eco-system, and should not only look appealing, but should also provide as little resistance as possible to using the PSS. For this design artifact, this project will generate an accurate, realistically considered 3D cad model and present it in context. The CAD model will aim to use the same components used in Artifact 2, the feasibility prototype.

Feasibility analysis

The Sensor relies on reliably measuring other sources of energy (vibration, heat, etc) released by an electrical device, and using this to estimate its energy consumption. This concept should be tested, and validated. For this design artifact, this project will construct a real life prototype version of the sensor using feasible components, and use it to collect data, and correlate this with direct energy consumption data from a smart plug.

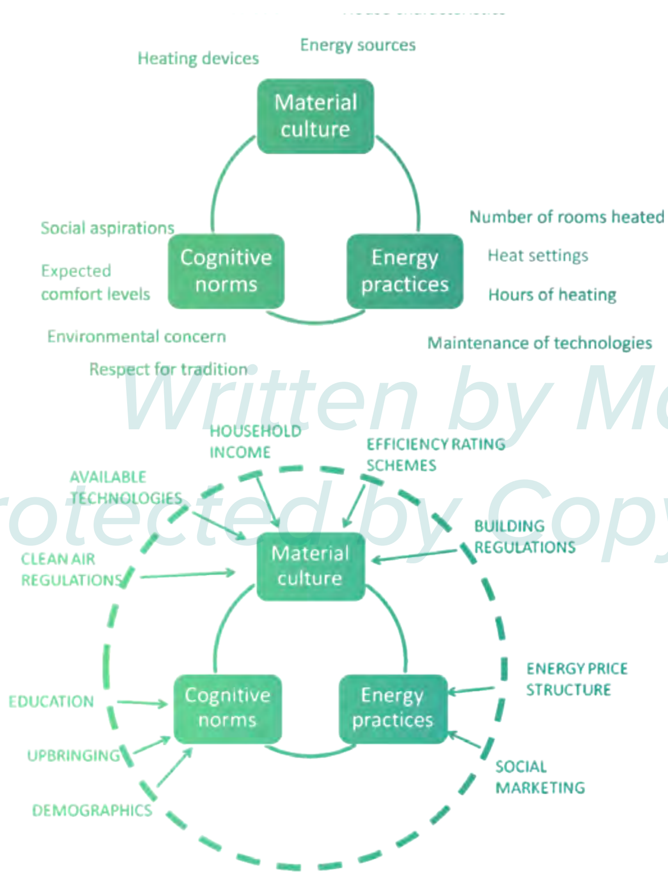


Figure 22 - Energy Culture's Framework, Top to Bottom: Characterising heating behaviours, Depicting wider systemic influences on behaviour (Stephenson et al,. 2010)

Section 2 - Interface development

Subsection 1: Environmental behaviour research review

While the interface is an important feature in creating clear, coherent pathways between parts of the application, the interface is also essential in employing techniques that are more likely to keep users interested and engaged with reducing/shifting their energy consumption. Understanding what existing research has found in the realm of environmental action and user behaviour provided this project with a good foundation for incorporating behaviour change, which could be further explored through user testing and evaluation.

Numerous research studies have already been undertaken in this realm (Abrahamse et al., 2005), and the field continues to grow as new models are developed to account for different influencing factors (Sweeney et al., 2013). One of the simplest, and still relevant models is the Energy Culture's Framework (Figure 22) developed by Stephenson et al (2010). As noted by their research paper

"The Energy Cultures Framework suggests that consumer energy behaviour can be understood at its most fundamental level by examining the interactions between cognitive norms (e.g. beliefs, understandings), material culture (e.g. technologies, building form) and energy practices (e.g. activities, processes)" (Stephenson et al., 2010). Within this framework there are a multitude of barriers to Pro-Environmental (PE) Behaviour, but some of the core barriers gathered from research in relation to this project are money, cognitive biases/human factors and the individual's locus of control.

Money is both a great motivator and a difficult to overcome barrier (Blake, 1999). Energy efficient actions (primarily installing insulation and more efficient appliances) which create large home energy reductions, also have large resistance to adoption due to the generally steep price tag (Gardner & Stern, 1996). This is partially why curtailment actions (switching off lights, adjusting washing schedules) are much more readily implemented (Gardner & Stern, 1996). Even if money isn't an issue for an individual, money may continue to act as a barrier. This is reinforced by the idea that as long as their energy bill is affordable, there is no need/motivation to change their behaviours to reduce it (Sweeney et al., 2013).

Human factors, specifically a lack of self efficacy, is another core barrier to PE behaviour (Iwasaki, 2019). Individuals may believe that they don't have the ability to make changes to their energy usage, or that changes to their energy usage will not have a significant impact, so they therefore don't attempt it (García et al., 2017). Even if someone does have the motivation to create change in their household, their locus of control (derives from living factors such as renting or ownership, weather and building characteristics, conflicts from co-habitation) may provide enough resistance to dissuade the individual to do otherwise (García et al., 2017). This resistance can be partially overcome by good implementation of motivation techniques, or motivators. Research for this project found that three core motivators were money, feedback, and goal setting.

Money is the prime motivator for reducing/ shifting energy consumption (Blake, 1999).

Design Development

For example, among EU countries (Belgium, Bulgaria, Czech, Denmark, France, Germany, Greece, Hungary, Norway, Portugal and Romania), energy savings were motivated mainly due to financial reasons (63% on average). Greenhouse gas reduction had a much lower percentage (19.6% on average) (45% in Denmark and Greece) (García et al., 2017).

However, money is only as effective a motivator as the quality of the feedback provided. Consistently delivered, tailored feedback on a household's energy usage that includes clear figures on consumption and related price is essential in making energy consumption visible, and motivating action (Abrahamse et al., 2005). Feedback increases in influence if it is comparative, historic and provides a breakdown of energy usage within the home (García et al., 2017).

Tied in with feedback, research has also found that setting goals is another great motivational tool. Energy reduction goals, which seem difficult to attain, and are publicly declared, provoke stronger action.

From this research review, the core motivators will be implemented into the interface, and the core barriers will be considered for ways around them. The PSS already primarily focuses on curtailment action over efficiency action, but because curtailment actions have less of an impact than efficiency actions, implementing good methods of showing user influence and change within their usage will be crucial. It is especially important to solidify which curtailment actions in particular have the greatest impact, so these actions can be what the PSS is more designed to assist change and improve.

Subsection 2: Areas of Focused Impact

As previously discussed, PE actions can be difficult to encourage. The greater the carbon emission reduction of performing the action, the less willing people are to perform it (Dubois et al., 2019). Certain actions such as eating more vegetarian food have great potential emissions reductions (see Appendix 1), but aren't (easily) tied to the way a specific piece of technology or appliance works. This doesn't necessarily mean that it can't be explored within the breadth of this project, but the project's focus is tied more to its technology aspect.

Simply for the sake of showing the connection between the technology and the user interface, it was important to focus on two actions that exemplified this part. Dietz et al (2009) (see Appendix 2) showed in their research that thermostat setbacks on their own had a potential 10.1 MTC reduction if implemented across America; the highest emissions reductions that don't require making changes to the house itself, or driving.

However, reliably measuring and calculating heating/cooling usage (potentially using multiple sensors) would be difficult. The third and fourth most effective action in the Diet et al (2009) study), "Routine auto maintenance" and "change HVAC filters" also yielded high potential emission reductions, but these actions are routine, and can't be measured. There may be a method for reminding and encouraging these methods of reduction if the feedback was tailored enough to the user. The same goes for methods explored in Dubois et al.'s research (2019) (see Appendix 1, source 2); much of them would need specific sensors to measure, or are activities that the user pledges to undertake/perform routinely.

The intent was to build a sensor that was incredibly multifunctional, and could focus on finding even small energy use reduction potentials. Part of the battle of finding carbon reductions is simply in overcoming initial resistance to making changes around the house, no matter how small (García et al., 2017). Continuing from Dietz et al's research, actions of reducing laundry temperature and line drying have a significant impact; 6.5 MTC reduced if implemented across the entirety of America. The main feature of these two actions, the washing machine, easily lends itself to being monitored by the heat that it gives off, and how much it vibrates. Each phase of a washing machine cycle has a distinct type of vibration, and a could very easily be trained to sense those specific phases of a washing cycle. Accelerometers, for detecting and measuring motion, are fairly cheap electronic components. Depending on the type of washing machine, some amount of heat could also be detected through the front window of the unit, so a temperature sensor could be used.

Design Development

Subsection 3: UX Visual development/ method implementation

Understanding of how apps promoted and incentived good behaviour was developed by conducting a series of case studies on relevant apps (see Figure 23). Breaking down an entire household worth of energy consumption into smaller activities was reminiscent of a lot of habit change and self-improvement apps like Headspace. Headspace makes the seemingly daunting task of practicing meditation into something gradual, starting with basic courses made up of short, daily meditations. In many respects, energy reduction can also be a particularly daunting task, so apps like these were a good reference for existing material that handles changing and rewarding behaviour. Many of the techniques used within these apps resonated with the behavioural research already undertaken.

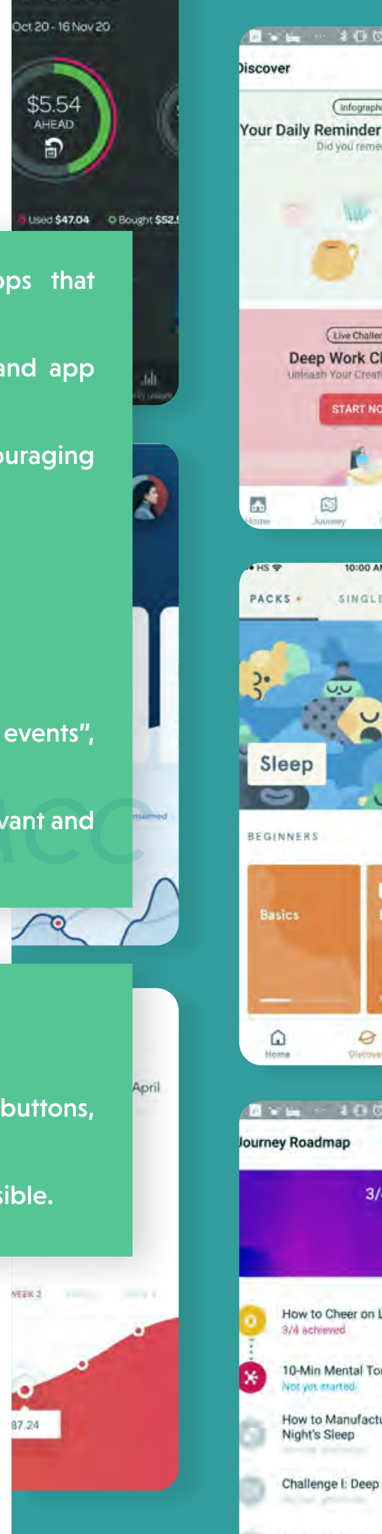
Another similar service to tracking your energy usage is tracking your physical activity. Google Fit and Apple fit, along with many other physical activity tracking applications such as Strong, Strava and FitBit were viewed for this

The main techniques used by these apps that provided design cues for this project were:

- Gradual introduction to app features and app ideas
- Empathetic, engaging and encouraging animations.
- A unique, fitting emotional style to text
- Clear and simplified navigation
- Streaks and rewards
- Gamification
- Reminders (notifications) for "habitual events", and inspirational dialogues.
- Easy data literacy, and data that was relevant and personalised to me

Where did others go wrong?

- Overwhelming right at the start.
- Visual noise/page furniture, unclear buttons, indicators, when to scroll etc.
- Language that isn't instantly comprehensible.



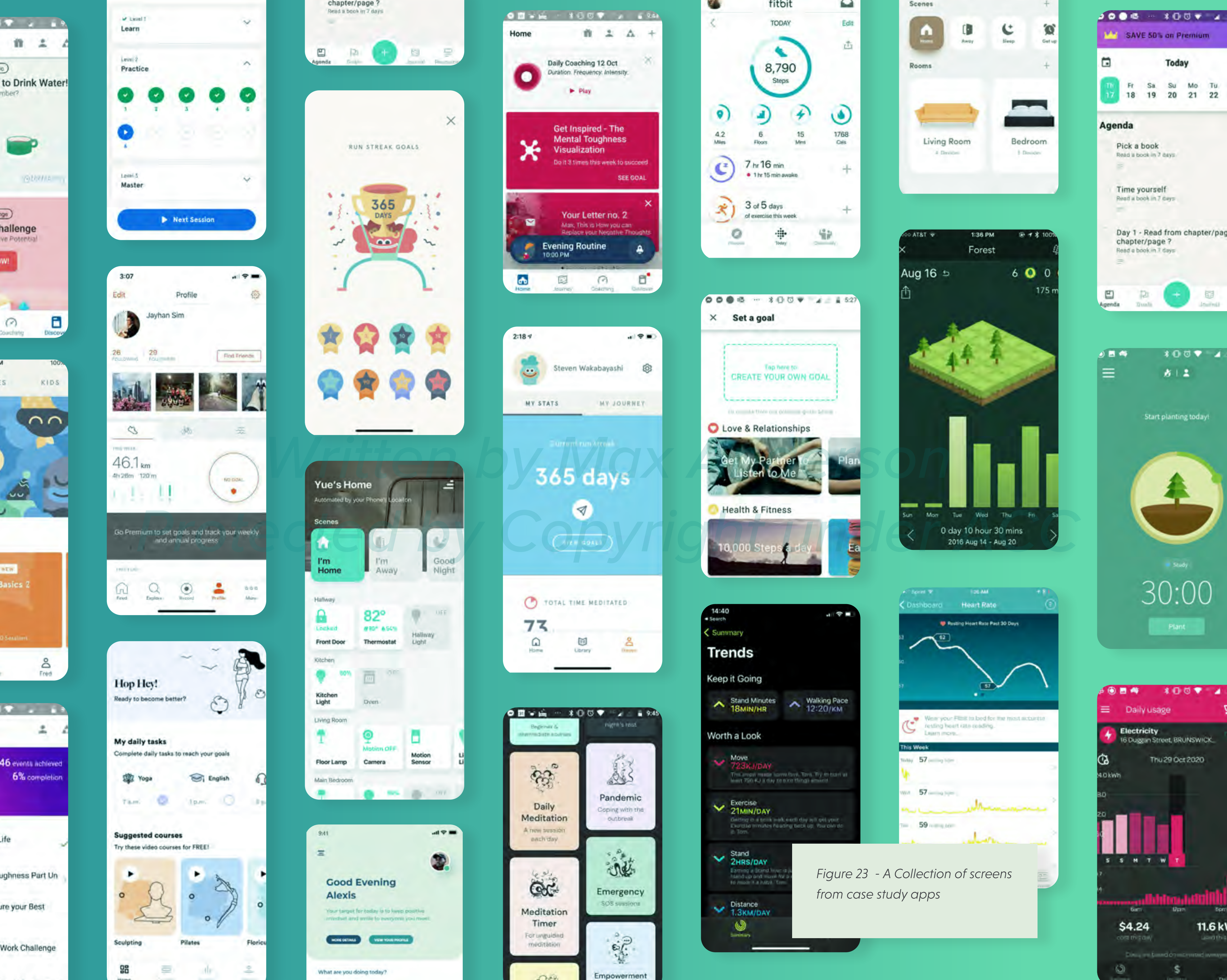
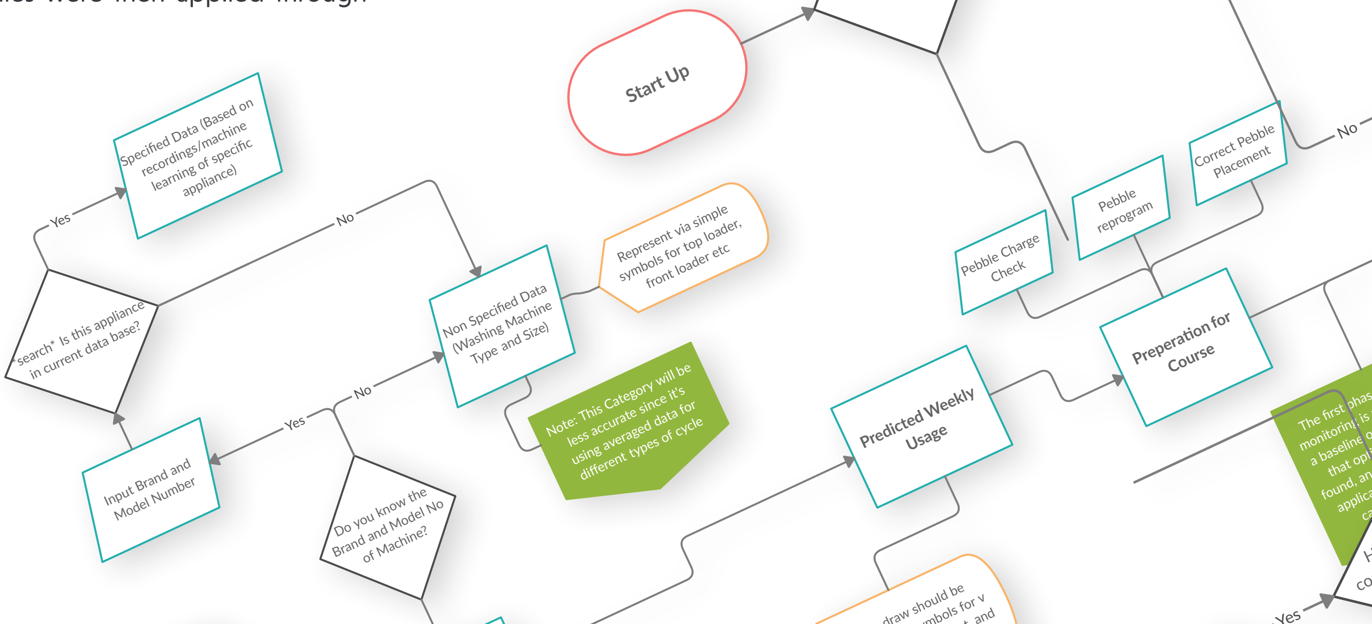


