# Symbiosis of Digital and Environmental Artefacts in Blended Spaces Using Permaculture Design as a Framework

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## MSc dissertation check list

| Milestones | Date of completion | Target deadline |
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| Proposal | 30th May 2018 | Week 3 |
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| Full draft of the dissertation | 5th August 2018 | 2 weeks before final deadline |

| Learning outcome | The markers will assess | Pages[1] | Hours spent |
|---|---|---|---|
| **Learning outcome 1** Conduct a literature search using an appropriate range of information sources and produce a critical review of the findings. | * Range of materials; list of references * The literature review/exposition/background information chapter | 13 - 30 | 220 hours |
| **Learning outcome 2** Demonstrate professional competence by sound project management and (a) by applying appropriate theoretical and practical computing concepts and techniques to a non-trivial problem, <u>or</u> (b) by undertaking an approved project of equivalent standard. | * Evidence of project management (Gantt chart, diary, etc.) * Depending on the topic: chapters on design, implementation, methods, experiments, results, etc. | 31 – 61 Appendix B Appendix C | 190 hours |
| **Learning outcome 3** Show a capacity for self-appraisal by analysing the strengths and weakness of the project outcomes with reference to the initial objectives, and to the work of others. | * Chapter on evaluation (assessing your outcomes against the project aims and objectives) * Discussion of your project's output compared to the work of others. | 62 - 72 | 120 hours |
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## Abstract

Interactive technologies are becoming more and more pervasive as everyday objects are increasingly being embedded with always-on, network-connected technology, enabling new ways of interacting with technology. These pervasive technologies create ever more complex ecologies of devices, and “blended” spaces that integrate the physical with the digital. Finding ways to design for these ecologies and spaces in a holistic way that considers the assemblage of artefacts, users and technologies has been explored in research in recent years, however there has lacked discourse in the Human-Computer Interaction (HCI) and interaction design communities on how to do so in a sustainable way. Sustainable HCI and Sustainable Interaction Design research has tended to focus on either energy efficiency or material disposal, or framed sustainability as an awareness and persuasion problem. Others have argued that these approaches oversimplify the complexities of the sustainability issues with the current paradigm of how we design and make things. There has also been little in the sHCI corpus to apply a relations-based approach to designing sustainable interactive systems in complex ecologies. Permaculture is a holistic design approach that aims for synergistic relationships between components and consideration of the spaces they inhabit, and to do so in a way that fundamentally incorporates sustainable thinking. It promotes actively cultivating collaboration between people and nature; working with nature, not against nature. In this study, permaculture was used as a framework to design a novel artefact, embedding plants with technology, within a complex ecology and a blended physical-digital space. It proved a useful tool in considering energy efficiency, material disposal and waste, temporality and maximising the benefit of the relations between people, nature, technology and space. Evaluation of the designed artefact also suggests that objects in nature, such as plants, embedded with technology and physically interacted with may be able to also foster a connection with nature, through embodied engagement, which research suggests can improve environmentally responsible behaviour.

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## Acknowledgements

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# 1 Introduction

## 1.1 Context

> *"We see a world of abundance, not limits. In the midst of a great deal of talk about reducing the human ecological footprint, we offer a different vision. What if humans design products and systems that celebrate an abundance of human creativity, culture, and productivity? That are so intelligent and safe that our species leaves an ecological footprint to delight in, not lament?" - (McDonough & Braungart, 2002)*

Anthropogenic climate change, loss of species diversity, soil and ocean pollution, and contamination of the biosphere are some of the most important issues facing humanity and the world we inhabit. In their seminal book *Cradle to Cradle: Re-making the Way We Make Things*, Braungart & McDonough (2009) propose taking inspiration from the robustness and sustainability of natural systems to enact technological change. The problems with the way we currently design things are manifold (McDonough & Braungart, 2009): many systems and products are designed with "built-in obsolescence", to last for a certain amount of time before customers are encouraged to dispose and replace them; universal design decisions are imposed without consideration for local conditions and customs by applying brute force to make solutions fit; a culture of monoculture has been caused by overwhelming and ignoring natural and cultural diversity, leading to less variety. This is a mentality that views nature as something to overcome, not work *with*. Braungart & McDonough call upon scientists, engineers and designers to rethink the way we currently make things: to reduce the waste, pollution and other negative effects that are the consequences of outdated and unintelligent design. They also posit the need to find nurturing solutions that use a longer perspective and take into consideration human and ecological health, and cultural and natural diversity. Braungart & McDonough propose doing this by incorporating cooperation with nature and awareness of its complexity and interconnectedness into the design agenda.

In the field of computing, some progress has been made in the sustainable Human-Computer Interaction (sHCI) and Sustainable Interaction Design (SID) communities. However, there remains a need for further discourse involving how to approach sustainability in projects, how to apply and educate on SID concepts and how to improve HCI evaluation methods to consider sustainability (Nunes & Alvão, 2017).

A contemporary sustainable framework is permaculture, a holistic agricultural and social design philosophy that is kind to both planet and people, based on intelligent design (Whitefield, 2016). It proposes mimicking natural ecosystems to create robust and sustainable systems, with a central aim to reduce our ecological impact. This paper seeks to explore using permaculture design as a framework within the domains of User Experience (UX) and SID to see what can be achieved in realizing sustainable design in practice.