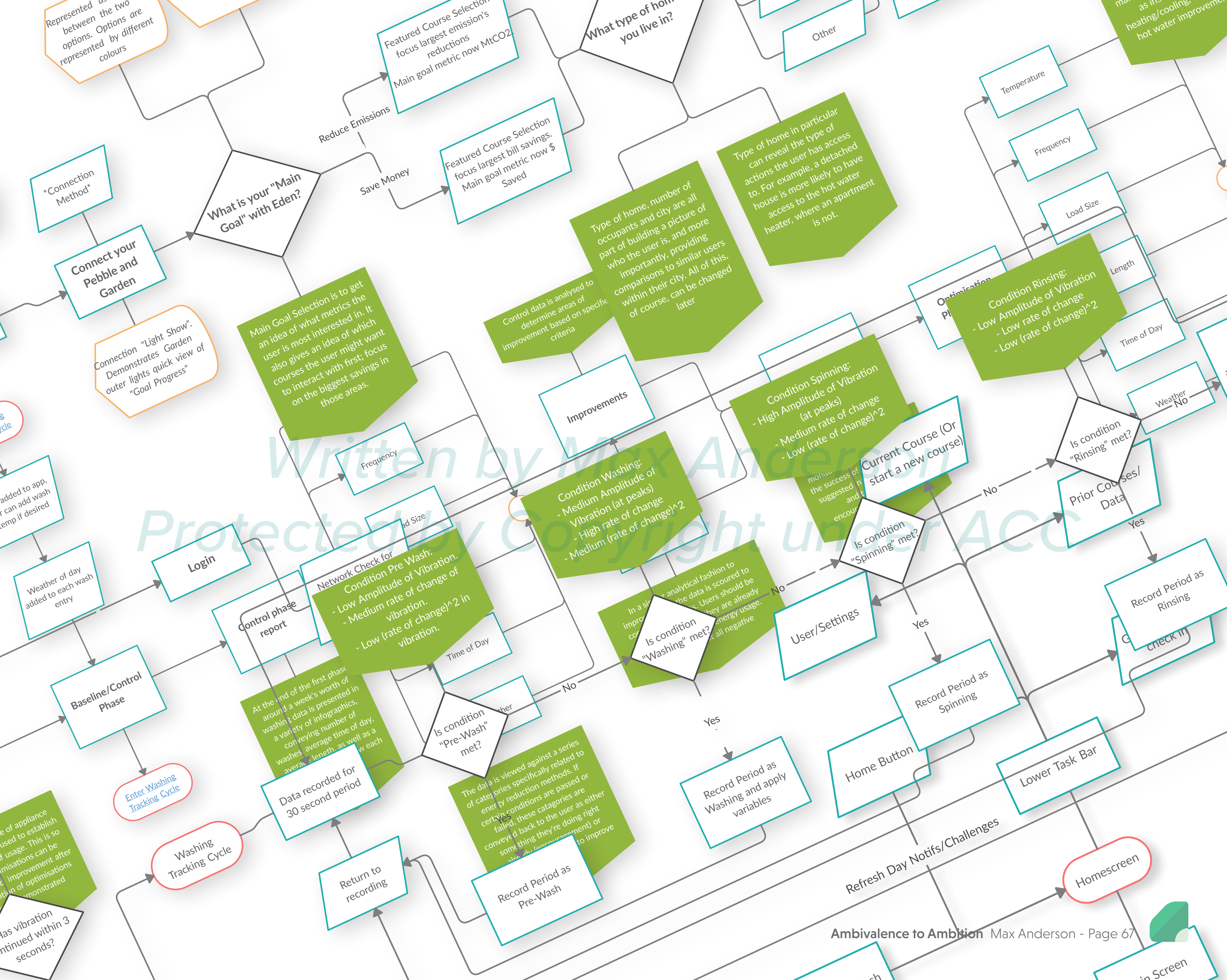
Figure 23 - A Collection of screens from case study apps

FitBit is particularly interesting. As another product service system, the FitBit is a wearable sensor that tracks your physical activity throughout the day, and records it within its application. The FitBit app also includes numerous motivation and social features that aim to encourage and celebrate physical activity. These include progress notifications, creating groups to compete with your friends, and earning milestone badges to display on your profile. In summary, FitBit and similar devices have successfully gamified physical exercise.

The relevant elements discovered through the app case studies were then applied through visual and user flow exploration. User flow was initially mapped out and considered by creating free form diagrams that explored navigation options, text, visual motifs, and intent (as seen in Figure 24). Having a visual, progressive reference proved to be helpful in understanding the path a user would take, as well as helping directly with the design and construction of the screens that would make up the visual interface.

Figure 24 - Snapshot of user flow diagrams used in the design process





between the two options. Options are represented by different colours
Featured Course Selection focus largest emission's reductions
Main goal metric now MtCO2
What type of home do you live in?
Other
as insulation, heating/cooling, hot water improvements
Reduce Emissions
Save Money
Featured Course Selection focus largest bill savings.
Main goal metric now $ Saved
Temperature
Frequency
Load Size
Length
Time of Day
Weather
Connection Method
Connect your Pebble and Garden
What is your "Main Goal" with Eden?
Type of home in particular can reveal the type of actions the user has access to. For example, a detached house is more likely to have access to the hot water heater, where an apartment is not.
Type of home, number of occupants and city are all part of building a picture of who the user is, and more importantly, providing comparisons to similar users within their city. All of this, of course, can be changed later
Connection "Light Show". Garden Demonstrates outer lights quick view of "Goal Progress"
Main Goal Selection is to get an idea of what metrics the user is most interested in. It also gives an idea of which courses the user might want to interact with first; focus on the biggest savings in those areas.
Control data is analysed to determine areas of improvement based on specific criteria
Improvements
Condition Rinsing:
- Low Amplitude of Vibration
- Low rate of change
- Low (rate of change)^2
Condition Spinning:
- High Amplitude of Vibration (at peaks)
- Medium rate of change
- Low (rate of change)^2
Current Course (Or start a new course)
Is condition "Rinsing" met?
No
Yes
Prior Courses/ Data
Frequency
Condition Washing:
- Medium Amplitude of Vibration (at peaks)
- High rate of change
- Medium (rate of change)^2
added to app, can add wash temp if desired
Weather of day added to each wash entry
Login
Network Check for
Condition Pre Wash:
- Low Amplitude of Vibration.
- Medium rate of change of vibration.
- Low (rate of change)^2 in vibration.
Control phase report
Time of Day
Is condition "Spinning" met?
Is condition "Washing" met?
User/Settings
Record Period as Rinsing
Baseline/Control Phase
At the end of the first phase around a week's worth of washing data is presented in a variety of infographics, conveying number of washes, average time of day, average length, as well as
Is condition "Pre-Wash" met?
Yes
Record Period as Spinning
Enter Washing Tracking Cycle
Data recorded for 30 second period
The data is viewed against a series of categories specifically related to energy reduction methods. If certain conditions are passed or failed, these catagories are conveyed back to the user as either something they're doing right
Record Period as Washing and apply variables
Home Button
Lower Task Bar
Washing Tracking Cycle
Return to recording
Record Period as Pre-Wash
Refresh Day Notifs/Challenges
Homescreen
Has vibration continued within 3 seconds?

Design Development

UX drawings (see Figure 25) were made specifically to fit the user flow diagrams. Through their construction they assisted in refining one another, before a solid enough idea of how the prototype would work was established. These UX drawings mostly concerned navigation placement and flow, though consideration still went into the visual layout of each screen. Some early UX drawing were imported into Adobe XD, and made interactive, so a crude, interactive prototype could be produced for personal use.

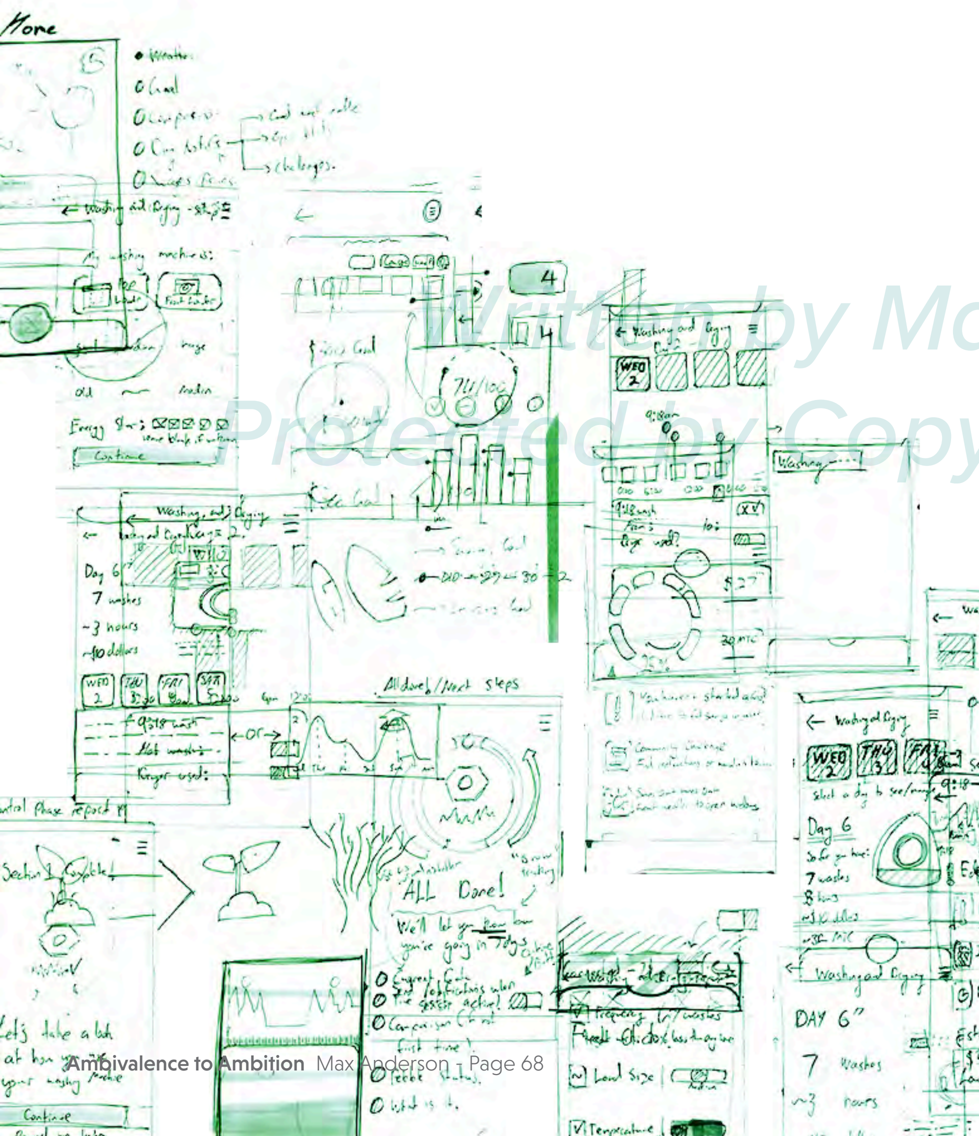
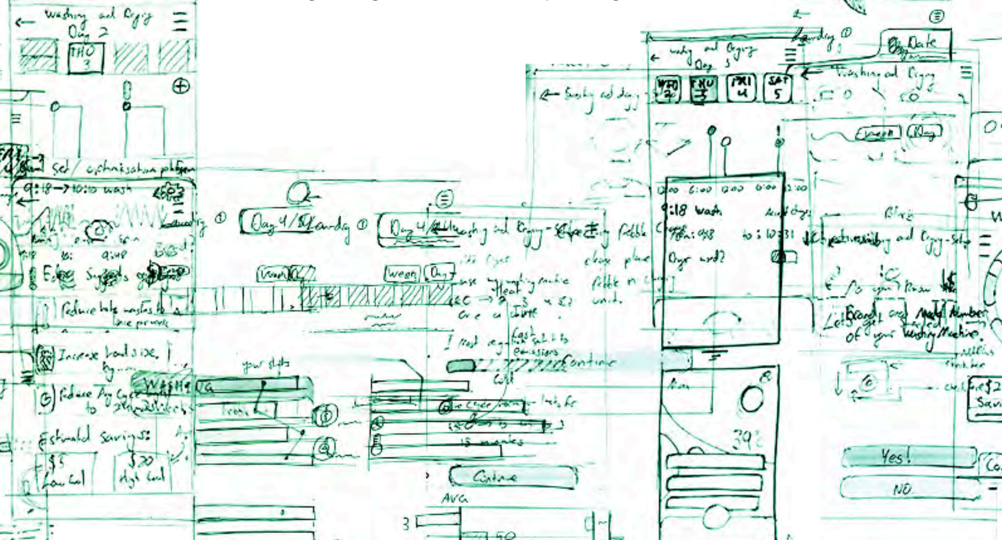
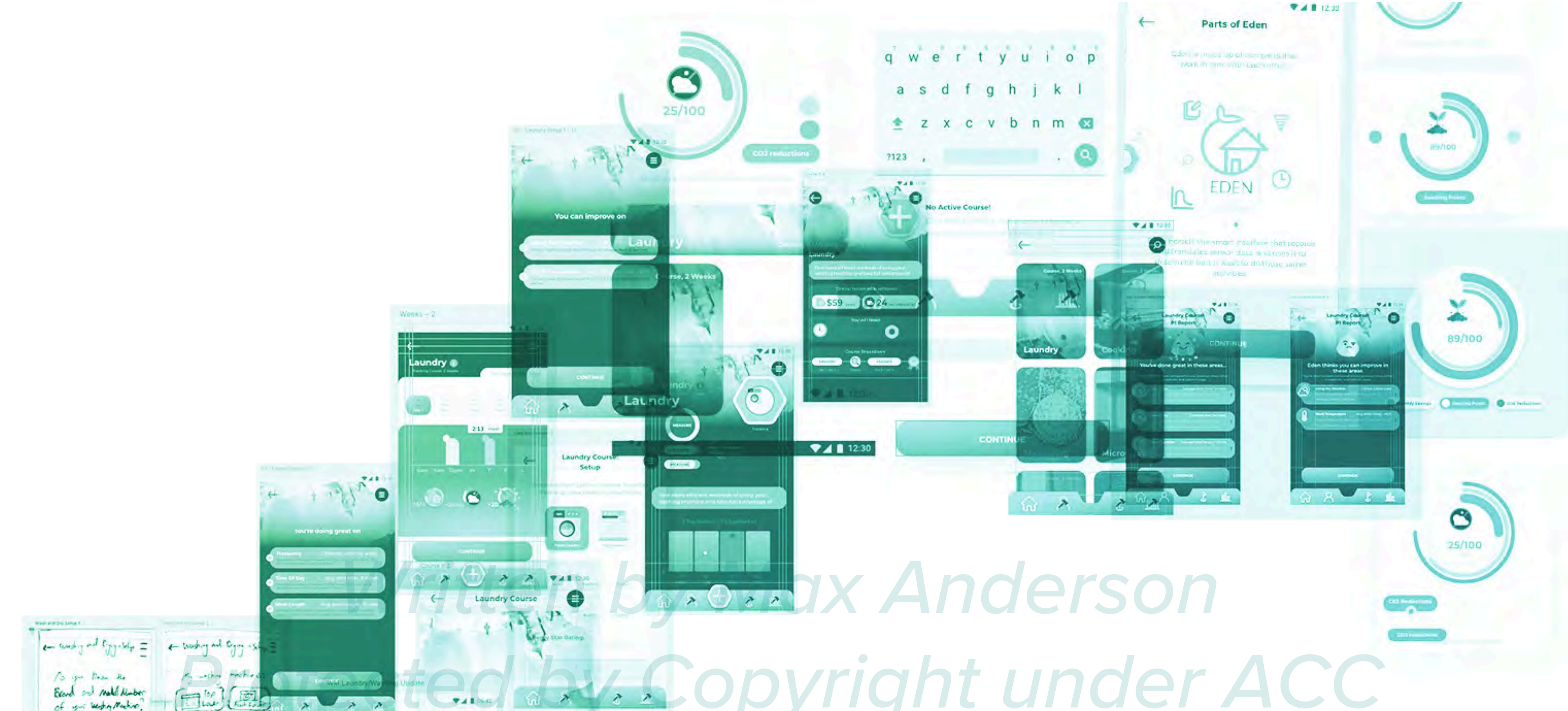
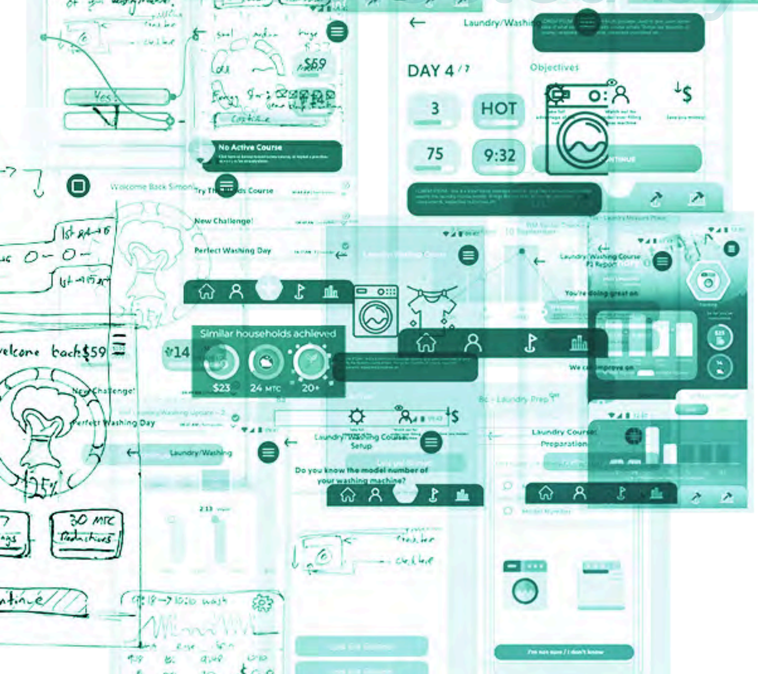


Figure 25 - The process of UX design, from drawing, to digital conversion, to pure digital







In tandem with using visual references collected from the prior case studies, the UX drawings were used as a template in Adobe XD, creating a half-and-half prototype between drawn and inspired digital assets. These prototypes were crude, but were the starting milestone for getting peer and mentor feedback on the visuals, navigation, language and cohesion of the interface. They proved to be good at provoking conversation on how things could be arranged, and what other features could be included (see Chapter 5).

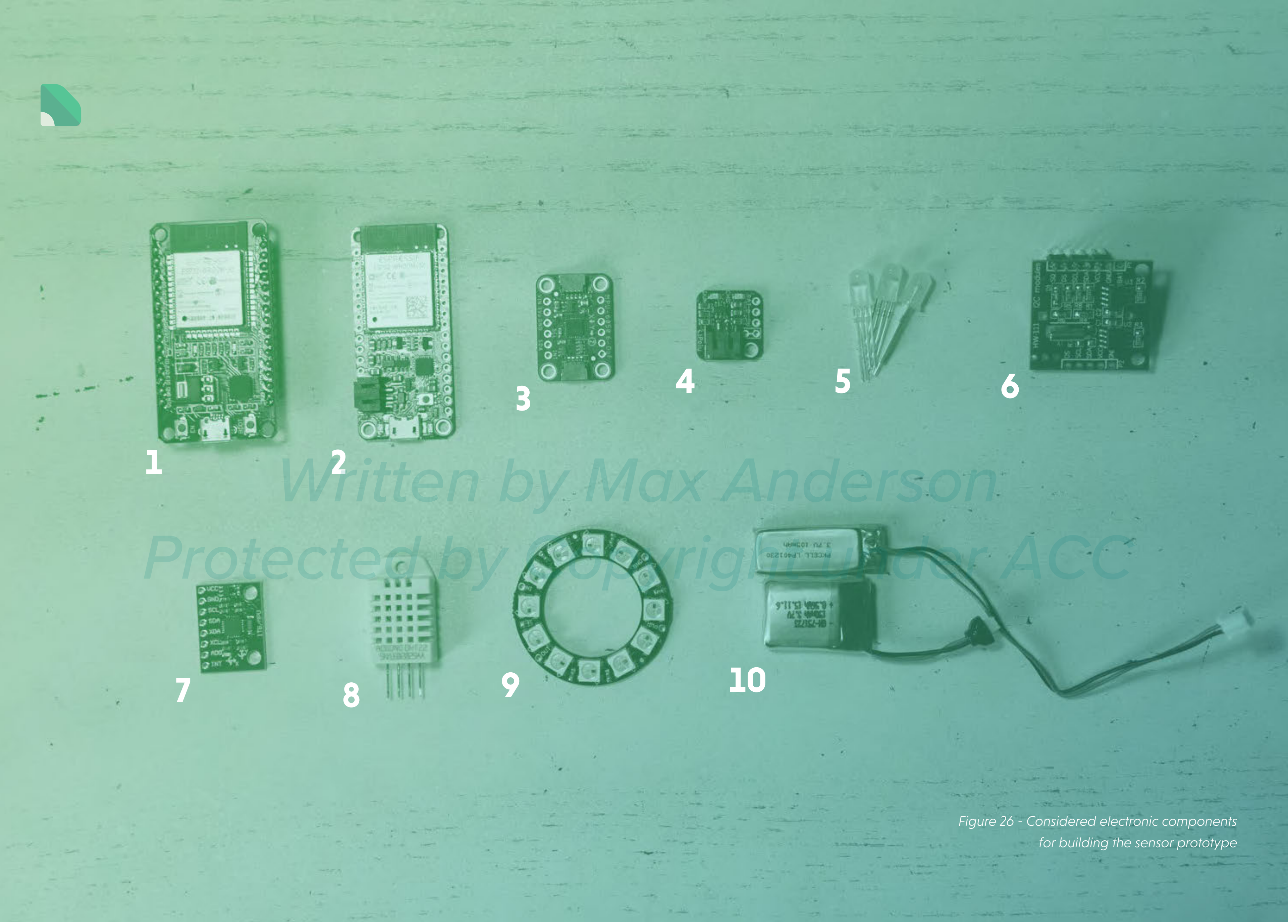


Figure 26 - Considered electronic components for building the sensor prototype

Figure 26 Key

1. ESP32-WROOM (development board)
2. ESP32-Feather (development board)
3. MPU-6050 (accelerometer and thermometer)
4. MicroLipo USB Charger (additional component)
5. Individual LEDs (lighting Ccmponent)
6. DS1307 RTC (real time clock)
7. MPU-6050 breakout board
8. DHT22 (humidity sensor and thermometer)
9. NeoPixel Ring (lighting component)
10. LiPo Batteries

Section 3 - Sensor development

Subsection 1: Engineering the sensor (programming/physical components)

Of course, much of the design of this project rested upon the feasibility and accuracy of the sensor unit. To address this, a protoype was built of the sensor, using realistic parts that would be able to purchased and used in a small scale production capacity. Figure 26 shows the components that were explored for the construction of the initial prototype.

It was important to build something "quick and dirty" early on so that there was more time to show a stronger connection between the vibration and heat, and the electricity usage of the unit. Initially, the sensor was to include parts 1, 3, 4, 6, 8, 9 and 10 (see Figure 26 key), but it quickly became apparent that in order to build something that would comfortably fit into the palm of your hand, there was a need to cut down on the number of parts that were to go into the enclosure.

Design Development

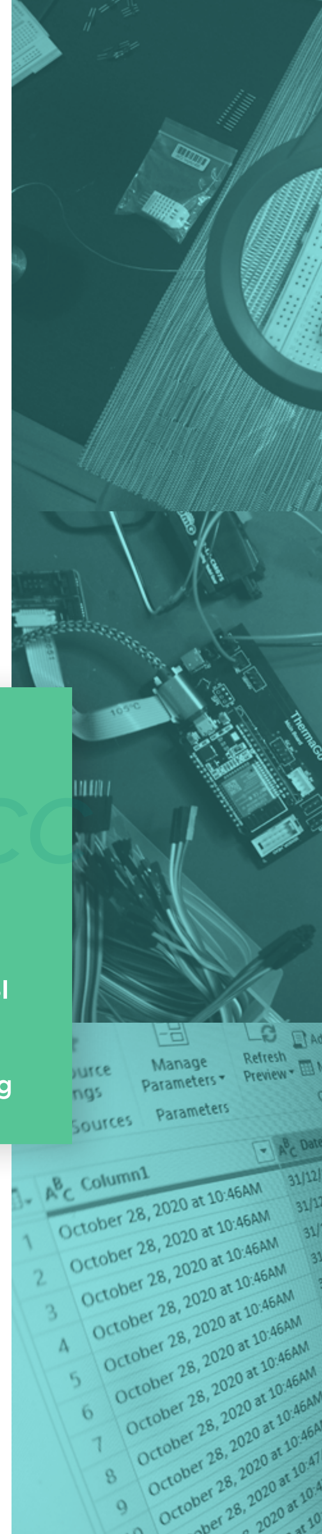
In fact, many of the parts explored were in some ways, building blocks that made up the internals of other parts. For example, it turned out that the MPU 6050 units also had a built in temperature sensor, saving a little bit of space and wiring. The ESP32 feather also included a lipo battery connector built into the board, something that the ESP32-WROOM did not include, and thus, would need to be additionally soldered in. While the shell of the sensor was still in development at this point, something to consider of was battery life, and the amount of space that might be required for it.

For the sensor to work for the anticipated, uninterrupted one week period of recording data, the battery would need to last at least that length of time (though preferably more to allow for battery degradation) without needing to be charged. In this case, as a backup, minimising components would not only make programming and assembly simpler, but would also provide more room in the shell for a larger battery, or for additional features.

The original prototype, for testing and programming purposes, was constructed from parts (ESP32, MPU-6050 non breakout), and was powered by a USB battery pack (see Figure 27; 6).

Figure 27 Key:

1. MPU-6050 Standoff Soldering
2. Wire Heat Shrink Installation
3. ESP32 Arduino coding
4. Work Test bench
5. Acceleration and Gyroscope data in POWER BI
6. Sensor prototype with portable battery
7. Sensor protype on washing machine recording



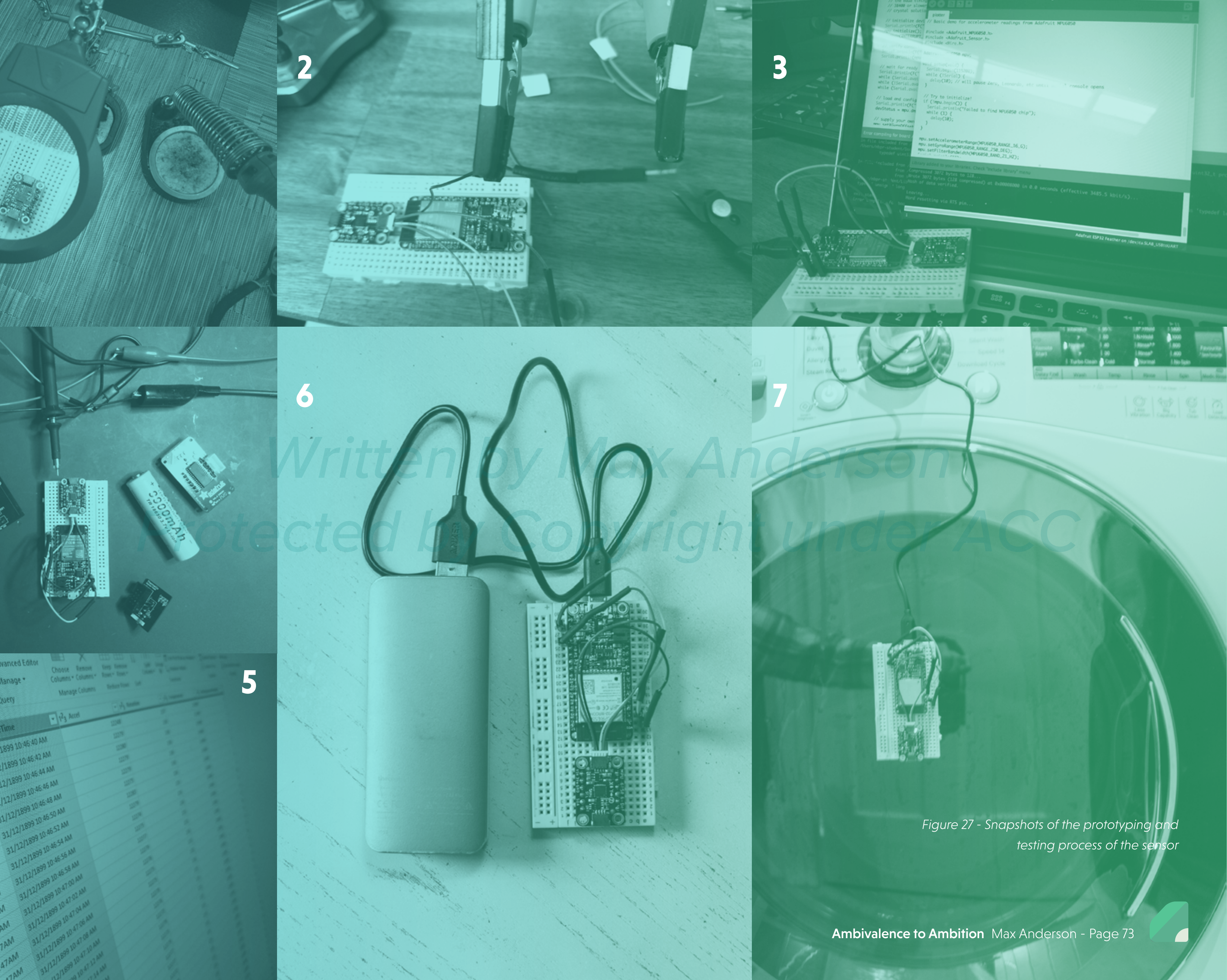


Figure 27 - Snapshots of the prototyping and testing process of the sensor

Subsection 2: Designing the sensor (CAD side)

Pushing aside the internals of the sensor for a moment, the exterior of the sensor is also an important aspect to design and consider. Before beginning with the design of the sensor, a couple of precedents had to be set. Visually, the sensor unit should refer to the styling of the visual interface, and vice versa. Otherwise, the design of the sensor was to closely match trends seen in other smart home devices. In particular, this was the use of clean, solid colouring, and using material texture (or details that created texture) to create visual interest. When creating the form and detail inspiration board (see Figure 28 for examples), traits like these were searched for, while recognisable smart-home products were specifically ignored.

Mirroring design traits in smart home appliances was done because smart home products are desirable. Not only for how they look, but also

Figure 28 - Some of the images found in the design form and detail inspiration board

the promise that they provide; comfort and ease. The intent is to make something visually similar to fit into this market and feel familiar to consumers.

Functionally, the sensor unit needed to small enough to fit in your palm and be easy enough to operate with one hand. The sensor also needed to be able to hold itself to objects and appliances without the fear of it falling its off, but also be easy enough to remove without impacting the surface it was placed on. Finally, the sensor needed to have some way of communicating its state quickly back to the user, and a simple way for the user to directly interact with it without having to go through the visual interface.

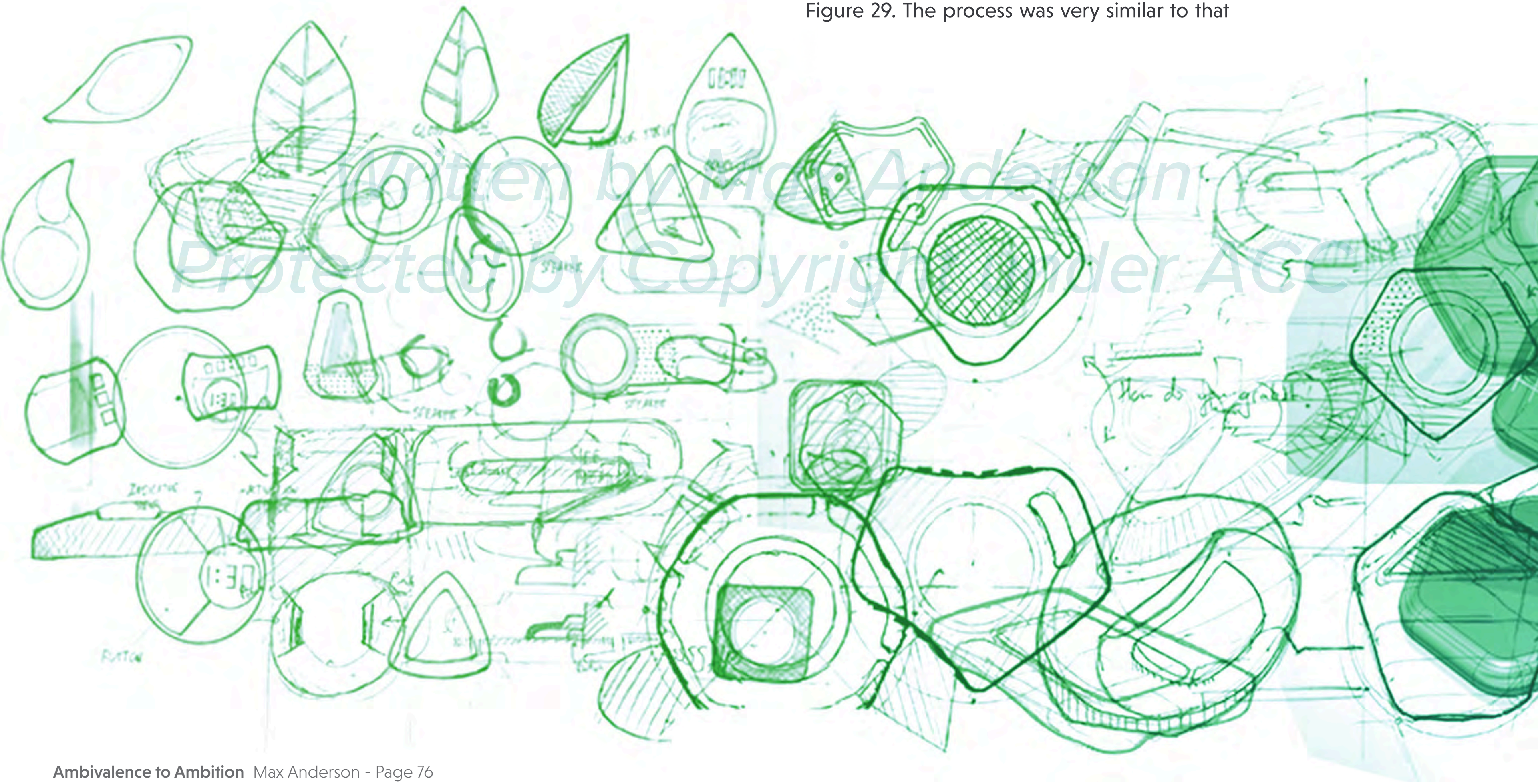
The design of the interface was started a bit earlier than the design of the sensor unit. When designing the bottom navigation bar, a hexagon (called the *Pebble*, see Figure 29) was used as the primary button for taking you to everything sensor related. In addition to the other design cues, this was another core inspiration in the development of the sensor.