The domains of UX and Human-Computer Interaction (HCI) are themselves currently undergoing a paradigm shift with the rise of ubiquitous computing. New ways of interacting with technology are possible and so new ways of designing interactive systems are required, presenting opportunities for new ways of making things. Tangible interaction, in which a user interacts with the digital through physical artefacts interfaced with computers, is one such area of interaction that new developments in ubiquitous computing continues to contribute to. Ubiquitous computing has also contributed to increasingly complex device 'ecologies'; where several devices work together to create an environment (Benyon, 2013, p. 7). Nicholas Makelburge (2003) proposes that ubiquitous computing with proper application could help us by illuminating the things that are worth reflection and help us value things that enrich the human experience. He writes:

> *"Technology and ubiquitous computing could be used to help us enjoy the whole spectrum of physical and mental sensations in life to a greater extent. Ubiquitous computing could make us aware of who we are and the impact we have on the environment and other lives, cultures and countries. It could help us re-enter into balance with our environment, animals, which in the long run will be what truly 'helps'*

*us, while coffee cups who'll let us know when they are dirty won't" - (Makelburge, 2003, p. 178)*

Closeness to nature can aid human wellbeing, both physically (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003) and psychologically (Kuo, 2001), and interacting with it teaches us to live cooperatively *with* nature rather than *against* nature. This study will look at how combining these ubiquitous technologies ('digital artefacts') with objects in nature ('environmental artefacts') can be done in a sustainable way using permaculture as a design framework, so as to foster an engagement with nature and to explore what can be achieved.

## 1.2 Research Aims

This project aims to demonstrate permaculture as a design philosophy that can contribute to debates on sustainable HCI and to explore how tangible interfaces can enhance our interactions with novel environmental-digital artefacts within physical-digital blended spaces (Benyon, 2014). It also seeks to explore how UX and ubiquitous computing technologies can enhance our interactions with the natural world in a way that supports sustainability by using real world garden objects as an interface to provide more engaging experiences.

The main research questions that this work will address are:

1. In what ways can permaculture make the design of interactive systems in complex artefact ecologies a sustainable practice?

2. Can an interactive system combining environmental and digital artefacts foster engagement with nature?

3. What can be achieved by engagement with an environmental-digital artefact?

These aims will be explored through the design, implementation and evaluation of an interactive system promoting reflection on nature and sustainability, utilising tangible technologies and garden objects, within an interactive permaculture garden.

## 1.3 Dissertation Arrangement

Following a literature review of relevant research in associated topics in Chapter 2, the methods used to research the aims and objectives of this study are described in Chapter 3. Chapter 4 will describe the artefact designed as a part of this study with Chapter 5 giving a detailed account of the results of the research methods described in Chapter 3, including evaluation of the designed artefact. Following this, Chapter 6 discusses and critically evaluates the findings of this research. Finally, chapter 7 summarises the study, evaluates the research methods chosen and suggests future avenues for further investigation.

# 2 Literature Review

User Experience (UX) design is increasingly more concerned with providing great experiences rather than just designing usable systems. McCarthy and Wright say experience in technology refers to the “irreducible totality of people acting, sensing, thinking, feeling, and making meaning” including their perception and sensation of the artefact in context (McCarthy & Wright, 2004). UX encompasses the feelings, thoughts and sensations of engaging in an activities involving interactions with technology (Benyon, 2013, p. 2). It is emotional and cognitive. User engagement is a quality of UX characterised by temporal, emotional, and/or cognitive user investment with a digital system (O’Brien, 2016). UX is also an explorative field. As technology becomes increasingly pervasive, the already complex interactions “between space, infrastructure, culture, and experience” (Dourish & Bell, 2011, p. 116) become increasingly so. The rest of this chapter will explore some of the existing literature on these complex ecologies, the tangible interfaces used to interact with them, the blended spaces they inhabit, current approaches to designing sustainably and a background to permaculture design.

## 2.1 Ubiquitous Computing and Complex Artefact Ecologies

Our perception is shaped by our physical ecology; the artefacts we interact with to realise our activities. The use of these interactive artefacts influences other artefacts in the ecology and cannot be fully understood in isolation (Jung, Stolterman, Ryan, Thompson, & Siegel, 2008). Physical objects in our environments become different things when they are combined with technology; their functionality expands and new relationships within our ecologies are created. The forms of interaction within these ecologies are becoming increasingly multi-modal as new technologies bring new forms of interaction which affects the user experience.

Ubiquitous computing (also known as pervasive computing) is a paradigm concerning the embedding of always-on, network-connected technology into everyday objects. It is about blending the physical and the digital, and concerns spaces and movement (Benyon, 2014, p. 14). Interaction design in ubiquitous computing environments concerns many of these networked objects communicating with each other. In his book *Mobile Interface Theory: Embodied Space and Locative Media*, Farman (2012) argues that our existing mobile devices are the tools that will bring about the age of ubiquitous computing and should always be a consideration in future research concerning ubiquitous computing.

Examples of ubiquitous computing technologies and subject areas include Wireless Sensor Networks (WSN), Radio-Frequency Identification (RFID) and the Internet of Things (IoT). WSNs are large-scale, multi-hop, wireless, ad hoc networks of homogeneous, tiny sensor nodes deployed in an area (Romer & Mattern, 2004) used for monitoring and recording the physical conditions of an environment, from natural ecologies to urban spaces. RFIDs use electromagnetic fields to automatically identify and wirelessly communicate with tags embedded with microchips (Herschel & Rafferty, 2012). One commonly deployed subset of RFID is Near-field Communication (NFC), a set of communication protocols that enable two devices, usually involving one portable device such as a smartphone, to establish communication. IoT is a wide subject area concerning the network of computing devices embedded into everyday objects. From a user-centred approach, the IoT for smart environments is defined as: “Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework” (Gubbi, Buyya, Marusic, & Palaniswami, 2013). At its core, the IoT is about communication and thus the relationships between physical artefacts embedded with digital technology.

As these ubiquitous technologies continue to develop and become more commonplace, the ecologies of physical, digital and hybrid artefacts we inhabit become increasingly diverse, numerous and complex. Designing for these ecologies requires considering how to “configure the varied properties of devices into a holistically-designed system, with desirable characteristics in terms of the assemblage of people, artefacts and technologies, and the transitions that occur between them” (Coughlan et al., 2012). Coughlan et al. point to an existing lack of knowledge as to how to design and evaluate for these device ecologies, putting forward concepts such as ‘seams’, ‘bridges’, ‘niches’ and ‘foci’ to enable users to utilise an ecology appropriately. Seams and bridges are characteristics of relationships between devices where seams are forms of disconnect affecting user behaviour and bridges are ways of overcoming the disconnect. Foci focuses on the social and collaborative aspects of an ecology; how social practices can be made visible to other people within the space. Their use of niche is drawn from niche as defined in ecology as all of the interactions of a species with other members of its community; in the context of device ecologies this is a configuration of users and/or devices in which an activity occurs. They also highlight the importance of designing the transitions between devices.

Jung et al. developed a framework for understanding digital ecologies based on people’s perceptions of their personal ecologies (Jung et al., 2008). The framework focuses on various ‘ecological factors’ as well as the concept of ‘ecological layers’ where the purpose of context and physical use create groupings of artefacts revealing potential dynamic interconnections.

Using activity theory Bødker and Klokmose (2011) developed the ‘human-artifact model’ to aid in the understanding of an artefact's action-possibilities in relation to its ecologies. They identify four interconnected levels of analysis: goal orientation and the instrumental aspects, motivational orientation and motive-related aspects, handling, and adaption.

In the context of the IoT, Hoffman and Novak (2018) argue that traditional, human-centric conceptualizations of user experience may be insufficient when ‘smart objects’, that can affect and be affected by both users and other objects, are involved. They propose a conceptual framework that is object-oriented rather than human-centric and based on assemblage theory. In assemblage theory, non-human actors are given equal ontological status to human actors and are more than just the user’s perception or interaction with them (De Landa, 2002). Assemblages are dynamic wholes whose characteristics transpire from interactions and relationships between components. This theory echoes Bruno Latour’s (2007) Actor-network theory (ANT), a social theory that posits that everything in the natural and social world exists in always changing networks of relationships and that all entities should be described in the same terms.

The merging of electronic systems into the physical world is altering the way we interact with computers. Novel artefacts that tightly couple physical and virtual objects have been explored using the paradigm of *tangible computing* for interaction with them, which will be discussed in the next section.

## 2.2 Tangible Computing

Tangible user interfaces (TUIs) are interfaces with which a user interacts with the digital through physical artefacts interfaced with computers. There are multiple ways this combination of the physical and digital can be achieved such as embedding technology into existing objects, using QR codes or RFID tags to link to digital information, superimposing digital information over the real world as in Augmented Reality (AR) or creating novel objects by combining digital technologies with physical artefacts at the conceptual stage. Since the publication of Paul Dourish’s Where the Action Is (Dourish, 2001) the idea of embodiment has been prominent in the field of tangible computing. Embodiment refers to our being manifest in and of the world we live in. Through his theory of ‘embodied interaction’, Dourish argues that we should better exploit our natural skills from interaction with the everyday world by interacting directly with physical objects themselves rather than interacting with computers via physical proxies such as keyboards and displays; that physical artefacts are the place computer technology should inhabit. TUIs offer a way to exploit embodiment through technology and change the way we perceive and interact with digital technologies. For example, TUIs and multi-touch screen interfaces are two combinations of embodiments that are psychophysically perceived differently by users (Alzayat, Hancock, & Nacenta, 2014). This suggests differences at higher levels of interaction such as emotional engagement with artefacts. Handheld mobile interfaces arguably also divorce a user’s attention from their surroundings (Silva &

Frith, 2012) however Farman (2012) argues that personal mobile devices are an extension of the body and extend the spaces the user inhabits.

Marshall, et al. (2003) argue for two classes of tangibles in artefacts embedded with digital technology: expressive and exploratory, and that use of this distinction in TUI design can promote reflection and learning in children. This distinction was based on Heidegger's idea of 'ready-to-hand' and 'present-to-hand' which describe attitudes towards artefacts (Heidegger, Macquarrie, & Robinson, 2013). Expressive tangibles are those present-at-hand and focus on external representations of activity. Exploratory tangibles are those ready-to-hand and used to explore a model. Heidegger's notion of ready-to-hand is based on the phenomenological tradition and refers to the use of a tool by a person making the tool in a sense 'invisible'. Dourish's theory of embodied interaction focuses on the 'ready-to-hand' and how meaning is attached to objects and embodies the user activity, arguably neglecting the 'present-at-hand' (Marshall et al., 2003). Marshall, et al. argue that the exploratory class of tangible can facilitate powerful learning from TUIs as learning often requires reflection, to step back and consider the system.

For UX and interaction designers, despite the development of frameworks and conceptualizations in recent years there is currently a limited understanding as to how to design for experiences in the emerging field of tangible computing. This need for principled approaches for research and design of tangible systems is highlighted by Hornecker and Buur (2011) in the introduction of their own framework focusing on the materiality of the physical interplaying with the social, something they noted as lacking in previous discourse.