Figure 29 - Interface "Pebble" symbol that became a key design inspiration.

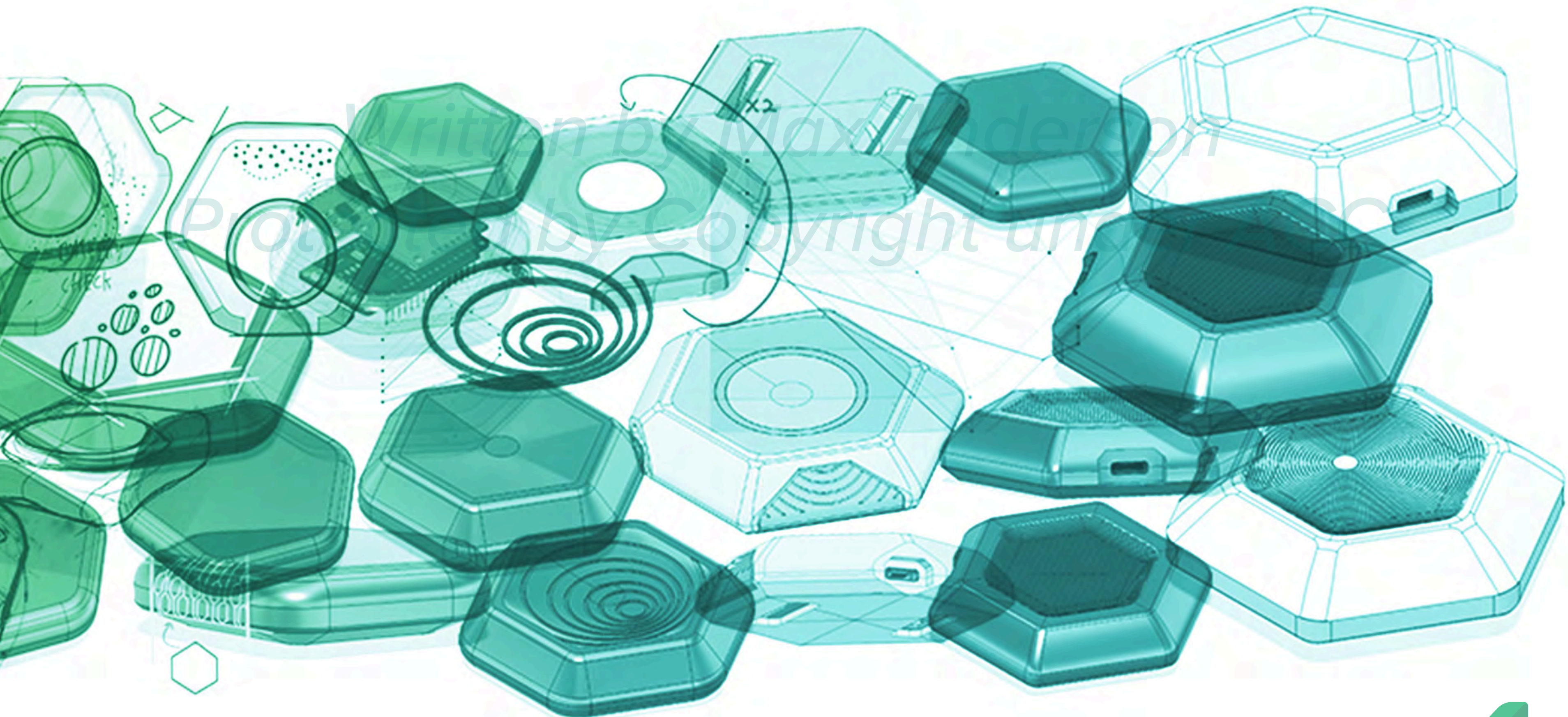
Design Development

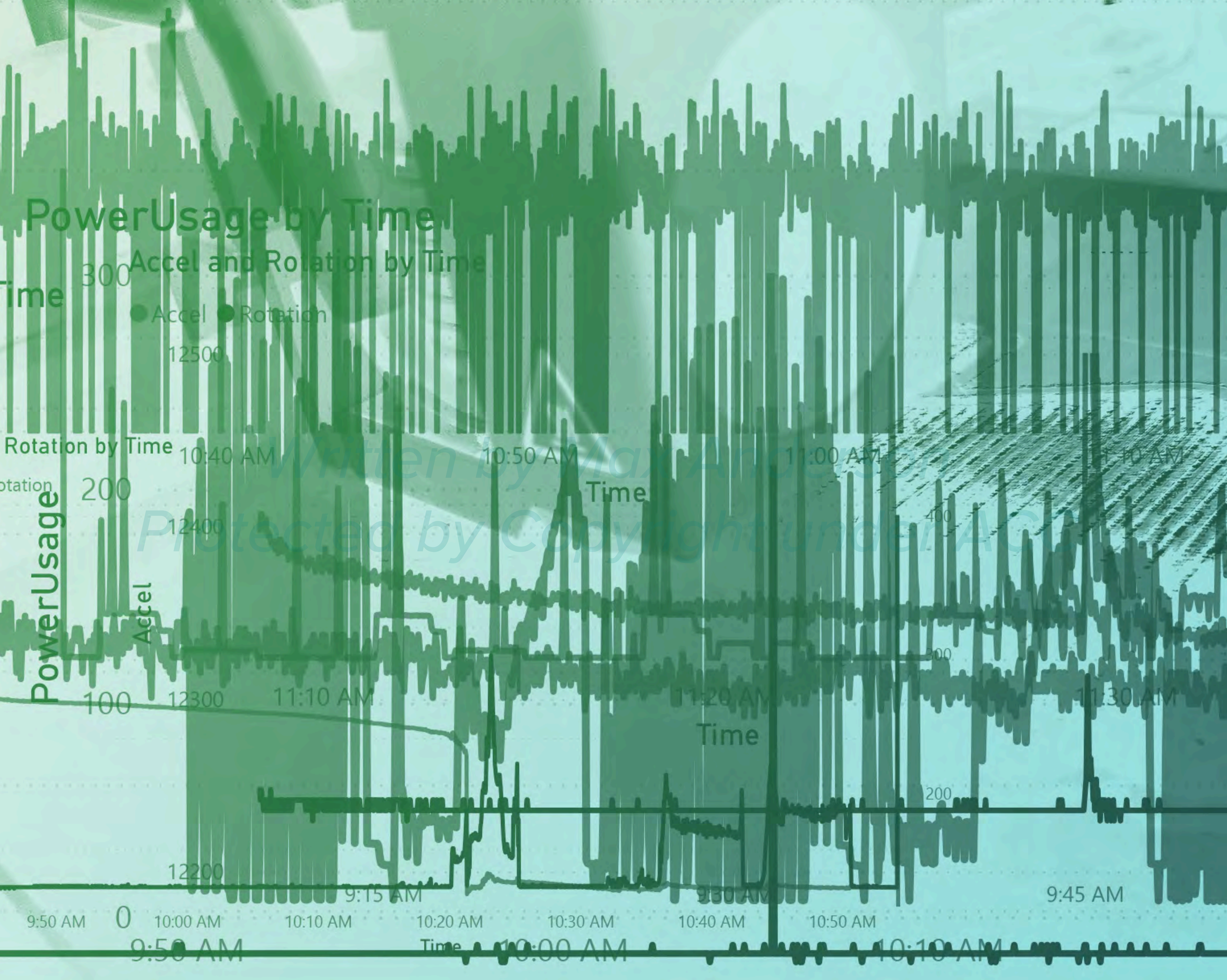
Figure 30 - The process of sensor design, from drawing, to digital/paper, to pure digital.

The design process initially started with going very broad and nature themed, but as the visual identity of the sensor matured alongside the UX design, the shape became more consistent with the interface symbol in Figure 29. The process was very similar to that



of the UX design; starting on paper, digital/paper, with finally moving to the full digital workspace to continue to experiment with the models exterior and interior (Figure 30). The final shape, (right edge of Figure 30) is a close physical mimic of the *Pebble* symbol




PowerUsage by Time
Accel and Rotation by Time
Accel
Rotation
PowerUsage
Time
10:40 AM
10:50 AM
11:00 AM
11:10 AM
11:20 AM
11:30 AM
9:15 AM
9:30 AM
9:45 AM
9:50 AM
10:00 AM
10:10 AM
10:20 AM
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12500
12400
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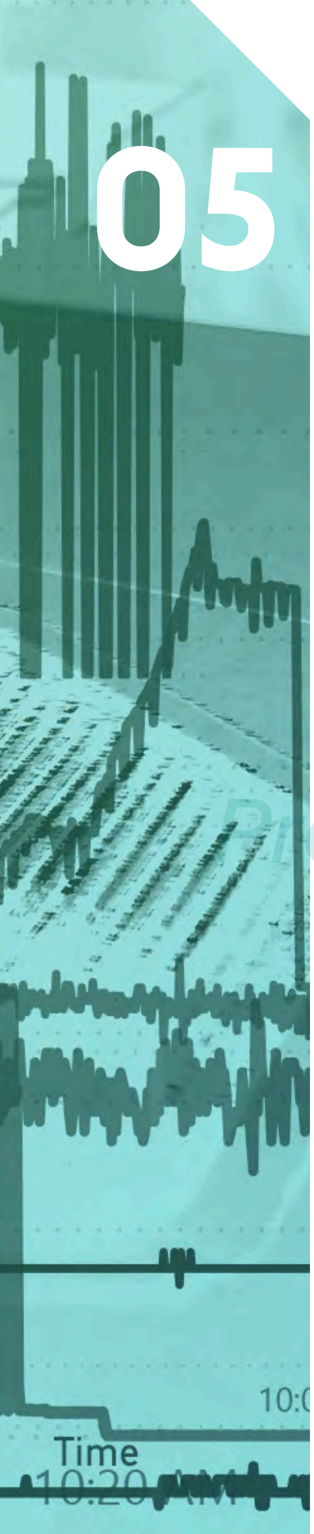
12200
300
200
100
0



05

Methods of Testing, Evaluation and Validation

Methods of Testing, Evaluation and Validation

Section 1 - UX iteration and testing

Designing the user experience involved the implementation of core motivators established during the research review. Instead of going with every motivator deemed worthy though, it was more efficient to only focus on a handful. The feedback pursued for my design was on the presentation and implementation of these motivators, the user flow of the app, and any additional features that should be considered or included. The people contacted were:

Scott Anderson: Co-Founder (Space Tank Design)

Simon Curlis: Industrial Design Lecturer

Holger Dielenberg: Founder and Director (Space Tank Studios)

Jamie Ford: Lead Software Engineer (Woodgate Designs)

Tom O'Dwyer: Professional Designer

Tim Ottaway: Professional Designer

Mathew Woodgate: Founder and Project Manager (Woodgate Designs)

Subsection 1: Additive energy mapping

The scenario of having a sensor that monitors waste energy from individual appliances, means that only one appliance can be monitored at a time. This physical limitation is turned into a positive design feature of the user interface; breaking down an entire household's energy usage into smaller activities and habits. Activities could be how you use your washing machine, microwave, TV, shower etc. (see Figure 32).

This approach to mapping a household's energy usage is additive, where individual appliance usage is gradually summed together to build a home's energy profile (Figure 31). This in turn creates a gradual flow of new appliance usage information over time at a pace directly in tune with the user's usage of the app. This creates a less demanding initial experience for the user as they become familiar with the interface, and makes each activity that they monitor and complete more personal to them.

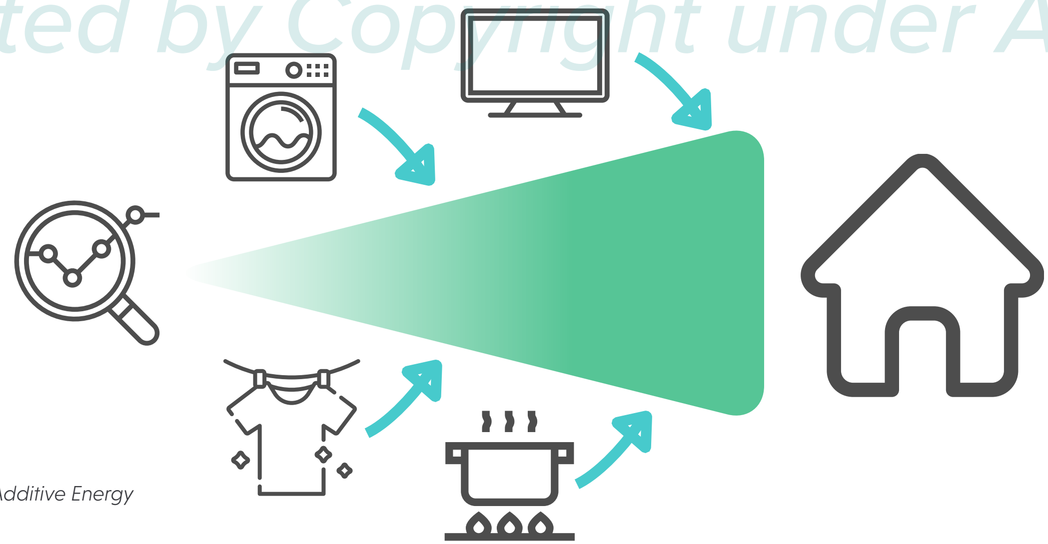


Figure 31 - Visual description of Additive Energy Mapping Energy Mapping

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Figure 32 - Activity select screen featuring different household activities a user can track

Feedback regarding implementation of this feature was primarily positive. Testers instantly picked up on other potential activities that could be monitored, aside from the one working activity that had been built, and the remaining five placeholders (as seen in Figure 32). Concerns raised from Mathew Woodgate were about whether this method of energy mapping would be able to accurately map an entire household. Measuring specific appliances over time covers a part of our energy usage, but excludes lighting and heating; which are potentially much trickier to track. This query unfortunately cannot be answered until further research has been put into the development of the sensor.

Subsection 2: Tracking and feedback

Feedback is the backbone motivator of all energy behaviour change research. Developing a good way of showing users the difference in energy use before and after changing their behaviour was crucial. This became somewhat of a problem, since the sensor is only able to monitor one appliance at a time. The interface would require a control period in order to provide details on level of improvement. The chosen solution to this issue is building a control period into the way activities are tracked.

When an activity is tracked, it is broken into two phases (see Figure 33). During phase one, the interface is learning how you use your washing machine over the course of the week. It encourages you to use your washing machine as normal for the best reliability of data. In phase two, the interface is measuring your washing machine usage, and comparing it how you used your washing machine in phase one. Between phase one and phase two is a report (called "Check-in") on where you did well compared to other households, and where you can improve (see Figure 33).

Figure 33 - "Activity" Feedback loop

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Equally crucial for the user, was showing the effect that their household actions had on the environment and their wallet. Each activity, and the data collected from it, should be clearly understood. While energy consumption is tricky to understand, money isn't. This is the reason why direct references to energy have a smaller part than money. In Figure 34, (idealized) vibration data from a recorded wash is graphed, broken into its cycle stages. This correlates into the total power consumed seen in the bottom right hand corner, as well as the price of the wash, calculated using the power consumption and prices of their local electricity provider.

Feedback with regards to this broke down into two core areas. Language was the first (Ottaway, Dielenberg), with both stating that the names of the phases should change to something more exciting. The original names of the phases were "analysis" and "improve"; analysis being a word of great critique for sounding too cold. Even the name "learn" for phase one still sounded tedious to

Figure 34 - In-progress activity screen

Dielenberg; an agreeable point once raised, and the name "play" was suggested instead. The name for the second phase still hasn't been decided upon, though "improve" is free enough from boring connotations, and is positive in nature. The second area is the potential maximum accuracy of the method of collecting and building usage data. Woodgate stated that building usage data required knowing about each individual appliance's base consumption. While it was agreed that the device survey could deliver decent results, it would heavily leverage a database of similar known appliances. Woodgate proposed using the EPA Energy star platform, which provides a product finder that gives energy consumption, as well as an estimated consumption over a year.

Subsection 3: Metrics, goals and rewards

Similar to step counts or calories burned in fitness apps, seeing simplified numbers that represent our progress towards a goal is a great, consistent motivator. If these goals are personally set, the motivation received is increased. The metrics that these goals are measured against are also important, in that they have to quickly be understood, and then recognised throughout the app. Goals and metrics can only go so far in encouraging good behaviour. Rewards also need to be considered, whether it is an exciting animation, a phrase of affirmation or a monetary tip. Within the interface, there are a few ways metrics, goals and rewards have been implemented.