## 2.3 Maker Culture

An emerging trend of note in Human-Computer Interaction are the practices of maker movements and do-it-yourself (DIY) cultures as a form of participatory design (Smyth et al., 2018). 'Maker culture' is an artisan contemporary culture emphasizing learning through making. They are presently influencing research and innovation in the domains of physical and tangible computing in particular due to the accessibility of low-cost, open-source microcontrollers and platforms such as Arduino and the falling costs and miniaturisation of components for connectivity, sensing and actuating. This has enabled ‘makers’ to more easily embed physical artefacts with digital technology, creating tangible systems of their own using reconfigurable components. Similar to this concept of users as makers, Lucy Suchman (1993) argues for designing “working relations” rather than “discrete devices” and removing the boundary between use and production to sustain the work required to construct interactive systems and put them to use. She proposes that design in this context should be holistic and sensitive to local ecologies rather than focusing on particular functionalities and technical requirements. Makers culture has also been viewed by some as a more sustainable alternative to the current paradigm of mass production and built-in obsolescence (Millard, Sorivelle, Deljanin, Unterfrauner & Voigt, 2018) promoting sustainable interaction design (Wakkary & Tanenbaum, 2019).

## 2.4 Sustainable Interaction Design and Sustainable Human-Computer Interaction

As digital technologies continue to pervade everyday life more and more, there is a greater need for designers to consider the environmental implications of products and systems. Sustainable Interaction Design (SID) is a field of study within Sustainable Human-Computer Interaction (sHCI) that posits that sustainability should be an important consideration in the design of interactive technologies. In this context, *design* is defined by Blevis as “the act of choosing among, or informing choices of future ways of being” (Blevis, 2007). The focus in this field of study is environmental sustainability as a future way of being, although it can include other considerations regarding humanity and the biosphere such as social equality and public health. SID explores how interactive technologies can promote more sustainable behaviours and how sustainability can be used as a critical lens in their design and evaluation. Five principles of SID (Blevis, 2006) that can frame design criticism and design goals are:

I. *Linking invention and disposal* which means taking into consideration when designing new technologies what will become of physical materials that may be displaced or made obsolete. What effect is there on the environment by materials disposed of during manufacture, use and retirement? Are there systems in place to lessen the amount or impact of these disposed materials? What can be done to encourage people to use them?

II. *Promoting renewal and reuse* refers to maximising the salvage of these disposed of physical materials and minimising the need for salvage as part of the design. Can existing objects be reused or recycled and implemented in the design?

III. *Promoting quality and equality* means designing with longevity in mind, prolonging use, considering renewal and reuse, and providing equality of experience when ownership is transferred.

IV. *Decoupling ownership and identity*; does the design enable a transfer of ownership? Can it be reused without the need for remanufacturing or recycling?

V. *Using natural models and reflection* means learning from nature to achieve sustainability, as natural ecosystems are sustainable, when designing systems and reflecting on those principles.

In essence, Blevis (2006) argues that the field of HCI needs to rethink its practices to reduce, delay or avoid the disposal of products caused by technological developments of both hardware and software.

Research into sHCI covers a variety of different genres of which SID is one. According to DiSalvo et al. (2010) the dominant genre in research is Persuasive Technologies; systems that encourage users to live more sustainable lives. Common methods in this genre include using strong persuasion where the user is judged as being environmental or not, and passive persuasion where the user is provided with information relating to sustainability. The aim of persuasive technology is to cause behavioural change in users to live more sustainably. However, DiSalvo et al. found that the concept of sustainable as defined in research into persuasive technologies tended to be limited to only conservation of resources and drew more from the fields of communications and psychology rather than design. Analysis of subsequent research in this genre (Brynjarsdottir et al., 2012) additionally found that its focus is limited to affecting only individual behaviours and not the societies into which they are embedded, that it does not take into consideration the complexities of real life and assume that providing information and awareness will be enough to alter behaviour which as a form of persuasion often borders on coercion. Brynjarsdottir et al. offer three suggestions to address these issues when designing persuasive systems for sustainability; using participatory design to better consider the daily lives of users and to improve user engagement, broadening our understanding of persuasion to inform and shape beliefs and actions by recognising persuasion as a process through which perspectives are shared, and by considering community and organizational as well as individual engagement.

Along with SID, the lesser-researched genres of sHCI are Ambient Awareness, Formative User Studies and Pervasive Sensing Systems. Ambient awareness focuses on the design of systems to increase awareness of aspects of sustainability or environmental qualities. Like persuasive technologies this method relies on providing information to change behaviour. It is often achieved by making consumption visible to users and by making desired related behaviours visible and aesthetically pleasing. Formative User Studies focuses on understanding user attitudes and behaviour as a basis for design by analysing how users approach sustainability. Pervasive Sensing uses sensors to monitor and report environmental conditions. Some of this research is participatory, involving end users to collect sensor data.

A sustainable design philosophy that is gaining traction in multiple research disciplines, such as environmental anthropology (Veteto & Lockyer, 2008), resilience research (Henfrey, 2018) and interaction design (Egan & Benyon, 2017), is permaculture.

## 2.5 Permaculture

Permaculture is a whole-systems design process informed by agricultural and social design principles that take natural ecosystems as a model for human habitats with a central aim to reduce our ecological impact (Whitefield, 2016). This is an approach that echoes Blevis' SID "using natural models and reflection" (Blevis, 2007). Natural ecosystems are sustainable and if we can understand how they work, we can apply this understanding to design sustainable systems. What makes an ecosystem work is its diversity and the beneficial relationships between its components. Permaculture goes beyond just taking direct imitations of natural ecosystems; it proposes understanding the principles on which they operate and applying them more widely to create systems that are kind to both people and planet, based on intelligent design.