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Figure 35 - Original (October 18th) measured metrics, with their associated blurbs and symbols

Metrics for an app focused around PE behaviour were pretty clear on the outset; something for emissions, energy and money. The difficult part was making them into something that could be understood. Energy was subtracted from the equation, and replaced with a metric that tracks engagement with the interface dubbed "Seedling Points". Money became "Energy savings", a total amount, and emissions became "CO2 reductions" (see Figure 35).

The interface as a whole is built upon these three metrics. Following the "Check-In" report on phase one, is a screen that provides users with a series of goals they can select, and pursue over the following phase. This report between phase one and phase two creates an intervention point, where users are praised for the good elements of their habits, and are granted clear opportunities to minimize the bad elements.

The metrics were a good topic of debate when discussed with testers. Ottaway and O'Dwyer both agreed that the emissions metric (which had simply been CO2 measured in metric tons of carbon) should be changed into something tangible. The CO2 metric was also something that users would likely want to see go down, rather than up; which wouldn't be as rewarding as having it be something that cumulates. The first change was turning the CO2 metric into "emissions produced from the equivalent consumption of barrels of oil". Unfortunately, it was agreed with O'dwyer that this was incredibly long-winded, and should be changed into "Equivalent number of trees planted by your actions". Planted trees was a much more positive idea, fitting better into the design's mission of empowering reduction and was a cumulative figure. Woodgate, liking the planted trees metric, suggested that trees a user has planted could be shown in a digital landscape to the user.

O'dwyer also suggested having more community features, like those seen in the FitBit application. Users should have an outwards facing profile, with the ability to "show off" their best achievements from interacting with the app. Discussing additional community features also lead to further feedback from Dielenberg, who questioned how people can be encouraged to do activities again. "How can [the researcher] make it more fun". Dielenberg credited the interface as having a strong data centric response, but lacking an emotional response.

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Subsection 4: Additional feedback

Dielenberg, Ottaway and Woodgate all made good points on how the app could be monetised. Ottaway suggested looking into Strava, a bike riding application, for how they incorporate community challenges, and corporate sponsorships. Woodgate suggested looking at newer energy providers like Amber, and considering how a system like this could provide benefit to their business. Dielenberg credits the system as having the potential to have sources of income from both the supplier and the consumer. The consumer pays for the sensor, and suppliers are incorporated in via coupons for like-minded products and advertising space for carbon neutral products and services that align. Dielenberg also proposed the potential of the sensing capabilities of the system extending to integrate transport, and rewarding PE behaviour.

Feedback also led to various small UX and prototype tweaks, involving some of the following:

- *Stronger visual hierarchy on course description page*
- *Changing colour and size of home screen buttons for stronger visual clarity*
- *Text contrast and font size*
- *Major goal circle reduced in size, buttons should include the symbols*
- *Tool tip for active course below major goal circle*
- *Wash capacity should be represented by symbols instead of weights*
- *Current statistics graph in active course panel should be smaller, and expand on tap.*
- *Colour delineation between old and new, part 1 and part 2*
- *Remove progress circle on metric dots.*

Section 2 - Sensor iteration and testing

The sensor design went through three main iterations when being developed in the digital workspace, with 3D printing being used as a method of building understanding of the true shape and scale (Figure 36). The goal with the iteration and testing of the 3D model was to produce a feasible schematic that could be used for a future small production run for user testing purposes. This small production run would likely take place after the sensor programming is in a working state, and provide an oppourtunity to expand the testing pool for recieving interface feedback and unique appliance usage data.

The first iteration was heavily based off the *Pebble* symbol (Figure 29) seen prior. On multiple occasions explaining how the sensor worked, it was referred to as a "digital stethoscope", an inspiration to create something that was similarly sized to a medical stethoscope. As seen in Figure 37, 1, the first iteration prototype was similarly blocked out to the *Pebble* symbol, but additionally marked out part lines and emphasised a pattern

Figure 36 - Collection of 3D printed prototypes for feasibility testing

Figure 37 - Core Model iterations (1, 2 and 3) 3D printed

texture built into the top of the unit. The first iteration prototype's primary focus was to get a sense of the size needed for internal components, and it revealed that it would be an incredibly tight fit to include prebuilt components, let alone a battery. Measuring 15mm in height, and 65mm in circumference, the sensor would have to be scaled up.

Iteration two (Figure 37, 2) was modelled off Iteration one scaled up by 30%. The height of the unit was now 20mm, with a circumference of 80mm. The design was more considered in this iteration. Smooth filleted edges were replaced with stronger edges, similar to those seen in high tech appliances. It also helped to disguise the increased thickness of the device. Once printed, the top face of the sensor wasn't nearly as impressive as before due to its decreased size compared to the first iteration. The main objective from this iteration to the next was to widen the top face of the unit, create realistic internals and build in functionality features.

Iteration three (Figure 37, 3) received changes to the curves joining the top and bottom

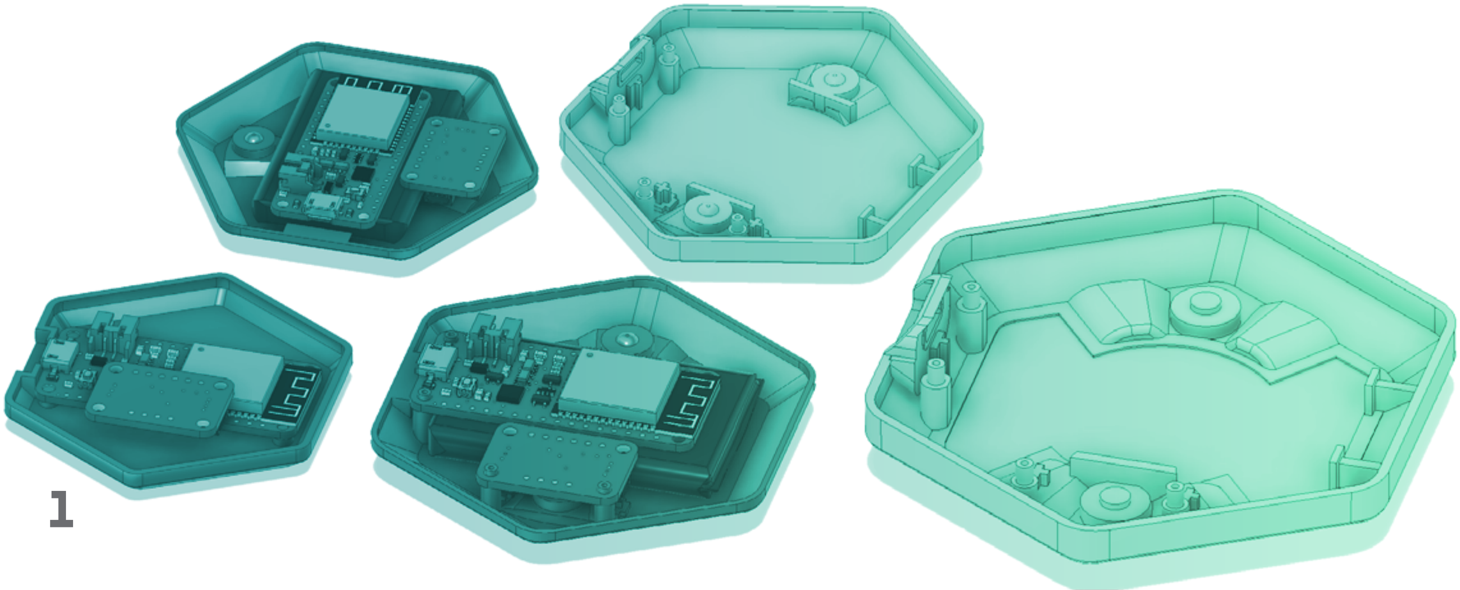

Figure 38 - Progression snapshot (left to right) of iterating on internal supports

to the middle edge. A good balance was reached between the size of the top face and the bulkiness of the curve, resulting in a top face slightly larger than that seen in iteration one. The internals of the sensor were modeled off the internals seen in a video game controller. Boards were mounted on hollow pins, with moving components like buttons being sleeved into the shell with framing objects laid over the top (see Figure 38). The position of the battery in particular was quite important, since it would be the heaviest part in the unit. The battery's placement would determine how the sensor would feel to hold and move. For example Figure 38, part 1, shows early component positioning in iteration two. The intent was to use the remaining space to the left of the development board for an additional battery, but that instead would have created a lopsided feeling for the sensor. With the new height came the ability to place the battery underneath the development board, leaving the left of the case free for another sensor in the future.

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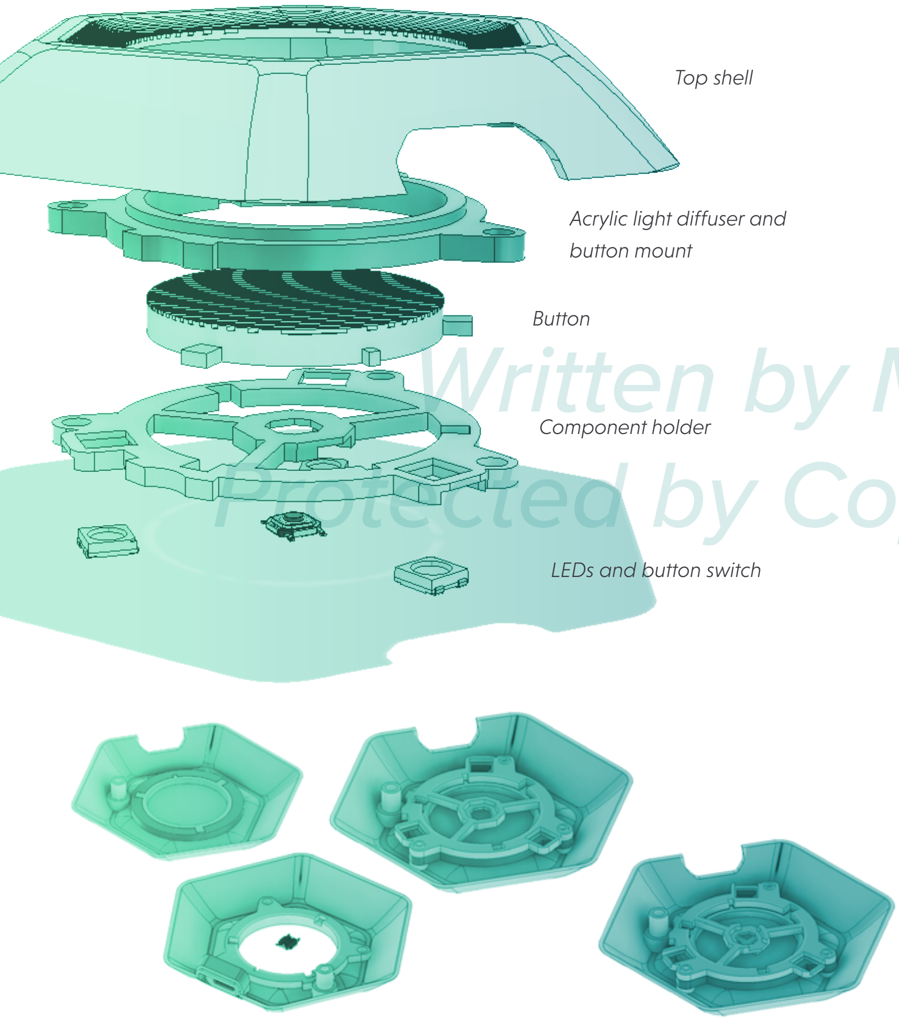

Not shown in the physical core model iterations was the development of the top's texture and function. Granting the user some form of direct interaction with the sensor instead of having to go through the interface was considered to be a good idea. Although the direct purpose for such a feature wasn't known at this stage, it's inclusion was a form of future proofing. So too was an indicator light included, to provide feedback alongside the button. A multilayered approach was created, with each part slotting into eachother (see Figure 39). Multiple layers had to be used for different levels of transparency to allow for light to diffuse or be blocked.

The pure internal parts had been designed to have one flat face for easier 3D printing, and once printed, the parts were light and strong. The tolerences could be improved, but needed are dependent on the production method.

Figure 39 - Top shell assembly deconstruction and process snapshots

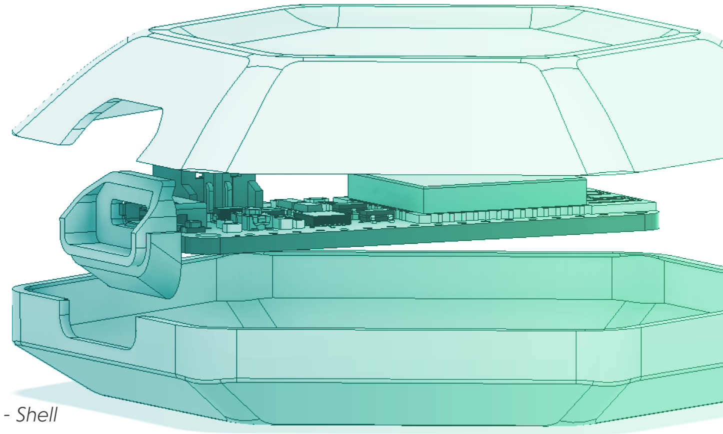

Figure 39 - Shell Deconstruction

In order to properly fit a charger port into the device, the shell needed to be separated into 3 pieces, not just two (See Figure 40). This third piece was quite small, and once printed, was quite delicate and fragile. If the sensor was to be printed on a resin printer (the preferred choice for a small production run), this would likely not have been such an issue.

Unfortunately, it was during this iteration that the 3D printer started to struggle with these fine details. A small groove running around the base of the sensor was lost due to the quality of the printer and built in supports. Prominent corners were lost to infill spray to mask the natural ridges of a 3D print. The bottom internals that would hold the development board and accelerometer did print successfully, and would easily hold these parts up with small changes to pin tolerances (See Figure 40).

Another point of consideration being tested in this iteration was how the sensor would attach to appliances and walls. Reusable adhesive

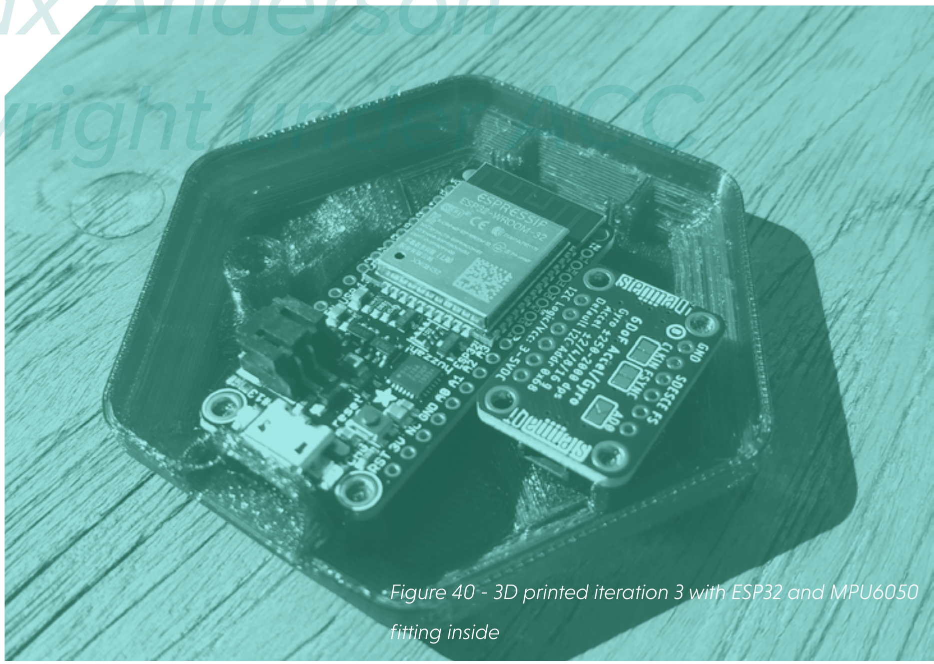

Figure 40 - 3D printed iteration 3 with ESP32 and MPU6050 fitting inside

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pads had been considered, and were deemed not long-lasting enough and would require some form of replacement. Some appliances were likely to have metal surfaces, so magnets were next considered, and then implemented into the base of the unit.

However, another method of attachment would be required if the appliance did not have a metal surface. Thus, a mount was developed that would attach to surfaces via "3M" like tabs, and hold the sensor in place with magnets. Before this design had been printed however, it was considered that pulling two magnetic things away from each other could be a fairly difficult task that might require some amount of grip strength. Magnets are more easily separated by peeling off one edge, or sliding the enter thing away. Considering this, grooves were built into the sensor and the mount, that once rotated, would push the magnets away and off from each other.

Figure 41 - Process snapsnots and demonstration of twist removal from the mount

The physical prototype proved to successfully do this, with the mount and sensor attaching and un-attaching easily from each other (see Figure 39). However, this mount/sensor attachment method would need to be further tested with a wider range of people to determine its true ease of use and clarity of design cues.

The bottom internals that would hold the development board and accelerometer did come out fine, and would easily hold these parts up with small changes to pin tolerances (See figure 40).

Section 3 - Feasibility analysis

Subsection 1: Setting up the wireless connection

A couple of data uploading techniques were considered. The first was having the sensor upload directly to a cloud, google sheets document. This would have been the most fundamental, and easiest upload technique to use, though a technique like this would not be used in other smart sensors. Instead, a smart sensor would be more likely to upload its data to its own server, which can be replicated for the purpose of the project by using an IOT platform; Losant. Losant provided a digital dashboard for live graphing, and a digital storage space for incoming data.