There are three maxims used to summarise the ethics of permaculture that act as a foundation to shape and inform the design of any system; (i) care for the earth, (ii) care for people and (iii) fair share (Holmgren, 2010). In his book ‘Permaculture Principles & Pathways Beyond Sustainability’, David Holmgrem describes twelve principles of permaculture (2010). These principles of ethics and design were devised to be universally applicable, although the methods used to achieve them would vary depending on the domain and situation to which they are applied. These principles are as follows:

I. *Observe and interact* – Good design requires good understanding of the design problem and domain. Observation and interaction with nature can inspire good design and make more effective use of resources.

II. *Catch and store energy* – We need to find ways to capture and store local flows of energy for long-term investment in natural capital. This means becoming more self-resilient and minimising the need to seek resources from the outside.

III. *Obtain a yield* – Systems that are productive will be more likely to last, functioning as a reason for people to maintain and replicate the system. This principle also refers to making use of stored energy to maximise yield.

IV. *Apply self-regulation and accept feedback* – Systems that self-regulate are sustainable systems and application of this principle requires understanding of the positive and negative relationships (or feedbacks) that exist in nature. This also applies to limiting or discouraging actions and behaviours detrimental to sustainability.

V. *Use and value renewable resources and services* – This principle proposes making the most of renewable natural resources and renewable services where the latter refer to passive functions in nature that can provide benefit within a system without consumption

VI. *Produce no waste* – Seeing output as an opportunity, this entails designing systems to make productive use of all outputs from its components to reduce waste and pollution.

VII. *Design from patterns to details* – An outcome of the first principle of observe and interact are the patterns found in society and nature. These patterns can be scaled and incorporated into the design process. This also refers to considering the bigger picture when designing.

VIII. *Integrate rather than segregate* – This principle focuses on the relationships between components which should be arranged to improve the benefits from other components.

IX. *Use small and slow solutions* – This means designing to the smallest practical scale; designing simpler and local systems.

X. *Use and value diversity* – As previously mentioned; the diversity of natural ecosystems and the beneficial relationships within are part of what makes them so successful.

XI. *Use edges and value the marginal* – This principle reminds us that the most obvious areas or components of the system may not always be the most important or influential and these edges and marginals are opportunities to increase diversity.

XII. *Creatively use and respond to change* – Natural systems are dynamic and will change over time in expected and unexpected ways. The challenge for designers are to make benefit of these expected changes and respond creatively to any unexpected ones.

These twelve principles can be regarded as general heuristics to support sustainable design. Many of them correspond to Blevis' principles of SID; notably with regards to reduction of waste, and observation and reflection on nature.

## 2.6 Space and Place

As our interactions with technology become spread across devices, the spaces in which they exist become increasingly significant in UX and interaction design. Farman (2012, p. 21). suggests that Marxist philosopher and sociologist Henri Lefebvre's argument for the production of space as simultaneously a production of embodiment means that embodiment is a spatial practice and that space is an embodied practice; that both spaces and bodies exist through their actions and relationships. While architects may decide a physical space's form, embodiment in regard to technology may therefore be considered as produced through the interaction between the physical and digital spaces. It is "people interacting with and within that space that produces the sense of place and being" (Benyon, 2014, p. 30). Space is an active participant in the making of meanings. Physical spaces can also become part of an interface themselves for example through ambient fixtures (Dahley, Wisneski, & Ishii, 1998).

## 2.7 Blended Spaces

Designing for an experience requires considering the different layers of interaction, including aesthetics, pleasure and emotional engagement, in context (Benyon, 2013). With the rise of ubiquitous computing it has become increasingly important for interaction designers to understand how to implement interactive systems across an ecology of interactive artefacts, as well as multiple types of spaces; digital, physical, social and blended spaces.

Blended spaces in HCI are typically spaces in which the digital and physical spaces are deliberately closely integrated; where the physical and digital are completely coupled to provide a sense of presence in a different type of space (Benyon, 2014). Blended space design aims to enable people to feel more present and engaged within blended spaces. The idea of blending two conceptual spaces to create a new blended space in design, rather than projecting from one source domain to a target domain as in the theory of metaphors in design, stems from blending theory. Blending theory is a framework for explaining the imaginative processes people use to make-meaning using novel conceptualizations (Fauconnier & Turner, 2008). In order for blends to work, correspondences must exist between the domains, as with metaphors. Benyon (2014) identifies four key characteristics for describing spaces: ontology, topology, volatility and agency. The ontology concerns the objects in the space; their quantity, size, distribution and functions. The topology concerns the relationships between objects; grouping, distance and direction. The volatility concerns how objects and elements change over time. The agency concerns the people, artificial agents and opportunities for action. Ed Hutchins contributes further to blending theory by positing that the use of a ‘material anchor’, where one of the input spaces is grounded in a physical, embodied experience, can stabilize conceptual representations (Hutchins, 2005), improving the blend.

Egan, Benyon & Thomson propose using permaculture as a framework for achieving principles of SID (2017). Egan et al. propose blending the conceptual spaces of UX and permaculture, using a garden as a material anchor as a means to create experiences that enable people to reflect on sustainability and foster a connection to nature, and as designers gain better understanding of UX, sustainable HCI and SID. UX and permaculture are both concerned with intelligent design and there are a number of correspondences between them, suggesting a blend of the conceptual spaces of UX and permaculture design can work well. Egan et al. point out a few of these correspondences (2017); that the permaculture design principle of ‘observe and interact’ maps well to UX design practices of interaction design and ethnography, how UX and permaculture design share an interest in design patterns, that ‘integrate rather than segregate’ shares a similar perspective to blended spaces and that notions of liminality bears similarities to the permaculture principle ‘use edges and value the marginal’. Permaculture, as increasingly in ubiquitous computing, is a makers culture, providing new insights by making.