Losant unfortunately was less than ideal. While the sensor was sending averaged readings every two seconds, Losant was only able to save readings a maximum of every 5 seconds, cutting the data from any measured washing machine cycle in half. Also, about two weeks into measuring washing cycles undertaken by the household, it was discovered that the data wasn't actually being saved in Losant (or it had simply disappeared).

This unfortunate discovery prompted having to add an additional step to the data upload process. It was discovered that Losant had no issue with receiving data every two seconds, it simply did not want to save it. Thus, a solution to send the data to a google sheets document was coded into Losant's platform.

When collecting data, ideally the research would have been conducted on a larger variety of washing machines, but due to the nature of the pandemic this research was conducted during, the sample size of washing machines was limited to one. Washing machines don't use a continuous amount of power, or exert a continuous amount of vibration, for the duration of their washing cycle. However, washing cycles are broken down into different stages of a wash. As such, each washing cycle involved a different vibration signature, and in turn, would consume a different amount of energy over time.

With the sensor successfully sending data wirelessly, testing now aimed to find correlations between vibration signatures and the power draw of the washing machine. As such, a three part data collection process was used: A smart plug to measure power draw, the sensor prototype to measure heat and vibration and a camera (in this case a Go-Pro) to visibly link all the data together. This set up is explained in Figure 42.

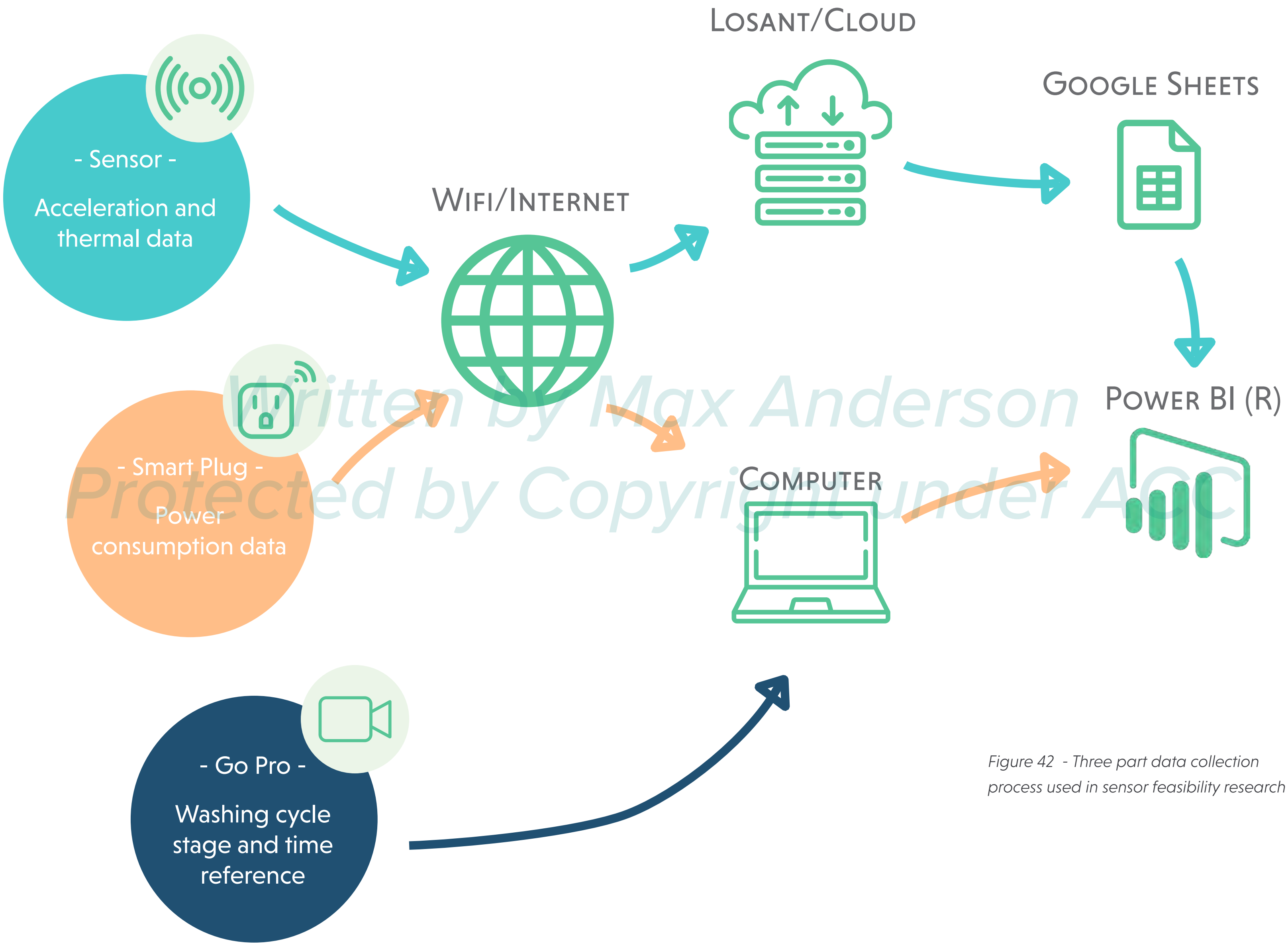

Figure 42 - Three part data collection process used in sensor feasibility research

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Subsection 2: Pulling the data, comparison, analysis and conclusion.

It is important to understand the four key stages of a washing machine cycle before viewing the collected data:

Typical Washing Cycle stages:

Prewash: The machine's tub is filled with water, and detergent is gradually mixed in.

Washing: Agitate the water and detergent to further mix, moving clothes around the tub.

Rinsing: A multi-step procedure where soapy water is spun out of the machine, and fresh water sprayed in.

Spinning: The machine spins incredibly quickly to centrifugally remove water from clothes.

After a somewhat successful collection of all three forms of data (power by time had to be reset), a data set can finally be analysed (see Figure 43), revealing some positive conclusions. Please note, that the following graphs have been manually scaled and aligned by hand, and the "Power by Time" may not perfectly in line with "Acceleration and Rotation by Time"

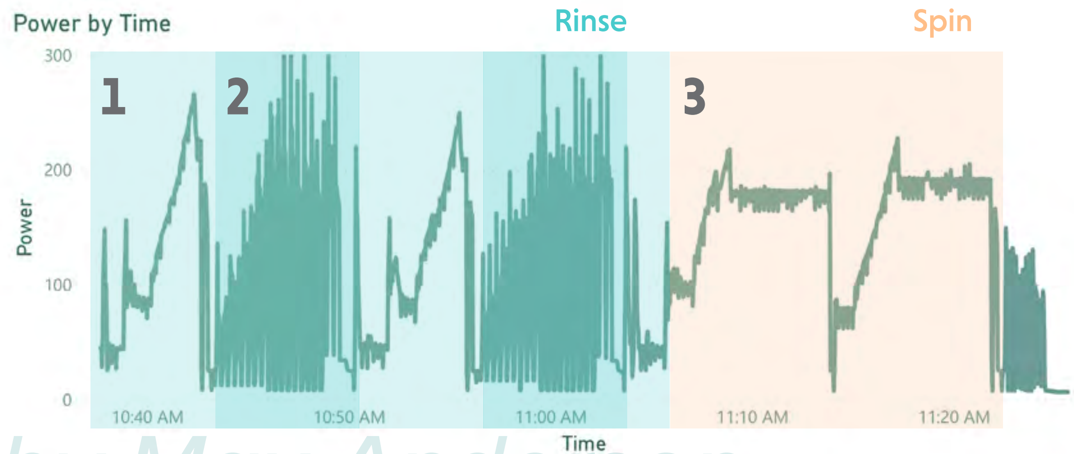
The power consumption on its own, can clearly be broken down into different stages, reflecting different stages of the wash that the washing machine is in. The blue areas of Figure 43 (marked in varying shades of blue) make up the rinse stage. The lighter shaded blue areas (see part 1) mark when soapy water is being spun out of the machine (consistently increasing energy usage). The darker shaded blue areas (see part 2) mark when the washing machine is when the machine is adding clean water to the basin, and jostling the clothes back and forth. This is evident from the high amount of fluctuation as it starts and stops its turning cycles while using additional energy to pump in water.

Machine - LG WD1411SBW 11kg

Wash Cycle - Dark Wash

Temperature - Cold

Spin Speed - 1000rpm



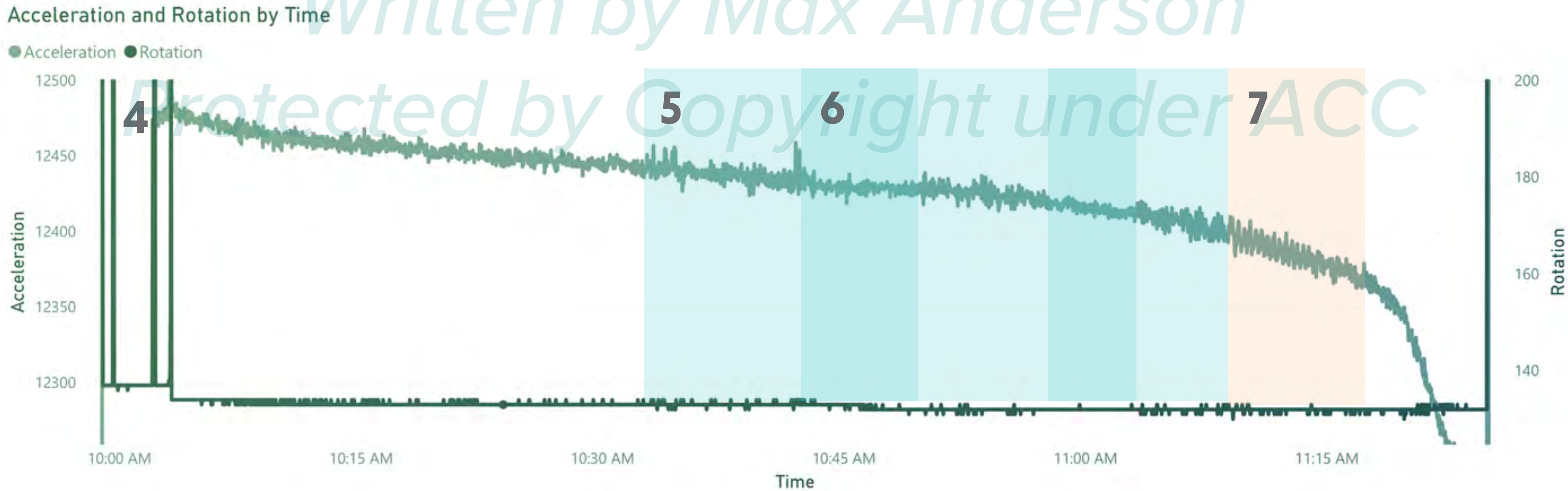


Figure 43 - Washing machine power consumptionand acceleration / rotation by time

Methods of Testing, Evaluation and Validation

The spin stage is marked by the orange shaded areas. Unlike the rinse stages, a high rotational speed is reached, and then maintained by inputted energy (see part 3).

Viewing the rotation of the sensor, times that the door has been opened and closed line up with the peaks (see part 4, near 10 am), meaning that the door of an appliance being opened and closed can be monitored, and potentially programmed into a start and stop point.

The acceleration data clearly suffers from a consistent decrease in its value, attributed to "sensor drift". Higher quality sensors, or a formal calibration sequence in the code, have a high chance of remedying the issue. However, even with the drifting data, the change in the values still reveal things about the washing machine. The amplitude of the graph increases and decreases in (rough) time with the power consumption. Comparing parts 5 and 6; it can be seen there is a difference between the amplitude of each of these sections, and this phenomenon is repeated as marked between the light blue and darker blue areas. The increase in amplitude seen in the "Acceleration and Rotation by Time" graph matches the changes in the Rinse cycle. Similarly, at roughly 11:10 am (part 7), the amplitude of the graph increases, and has visibly high consistent frequency that would be expected when the washing machine is in a spin cycle.

Unfortunately, because a working recording set up was finally achieved so late in the process, there was nowhere near enough time to compare power consumption and acceleration between different types of washes, and also to build a more concrete idea of how the acceleration could be converted into energy consumption. From this analysis, it is clear that recording acceleration shows potential, and improving the quality of the acceleration sensor and subsequent data could let better conclusions be drawn. Another point observed during the collection of this data, and reviewing the camera footage, was that each stage of a wash also produced certain sounds. Thus, in future research, sound (especially that recorded from contact with an appliance) should be monitored, and analysed.

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Course, 2 Weeks
Laundry
Course, 2 Weeks
Cooking
Course, 2 Weeks
Showering
Course, 2 Weeks
Microwave
Welcome to Eden
Activity
Month
Year
EDEN
GET STARTED

06

Design Outcomes

Figure 44 - Pebble next to Eden interface on mobile device

Introduction - How to become Energy LEAN

The solution to reducing energy usage is not just efficient technology, but also efficient human beings. Existing tools that gather energy usage data do little more than show one's kilowatt expenditure and the price one pays. They lack the ability to explain the way that usage of individual appliances combine to form this kilowatt expenditure. This realization spurred the development of *Eden*, a product service system that provides users insight into their energy usage behaviour, and suggests specific actions to positively improve it, becoming "Leaner" with their energy usage. It is an energy tracking interface that shows energy usage as actions, rather than purely numbers. *Eden* is integrated with a portable energy tracking tool called the *Pebble* that can be freely moved around one's house between different appliances and activities. Unlike direct energy monitoring solutions, the *Pebble* gathers motion and heat data, that reveals more about how an appliance is used. By breaking down energy usage it makes the overwhelming task of reducing and stabilising energy expenditure or energy bills much less daunting. In doing so, the strain on our energy transmission network is reduced, and so too are carbon emissions produced from the burning of combustible fuels.

Scan me to try the guided interface walkthrough

Design Outcomes

Turning a daunting endeavour into a step by step process

Whether the motivation to change is financially or environmentally based, reducing the energy consumption of one's household is a problematic endeavour. This is founded in the uncertainty of where to begin, and thus makes a simple task appear needlessly immense. Additionally, the general energy advice one might receive is repetitive, overwhelming and impersonal. Households need personalised and specific feedback on their energy usage in order to make and maintain new habits. To address this, *Eden* builds and delivers personalised energy saving feedback by presenting potential energy savings through various activities and appliances around the home (Figure 45).

Figure 45 - Activity Selection

Step 1:
Pick an activity

Step 2: Stick on the Sensor

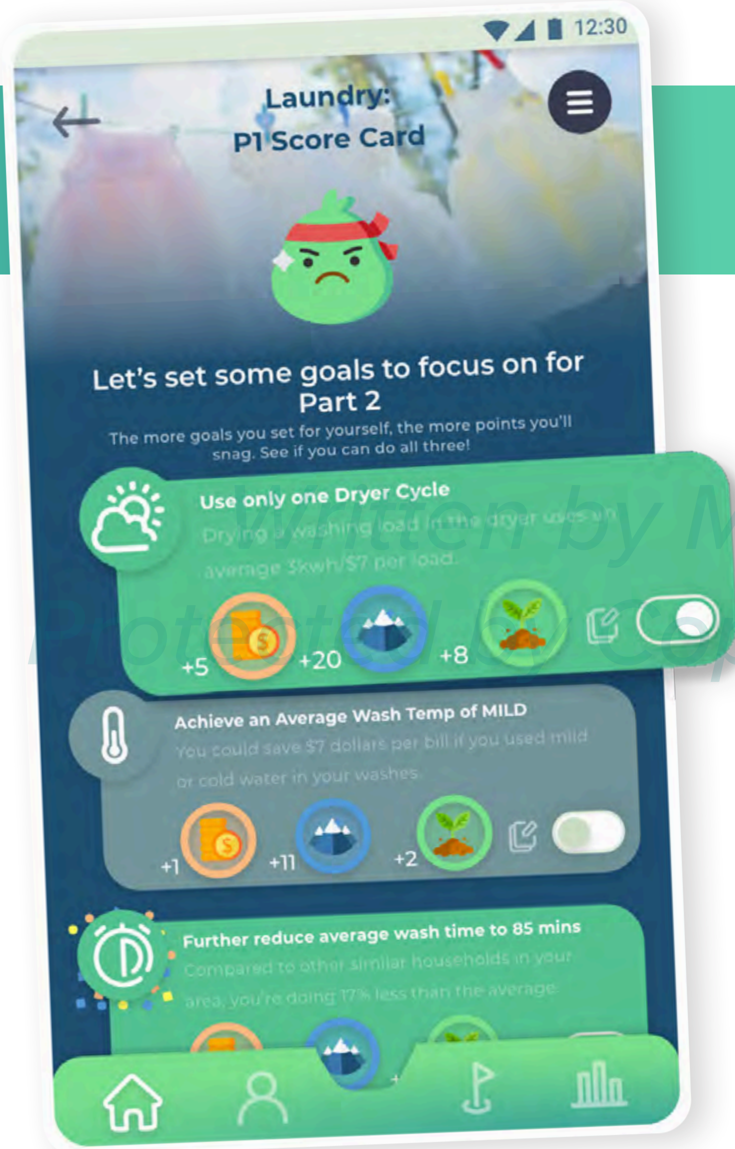
Figure 46 - Attaching the sensor

Step 3: Learn about your usage

Figure 47 - Scorecard

Once a desired activity (such as "Washing Machine") has been the selected in the interface (Figure 45), and the *Pebble* has been attached (Figure 46), the *Pebble* begins to monitor how you use that device. Over the course of a week, *Eden* learns about your specific routines and habits of using that appliance by breaking waste energy, motion and heat data from the *Pebble* down into different categories of use. This information is all compiled on a scorecard that details where the household has done well, and where they can improve. For example, as seen in Figure 47 a household has done great with the frequency, start time, and washing duration of using their washing machine, but can improve on using the weather, and the wash temperature.

Step 4: Pick your goals



Based on where the household can improve, *Eden* offers specific goals to the user, providing clear actionable steps to changing their personal energy usage (Figure 48).

Figure 48 - Goal Selection

Step 5: Accomplish goals and improve

Over the course of another week, the *Pebble* continues to monitor the appliance usage to determine the level of change since the previous week, and whether the household has succeeded in reaching their goals set prior (Figure 49). Fundamentally, this additional step shortens the feedback cycle in directly showing households the benefits of their changed behaviour. A shortened feedback cycle solves the issue of habits reverting to normal before the next piece of feedback (normally an energy bill) is received to validate and reinforce the change.

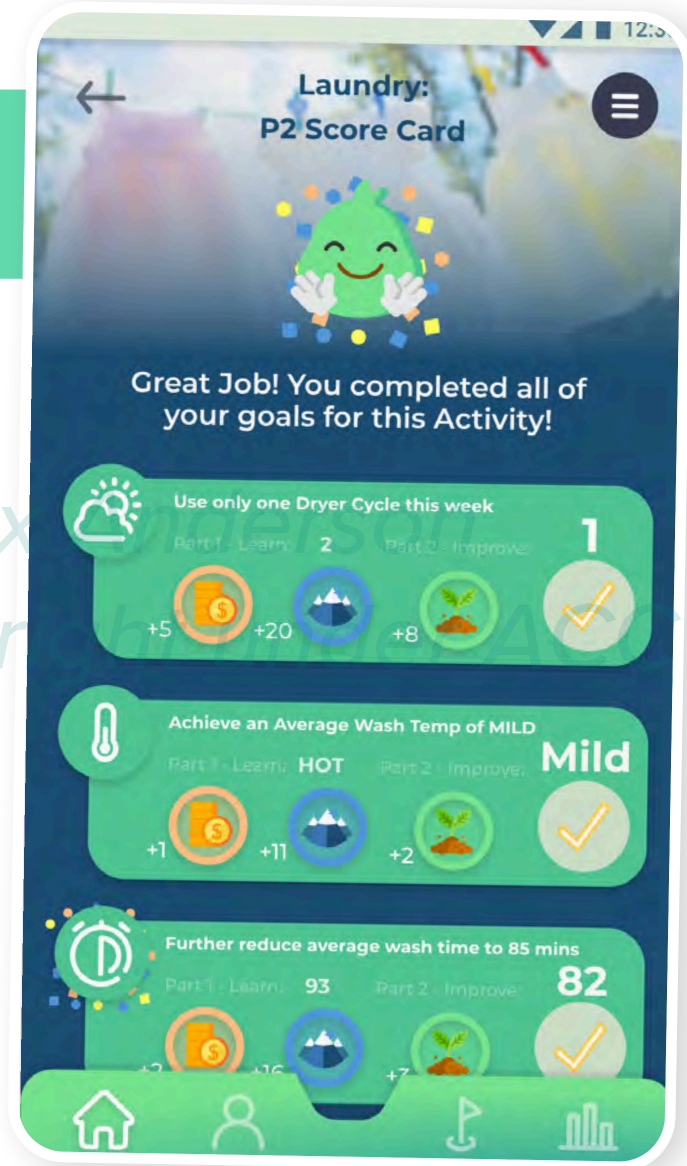


Figure 49 - Goal Completion


12:3
Laundry
Activity tracking 2 Weeks
Part 1: Play
Day 4
Tracking
Complete Part 1 to open
Wash
Week
1 T
2 W
3 T
4 F
5 S
6 S
7 M
3/9 Thur - Morning Wash
PART 1: LEARN
20
Fill
Wash
Rinse
Spin
10
9:33
9:45
9:58
10:12
10:21
Cold
0:48
9:33
$0.83
0.65
Line Dry
Dryer
3/9 - Afternoon Wash
1:02
$1.22
0.83

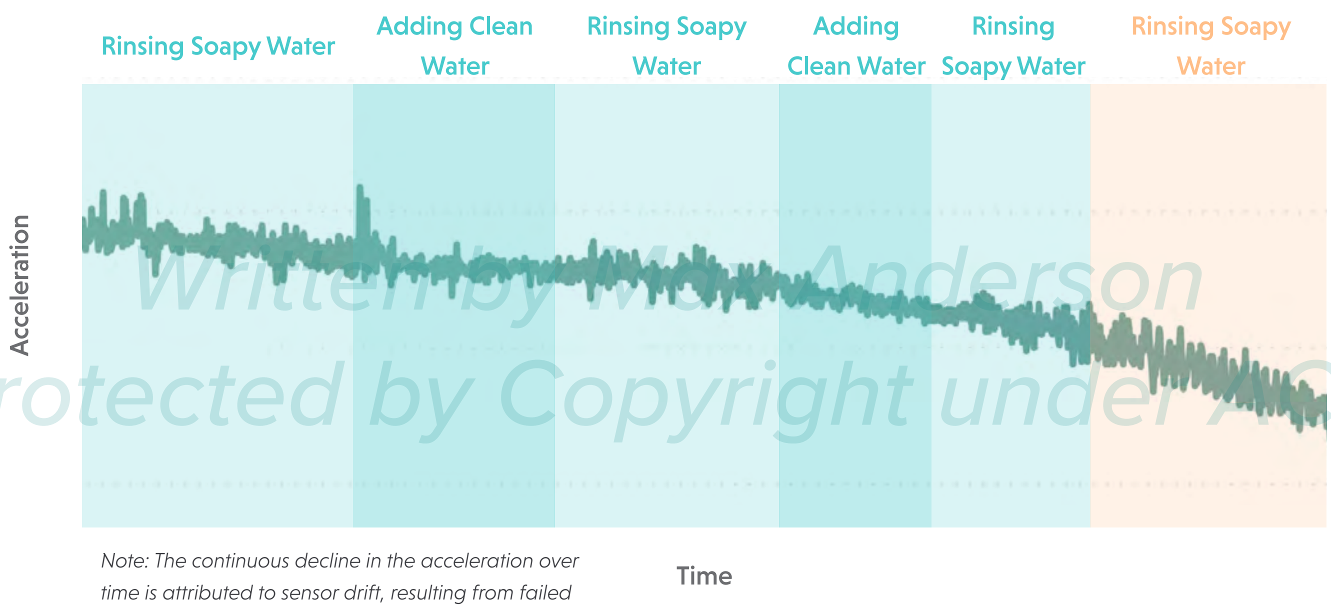
Figure 50 - Pebble in-context with Eden in-progress data screen

Putting the power into everyone's hands

To facilitate *Eden's* ability to provide specified energy saving feedback on multiple individual devices, the interface was integrated with a small, portable activity tracking tool: the Pebble. Existing solutions that track the energy consumption of an individual appliance (smart plugs) limit themselves by being very difficult to move once installed. Since these devices plug in between the appliance and the power socket, getting access to this for one's fridge, washing machine, dish washer etc, is enough of a burden that people won't easily be motivated to move it once it has been connected.

To counteract this, the *Pebble* is placed onto the door of the appliance, and measures motion and heat to interpolate into energy usage and activity. The motion the *Pebble* reads could be the change in vibration as a washing machine changes cycle stage (Figure 51), or the change in rotation as a fridge door is opened and closed. This type of motion expands the type of activity the *Pebble* can record far beyond a direct energy monitoring solution.

Design Outcomes



Note: The continuous decline in the acceleration over time is attributed to sensor drift, resulting from failed calibration

Figure 51 - Snapshot of acceleration measured from an LG WD1411SBW dark wash, 1000rpm

Combined with the known baseline energy consumption of the appliance, and the known different percentage usage for different stages of usage, *Eden* is able to predict an appliance's electricity consumption over time. The more that is known about the specific appliance, the better the prediction. While admittedly, these calculations will never be 100% accurate, the prediction is focused more on being a motivator for change. *Eden* ultimately is not an energy monitoring solution, but a behaviour change tool.

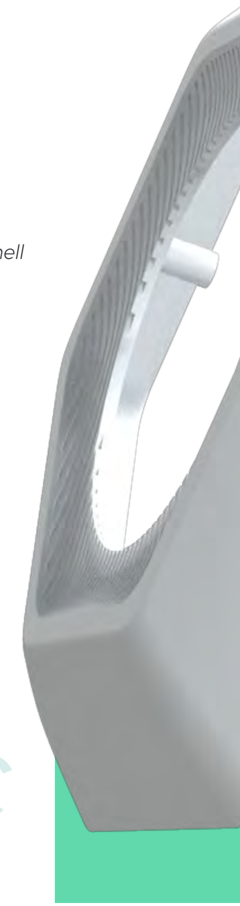
To ensure that the *Pebble* was easy to move between appliances, the *Pebble* is a completely wireless and standalone device that easily fits into the palm of the hand (Figure 52). Its unique form feels both distinctive and familiar, evoking material design cues of common smart home appliances (Figure 53), while simultaneously distinguishing itself with its texture and shape.

Figure 52 - Printed Model in the hand

The shell, and internal parts of the device are resin printed (Figure 54), and all easily joined together by one screw in the base of the device. This makes the sensor particularly easy to produce in a small production capacity. To ensure that the Sensor would not need to be charged frequently, it is installed with a rechargeable 1100mAH battery that allows for the unit to remain on for over a week at a time.

Figure 53 - Multiple Views of the Pebble

Top shell



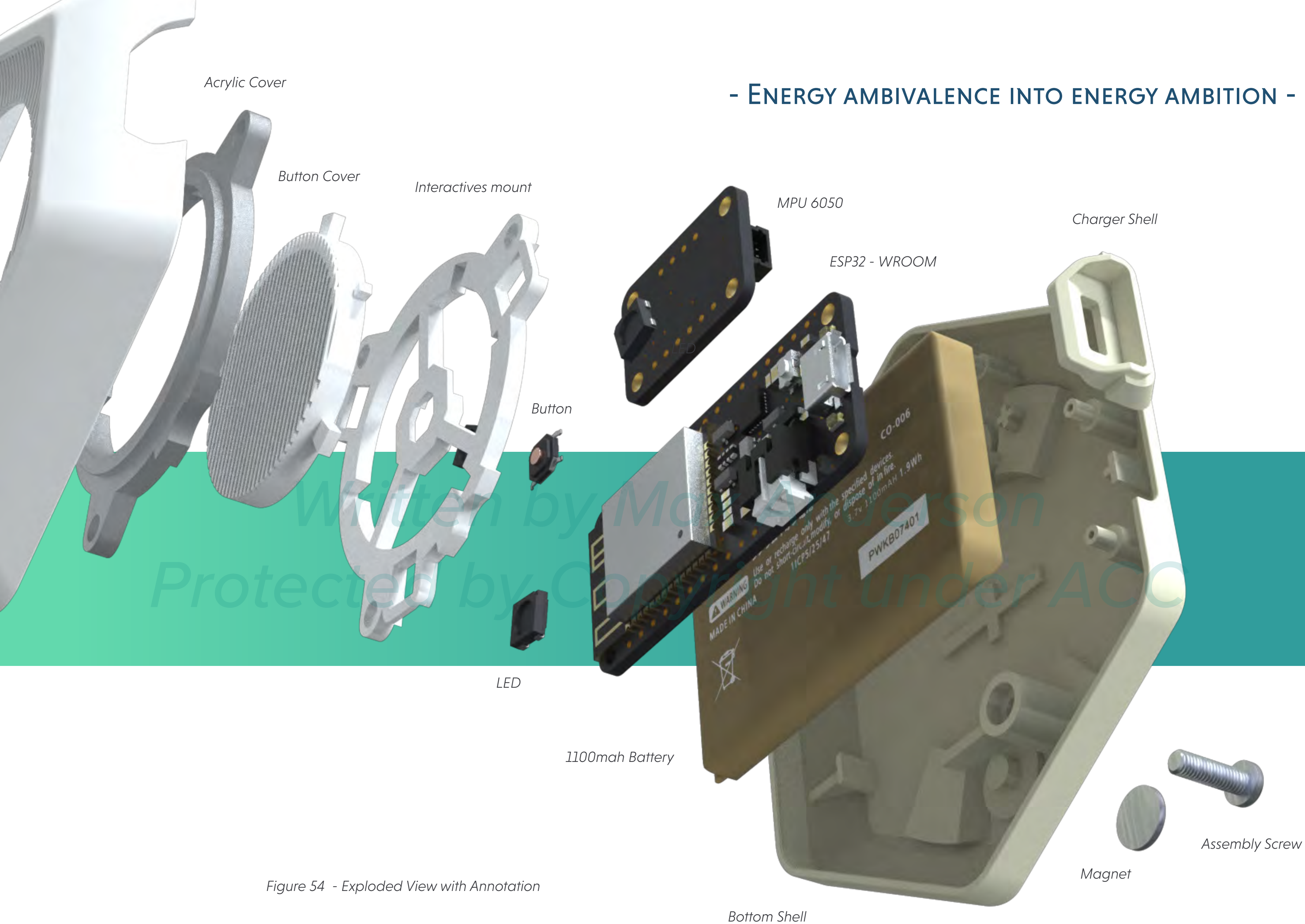


Figure 54 - Exploded View with Annotation

Design Outcomes

Figure 55 - Attaching the Pebble to the mount

Additionally, the *Pebble* has been designed to straightforwardly attach to appliances or surfaces. The sensor has two magnets on its base (Figure 53) that allow it to attach to the metal surfaces such as the fridge. For other types of surfaces, the *Pebble* is attached to a mount that can be fixed to walls and appliances via a 3M™-like adhesive strip. The mount uses its own magnets to hold the *Pebble* in place, and has raised grooves that push the sensor away once rotated for easier removal (Figure 55). The polarity of the mount magnets are such that the sensor can only be placed on it one way, further ensuring that the sensor is positioned in the correct orientation.

Reductions that matter

In addition to the core feedback procedure of *Eden*, and the *Pebble* sensor, *Eden* produces curiosity and investment in users by including methods of making intrinsic rewards clear, and adding extrinsic rewards. Parallel to the tracking and feedback are three key reward metrics that summarise a household's progress on becoming more Energy Lean. These reward metrics (Figure 56 and 57) turn abstract concepts of energy reduction and carbon emissions into forms that are more easily understood. These metrics make the intrinsic benefits of reducing one's energy bill and environmental impact transparent to the user, and are a continuous reminder on *Eden's* home screen of their positive actions as they accumulate. Every action a user undertakes in *Eden*, such as completing an activity or a quick activity, awards relevant points to the user's profile that go towards goals (Figure 57) and achievements (Figure 59).