There are also further similarities between the permaculture design principles and Blevis’ SID principles; ‘produce no waste’ corresponds well to the SID principles relating to material disposal, likewise the permaculture principle ‘observe and interact’ is analogous to the SID principle of ‘using natural models and reflection’. However, there appears to be little evidence of application of these principals in HCI design methods at present.

UX and permaculture are both exploratory design practices implying a close potential relationship; the unique context to which a design is produced creates unique results, even when common methods are used. They also both use iterative design cycles with an ongoing process of evaluation and re-evaluation.

## 2.8 Literature Review Conclusion

The emergence of new technologies, combinations of physical, digital and hybrid artefacts and means of interaction between users, objects and spaces bring fresh challenges for HCI, UX and interaction designers. However, with fresh challenges arise new opportunities to rethink the way we design systems to be an agency of change towards the sustainable. Permaculture blended with UX design to develop a framework could contribute to this, supporting SID and better incorporating all three core permaculture ethics of people care, earth care and fair share. UX design has traditionally been human-centred, corresponding to the notion of people care. However, research and proposed frameworks concerning the design of devices within complex ecologies acknowledge the need for a holistic approach ensuring synergistic relationships between components beyond the user-device paradigm. Could extending the scope even further to incorporate these ecological relationships to the Earth and its resources be feasible?

The democratisation of design and innovation in maker movements and DIY cultures also indicate a shift in HCI research further towards a notion of fair share beyond traditional participatory research. Maker culture, existent in permaculture, also presents new opportunities, by empowering the user, to explore solutions for SID toward the problem of designed obsolescence (Roedl, Bardzell, & Bardzell, 2015). Dourish's concept of embodied interaction in HCI also highlights the value of engaged designing and making with and through materials for the "creation, manipulation and sharing of meaning" (Dourish, 2001, p.126).

Ubiquitous computing and tangible technologies also bring new possibilities to engage with sHCI and opportunities to better achieve some of the permaculture principles. For example, passive RFID tags collect energy from RFID readers, enabling objects to become hybrid artefacts without the need for an external power supply, low-energy wireless sensor nodes in WSNs that can harvest their own solar or vibration energy correspond to the principles regarding energy.

This study will explore the research questions; a) in what ways can permaculture make the design of interactive systems in complex artefact ecologies a sustainable practice, b) can an interactive system combining environmental and digital artefacts foster engagement with nature, and c) what can be achieved by engagement with an environmental-digital artefact? This will be done through the making of a novel digital-physical artefact with a tangible user interface, inhabiting a 'niche' within an ecology, using permaculture as a design framework. Today's interactive systems require a sustainable and holistic approach that considers ecologies and relations between components. Permaculture design has several correspondences with UX and interaction design and the following chapters will examine what permaculture can be contribute to the domain of sHCI through making. Through engagement via the environmental artefacts augmented with technology this study will also explore what can be achieved by such systems. It is through activities that involve contact, meaning, emotional attachment and compassion mediated by engagement that connectedness with nature occurs, even in urban environments (Lumber, Richardson, & Sheffield, 2017). Studies have suggested that this connectedness with nature (Geng, Xu, Ye, Zhou, & Zhou, 2015) and natural places (Vaske & Kobrin, 2001) can encourage pro-environmental behaviour. This study will explore if the designed artefact can achieve similar connectedness.

# 3 Methodology

This chapter presents the research methodologies to be employed in this dissertation to answer the research questions proposed in Chapter 1. It will explain the approaches made to the research questions and the methods used to obtain data for analysis followed by discussion on why the research methods were chosen and their suitability for this purpose compared to alternatives.

The research methodology for this dissertation employs both established quantitative and qualitative methods, and emergent and creative methods. Interaction designers typically apply a variety of established and creative methods, concepts and techniques in the design process, so it feels appropriate to employ the same for research in the domain.

## 3.1 Research Through Design

### 3.1.1 Rationale

Research and creative practice have until recent decades been viewed as antithetical activities within HCI. However, some argue that research and designing of an artefact are essentially equal, as both practices produce new knowledge (Zimmerman, Forlizzi, & Evenson, 2007). Combining research and creative practice can sometimes result in distinctive methods and “exhilarating findings” (Smith & Dean, 2009). Research through Design (RtD) is a practice-oriented research approach identified by Christopher Frayling as “taking design as a particular way of thinking, and a particular approach to knowledge, which helps you to understand certain things that are outside design” (1994, p. 5). RtD is an approach where the process of design itself can produce knowledge. Zimmerman et al. further developed this concept within interaction design, explaining that through designing the interaction designer contributes to HCI research from acting as a facilitator between multiple disciplines (2007).

### 3.1.2 Procedure

In action research achieved through RtD, Frayling advocates a combination of a research diary detailing practical experiments step-by step and a resulting report contextualising it, with both diary and report “communicating the results” (Frayling, 1994). In order to provide some answers to the first research question ‘in what ways can permaculture make the design of tangible interfaces in complex artefact ecologies a sustainable practice?’ posited by this dissertation, a process of learning through making accompanied by a reflective journal is proposed. This will then be followed by analysis and contextualisation (see Chapter 5 and 6, respectively).

The reflective journal, included in Appendix C, is a detailed, rich description record of actions and thoughts compiled throughout the making process with particular emphasis on the source of or inspiration for certain design decisions. Using critical reflection, defined as “bringing unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice” (Sengers, Boehner, David, & Kaye, 2005) it is hoped to uncover opportunities and limitations of using a permaculture framework in the design process in interaction design.

There are several analysis methods available for qualitative research such as grounded theory, phenomenology, hermeneutics, ethnography, linkography and content analysis. For analysing “own design” activities in practice-led research, Pedgley (2007) recommends content analysis of diaries.