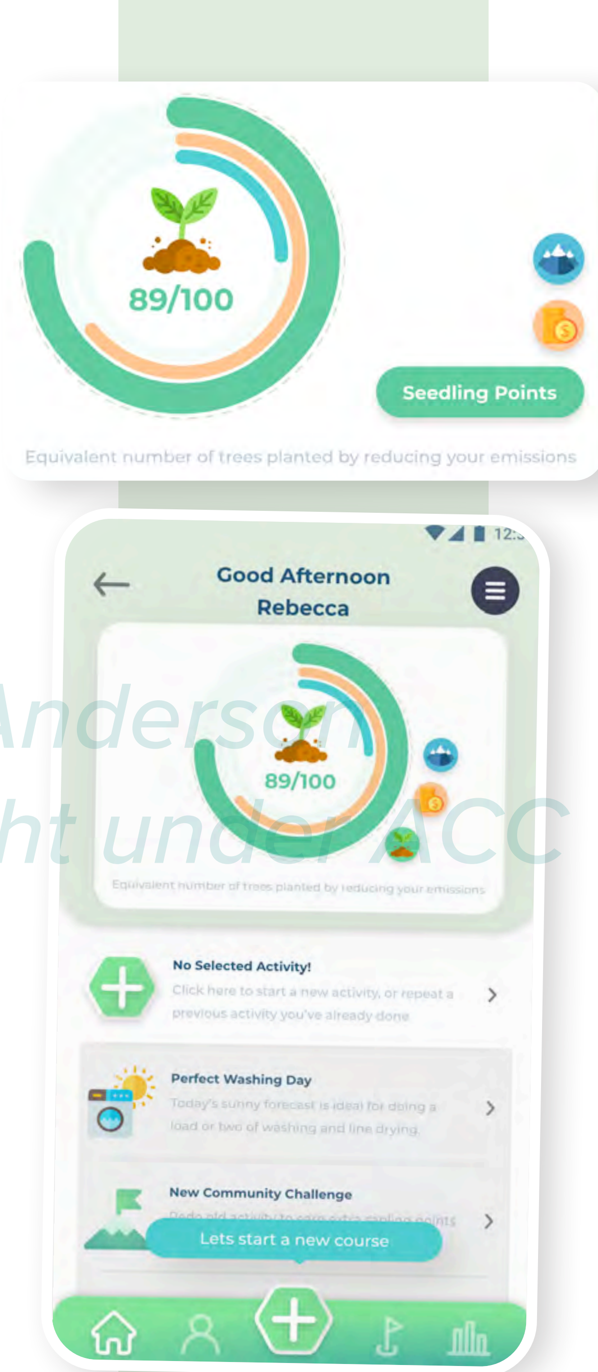
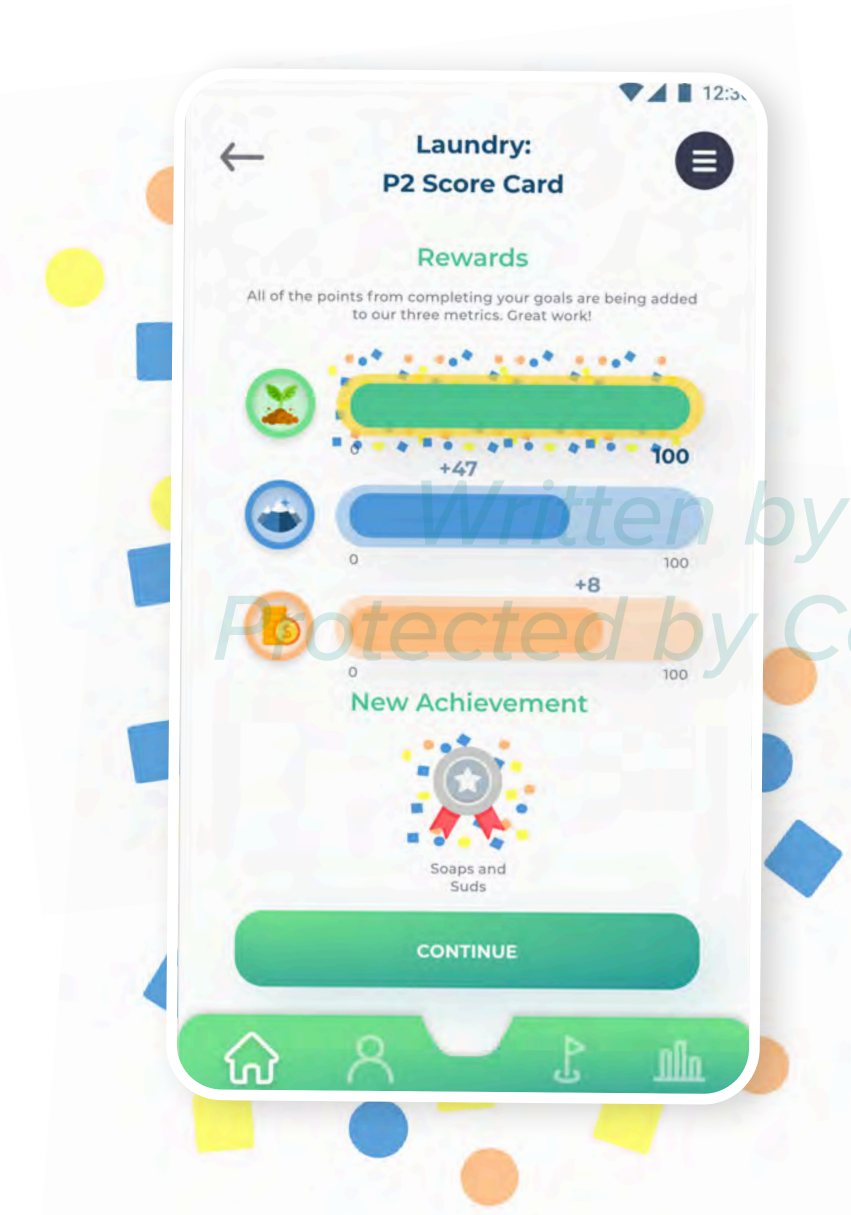


Figure 56 - Household metrics panel alone and on home screen

Design Outcomes



Progress points are a total measure of progress on improving your home, scored from completing quick and regular activities

Activity Points

Energy savings are an estimate of how much money you've saved on energy bills based on your reduction in kW consumption

Energy Savings

Seedling points are an equivalent number of trees planted by reducing your emissions.

Seedling Points

Figure 57 - Completion of activity rewards, and reward metric explanations

A quick activity is a time-based event outside of the regular activity structure. Quick activities are generated depending on current and future weather patterns, and provide intervention points to the user to take advantage of the natural environment (Figure 58). These behaviour change opportunities simultaneously grant users insight into new behaviours, and further rewards the user with points to provide a near instant extrinsic benefit to their actions.

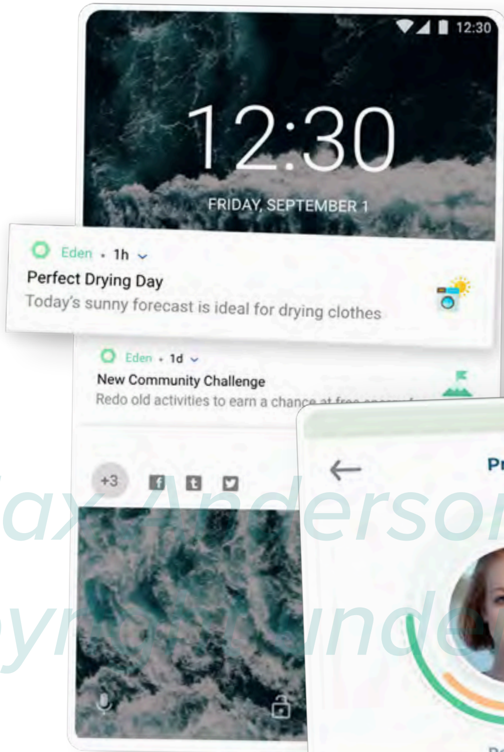


Figure 58 - Example quick action notification (Perfect drying day)

Even if the user achieves minimal reductions in their energy usage over the course of monitoring an activity, they are still rewarded progress points (Figure 57) to praise and encourage their attempt. This extrinsic reward is incredibly important to ensure users are not deterred if they do not instantly find large energy reductions and savings. In addition to users seeking potential extra energy savings, progress points also motivate users to try activites again, allowing *Eden* to "check in" on their new habits.

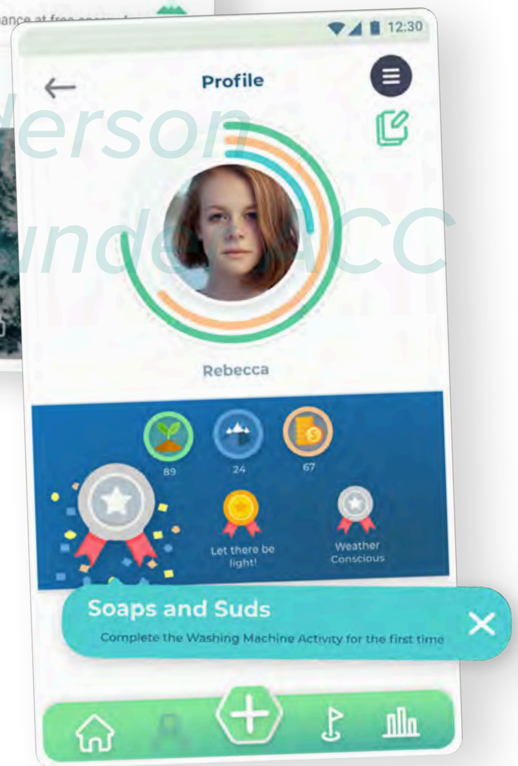
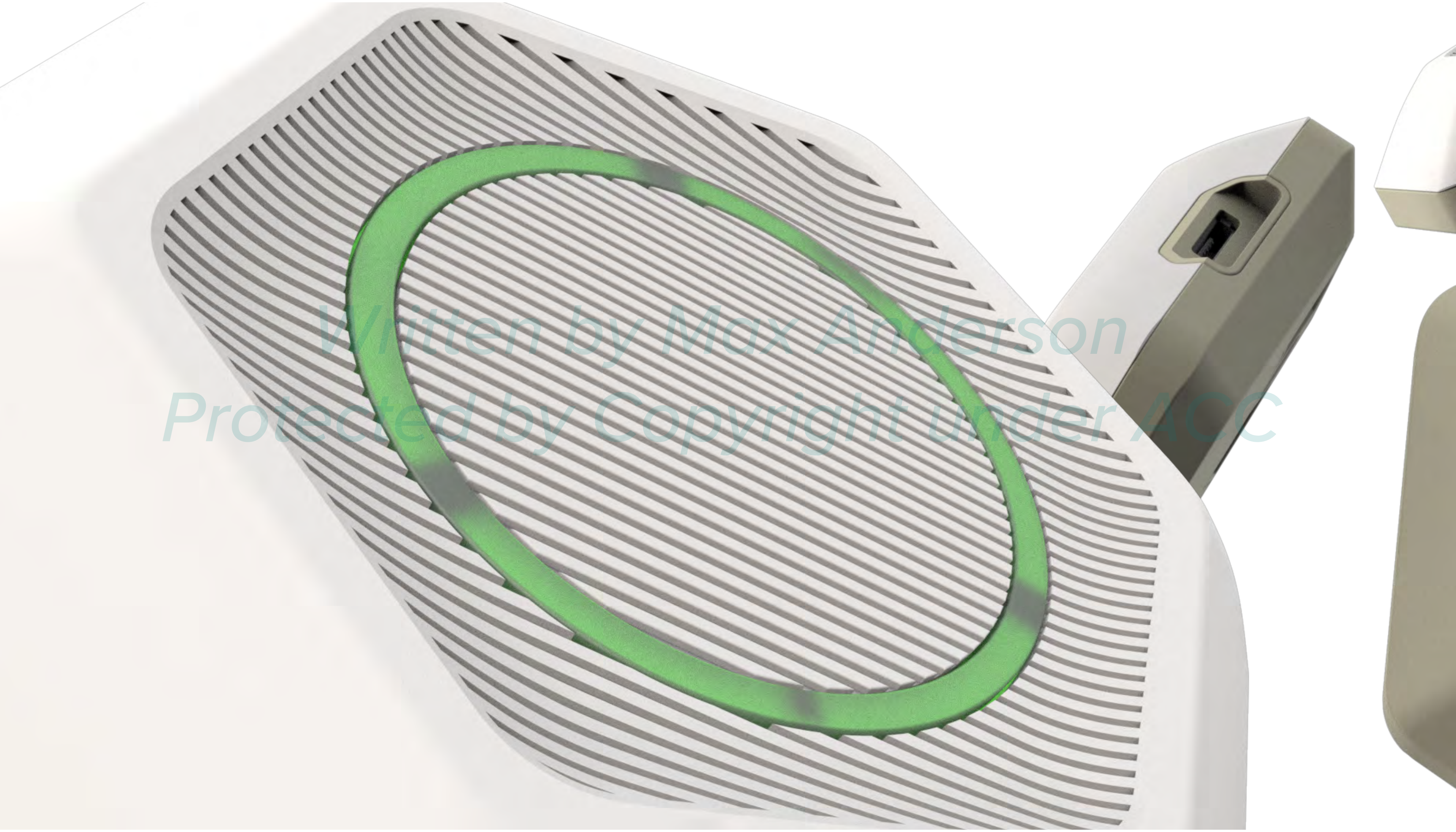


Figure 59 - User profile, and new achievement added from activity completion

Design Outcomes



Conclusion - Making energy visible and fun

In summary, *Eden* is a platform for motivating and visualising home energy behaviour change. At its core, *Eden* divides potential energy reductions into individual appliances and activities that make steps forward clear and simple. It delivers personalised feedback by monitoring both appliance consumption and appliance usage via the *Pebble*, giving users insight into how and when they use their appliances. Improved behaviour suggestions are tailored specifically to users, and are not only suggested, but are tested and reinforced by another period of monitoring that shortens the feedback cycle. The portable nature of the *Pebble* encourages users to monitor numerous appliances around their home, being further reinforced by an encompassing points system. *Eden* reduces the barriers associated with energy use reduction seeming too difficult, or too big a task. It turns energy Ambivalence into energy Ambition.

Figure 60 - Detail closeup of Pebble units


Before we begin, lets make sure your sensor is fully charged
Ready to go!
...Syncing, Checking Charge...
It may take a few moments for Eden to connect with your sensor
11a - Laundry Setup 1 – 1
12:30
Laundry: Setup
Before we begin, lets make sure your sensor is fully charged

Reflection

Throughout the course of these two semesters, my knowledge as a designer, my skills as a researcher, and my resolve as an individual have been tested. This journey to the finish line has been a difficult one, fraught with by-roads that went to nowhere and bumps that created new difficulties to my process. Through this all though, I have a new-found respect for design practice, as well as a understanding of some of the concerning challenges associated with the practice. For example, the development of prototypes is often time consuming and draining work, and sometimes amounts to little. It deepened my respect for the fortitude of designers who ultimately strive through this process. While I was certain I had a good foundational system for dividing energy usage, I struggled to get engagement and feedback from testers in its prototype state while it didn't look "real". The initial visual presentation acted as a barrier, however refining the visual presentation then allowed for the system beneath it to be seen.

The development of the system caused me to develop a new understanding of environmental focused behaviour change. This research into environmental behaviour change bled out into all forms of influencing user behaviour. While striving to utilise these techniques positively for the goal of reducing energy usage in homes, I was forced to consider the ethical question of utilising these "gamifying" techniques, which are not always used by designers to produce positive outcomes for humanity. Developers of games in particular are utilising some of these techniques to make us more inclined to spend additional time and money on their product. Our social media applications are tailor made to keep us invested and hooked, continuing to feed us small bursts of dopamine. In a world that is constantly grasping for our attention, does hoping to use these techniques for "good" make me as a designer any more ethically right than others?

Unfortunately, it is too early to say. What is a "good" element to come out of this process is my enormous increase in sustainably focused design. The research sections of this report brought to light the many complex factors that attribute to climate change, and so many of these factors became notes for potential future projects. Additionally, my increased understanding of household energy usage has made me incredibly conscious of my own energy usage. I now heavily consider the weather forecast when I consider watering my plants, doing my washing etc.

All of these new insights together, I hope to take what I have learned, and continue to refine it in my ever-growing practice as a designer.

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Appendices

Appendix 1 - Combined household actions and estimated CO2 emission reduction

Activity	Category	Plasticity (D) (%) or Rate of Choice (A)	Reduction of kg CO2eq/CU per person per year	Source
Laundry temperature	Appliances	35	28	1
Water heater temperature	Appliances	35	165	1
Standby electricity	Appliances	35	524	1
Buy more efficient devices	Appliances	51	150	2
Use fewer devices	Appliances	46	80	2
Low Flow Showerheads	Appliances	80	80	1
Efficient Water Heater	Appliances	80	382	1
Upgrade home appliances A+++	Appliances	60	70	2
Buy Products with less or greener packaging	Lifestyle	64	60	2
Recycle 30% more of your waste	Lifestyle	63	80	2
Give up frozen meals, and frozen/canned produce	Lifestyle	59	280	2
Green electricity provider	Lifestyle	53	170	2
+ 30% more locally produced food	Lifestyle	46	290	2
+ 30% more organic food	Lifestyle	41	300	2
+ 60% more vegetarian food	Lifestyle	21	560	2
Move to a low energy house	Lifestyle	16	740	2
Minus 90% of intercontinental flights	Lifestyle	8	1000	2

Activity	Category	Plasticity (D) (%) or Rate of Choice (A)	Reduction of kg CO2eq/CU per person per year	Source
Low Rolling Resistance Tires	Transport	80	421	1
Fuel Efficient Vehicle	Transport	80	3207	1
Driving Behaviour	Transport	25	1373	1
Carpooling and Trip-Chaining	Transport	15	2056	1
Thermostat setbacks	Weatherization and Heating	35	575	1
Change HVAC air filters	Weatherization and Heating	30	496	1
Tune up AC	Weatherization and Heating	30	171	1
Routine auto maintenance	Weatherization and Heating	30	490	1
Line drying	Weatherization and Heating	35	342	1
Weatherization	Weatherization and Heating	90	1435	1
HVAC Equipment	Weatherization and Heating	80	695	1

Note

Source 1: Dietz et al., 2006

Source 2: Dubois et al., 2019

Appendix 2 - Dietz Et al., (2006) Household actions, and estimated CO2 emission reduction

Table 1. Achievable carbon emissions from household actions

Behavior change	Category*	Potential emissions reduction (MtC)†	Behavioral plasticity (%)‡	RAER (MtC)§	RAER (%I/H)§
Weatherization	W	25.2	90	21.2	3.39
HVAC equipment	W	12.2	80	10.7	1.72
Low-flow showerheads	E	1.4	80	1.1	0.18
Efficient water heater	E	6.7	80	5.4	0.86
Appliances	E	14.7	80	11.7	1.87
Low rolling resistance tires	E	7.4	80	6.5	1.05
Fuel-efficient vehicle	E	56.3	50	31.4	5.02
Change HVAC air filters	M	8.7	30	3.7	0.59
Tune up AC	M	3.0	30	1.4	0.22
Routine auto maintenance	M	8.6	30	4.1	0.66
Laundry temperature	A	0.5	35	0.2	0.04
Water heater temperature	A	2.9	35	1.0	0.17
Standby electricity	D	9.2	35	3.2	0.52
Thermostat setbacks	D	10.1	35	4.5	0.71
Line drying	D	6.0	35	2.2	0.35
Driving behavior	D	24.1	25	7.7	1.23
Carpooling and trip-chaining	D	36.1	15	6.4	1.02
Totals		233		123	20

*See text for definitions of categories W, E, M, A, and D.
†Effect of change from the current level of penetration to 100% penetration, corrected for double-counting. Measured in millions of metric tons of carbon (MtC).
‡Percentage of the relevant population that has not yet adopted an action that will adopt it by year 10 with the most effective interventions.
§Reduction in national CO_2 emissions at year 10 due to the behavioral change from plasticity, expressed in MtC/yr saved and as a percentage of total US individual/household sector emissions (%I/H). Both estimates are corrected for double counting.

Note:

Table is direct from source