In this work, individual design decisions located within the reflective journal were assigned codes based on the source of the design decision; either stated explicitly in the text or inferred by the researcher. The codes are shown in table 1 and correspond to either a permaculture or SID principle, a UX design research method or ‘Other’ for design decisions that had a source that did not apply to any other code. Codes relating to permaculture have the prefix ‘PP’, SID principles have ‘SID’ as a prefix and those relating to a UX method have a ‘UX’ prefix.

**Table 1: Content analysis codification**

| Code | Design Decision Basis |
|---|---|

| | |
|---|---|
| PP1 | Observe and interact |
| PP2 | Catch and store energy |
| PP3 | Obtain a yield |
| PP4 | Apply self-regulation and accept feedback |
| PP5 | Use and value renewable resources and services |
| PP6 | Produce no waste |
| PP7 | Design from patterns to details |
| PP8 | Integrate rather than segregate |
| PP9 | Use small and slow solutions |
| PP10 | Use and value diversity |
| PP11 | Use edges and value the marginal |
| PP12 | Creatively use and respond to change |
| SID1 | Linking invention and disposal |
| SID2 | Promoting renewal and reuse |
| SID3 | Promoting quality and equality |
| SID4 | Decoupling ownership and identity |
| SID5 | Using natural models and reflection |
| UX1 | Competitive Analysis |
| UX2 | PACT Analysis |
| UX3 | User Journey |
| OTHER | Functional necessity or other practical consideration |

A detailed chronological catalogue of design decisions was then created containing the following headings: “code”, “week #”, “design decision” for use in analysis (Appendix D). Design decisions were also assigned a category regarding the aspect of design it involved; conceptual, physical, digital, spatial and energy, the latter referring to electrical consumption of the artefact.

## 3.2 User Testing & Mixed-Method Evaluation

A mixture of user testing, subjective time perception, semi-structured interview and questionnaire were chosen to evaluate the created artefact in Chapter 4; the interactive permaculture plant guild. The questionnaire and subjective time perception are quantitative measures to answer the second research question from Chapter 1: “Can such a system foster engagement with nature?” where a system is the designed artefact detailed in Chapter 4. The semi-structured interviews serve several purposes: to give qualitative context to the quantitative measures, provide answers to the third research question “what can be achieved?” with regard to engagement with nature, and also to gauge whether the designed artefact achieved the permaculture principle “obtain a yield” (detailed in Chapter 2).

### 3.2.1 Chosen Methods

#### 3.2.1.1 User Testing

User testing was employed to evaluate the designed artefact and to gain a measure of the success of the system in terms of both usability and functionality. User testing as a form of participatory research is a commonplace practice in both HCI and UX, and would enable the participants to describe their experience in the interview and questionnaire following their interaction with the artefact. The sessions took place in the Edinburgh Napier University campus kitchen garden and participants used their own mobile devices to access the artefact’s web application to provide ecological validity to the evaluation. The latter also enabled the researcher to test the system using a variety of mobile devices and observe any compatibility issues.

#### 3.2.1.2 Interviews

‘Think after’ (aka simulated recall) interviews, where interviews are held after the experience being queried, were conducted to probe several areas of investigation in the research. The ‘think after’ protocol was employed over ‘think aloud’, where verbalization takes place during interaction, to avoid interruption, distraction and increased cognitive load during the experience; important considerations when simultaneously measuring engagement of the experience. The interviews followed a semi-structured format to ensure the coverage of important topics while also allowing for probing at greater detail.

#### 3.2.1.3 User Engagement Scale Questionnaire

The refined User Engagement Scale (O’Brien, 2016b) is a 31-point self-report questionnaire that uses a 5-point Likert scale to measure overall user engagement and to capture several dimensions of user engagement identified by O’Brien in previous studies: focused attention, perceived usability, aesthetic appeal and reward factor (the latter covering aspects of involvement, endurability and novelty). The wordings of the scale items were adjusted to refer to the artefact as the “interactive plant guild” and the order of the items were randomized as recommended by O’Brien et al.

#### 3.2.1.4 Time Perception Comparison

When engaged in an experience, user attention is focused on the experience itself and drawn away from other things. This includes distorting their subjective perception of time (O’Brien & Toms, 2010) which has been used to aid in measuring immersion in games (Jennett et al., 2008) and as an indicator of cognitive involvement (Baldauf, Burgard, & Wittmann, 2009). To measure distortion of subjective perception of time, users were timed interacting with the artefact and retrospectively asked to estimate the length of time they think they had spent interacting with the artefact. Subjective time perception is regarded as an objective measure as it is measured against an actual value (time spent interacting) and as such can be incorrect to a calculated amount. Thus, its purpose in this evaluation is to provide objective validation to the temporal items in the UES, which is a subjective indicator of engagement.

### 3.2.2 Participants

In all, 7 persons agreed to participate. Four participants were recruited from postgraduate students and researchers from the School of Computing at Edinburgh Napier University, and the other three participants were graduates from the university and resident in Edinburgh.

### 3.2.3 Procedure

Evaluations took place in The Lions’ Gate garden at the Merchiston campus of Edinburgh Napier University. Evaluations were carried out individually. Participants were provided with a participation information sheet and a consent form which they were asked to complete. They were given a brief explanation of the study and what the session would entail, advised that the data provided would be transcribed and analysed, and compiled data could be submitted for publication. Participant data, they were informed, would consist of an interview and a questionnaire to be completed by the researcher. They were informed that they could withdraw from the study at any time and that all data would be anonymised as much as possible, with names to be replaced with participant numbers (participate numbers 1-7). Participant names were not used in the interviews so that they could not be identified in recordings or transcripts.

Once ready to proceed, participants were given a brief overview of the interactive plant guild (detailed in Chapter 4) and directed to start interacting with it using their personal mobile devices. The researcher was present to observe, monitor for any issues that may occur and provide assistance where applicable. Participants were given no time constraints and told to explore the system until all functions of the system had been experienced at which point they would be notified by the researcher and could choose to continue interacting with the guild or end that part of the session. The length of time the participant spent interacting with the interactive plant guild was recorded by the researcher.

The interviews followed directly after interaction with the system. Audio recordings of the interviews were made which varied from approximately 3 minutes to 10 minutes, varying with how talkative the participants were. Interviews were semi-structured, including some open-ended questions, and affording the opportunity to follow up relevant topics in more detail where it felt appropriate to the researcher. A list of the guide questions used by the researcher can be found in Appendix E. The participants were then asked to complete a questionnaire. The questionnaire provided was based on the User Engagement Scale (O’Brien, 2016b). A full list of the questions provided can be found with the results in Chapter 5.

## 3.3 Limitations of Chosen Methods

While the methods chosen for this research are the best I believe to be suitable to answer the research questions with the time and resources available, there are some limitations to what they can achieve.

Research through Design is limited by the fact that it is the subjective findings of a single researcher. Multiple projects and researchers would be required to strengthen validity and reliability of claims made as a product of the research. Making and designing also encompasses a range of activities including imaging, thinking and decision-making which are not easily captured. The use of a reflective journal is an attempt to capture this data, but any analysis of the journal is also dependent on the thoroughness, honesty and candidness of the journal being analysed.

With regards to ‘think after’ methods which take place after interaction (the interviews and questionnaire) answers rely on then participants’ memories. However, this was still felt preferable to the alternative ‘think aloud’ protocol which would distract the participant during interaction with the artefact and would likely affect measures of engagement. Self-measures, such as the questionnaire and interviews, also have more general disadvantages; misinterpretation of questions, and communication, reliability and validity issues. Self-measures also rely on participant subjectivity and are susceptible to the ‘halo effect (Saal, Downey, & Lahey, 1980). With regards to measurement of user engagement, an objective measurement of subjective time perception has been employed to check the validity of the outcome of the UES. The interviews and questionnaire would also have improved validity had a larger sample size of participants been available.

## 3.4 Ethics

Following consultation of Edinburgh Napier University’s guidelines (Edinburgh Napier University, 2013) this research was considered low risk. Participants were provided with a participant information sheet in advance of the session. Upon attendance of their session they were provided with a debriefing letter, and consent form to complete, as well as the participant information sheet (full text available in Appendix

F). Participant data was anonymized with interview recordings to be kept on a password-protected computer accessible only to the researcher until the end of the examination process at which point they will be destroyed.

# 4 Implementation

This chapter describes the artefact created from the Research through Making described in the previous chapter and utilized for user testing based on which participants completed an interview and questionnaire. I will explain the concept for the interactive system and the hardware and software created or employed for the artefact.

## 4.1 Concept

Taking inspiration from natural, sustainable ecologies, the designed artefact was an interactive system based on a 'plant guild'. A concept commonly applied in permaculture, a plant guild is a harmonious assembly of diverse plants (and sometimes animals and mycelium) whose components are chosen to be beneficial to each other (Fisher, 2018). Each component in a plant guild is useful and makes use of advantages that other components provide. The components in a plant guild are typically represented by several layers, an example represented in figure 1 (Burnett, 2006). The concept for the interactive plant guild was to add two additional layers; an anthropic layer and a technological layer, with both layers representing beneficial components (as shown in figure 2).

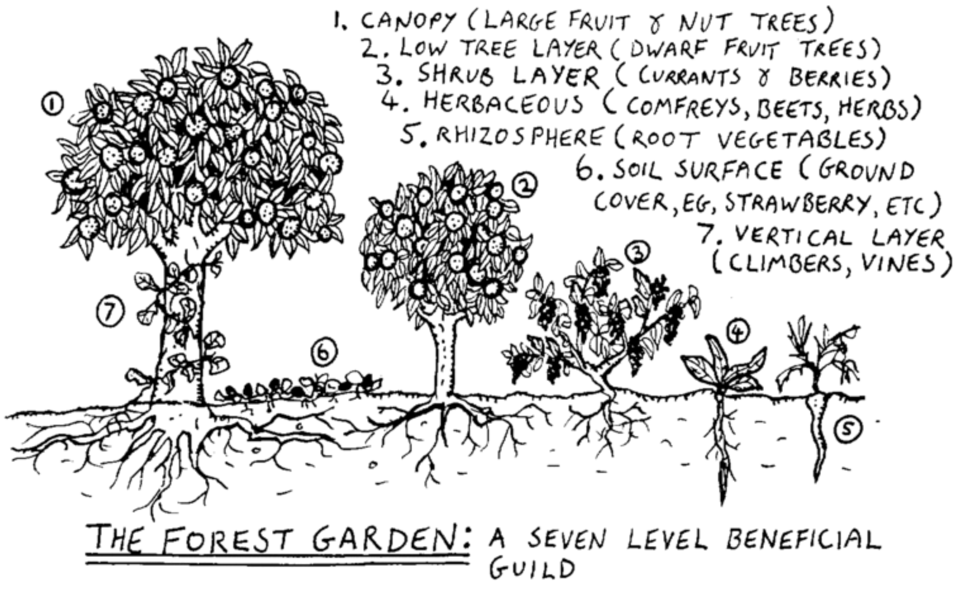


**Figure 1: A fruit forest garden plant guild (Burnett, 2006)**

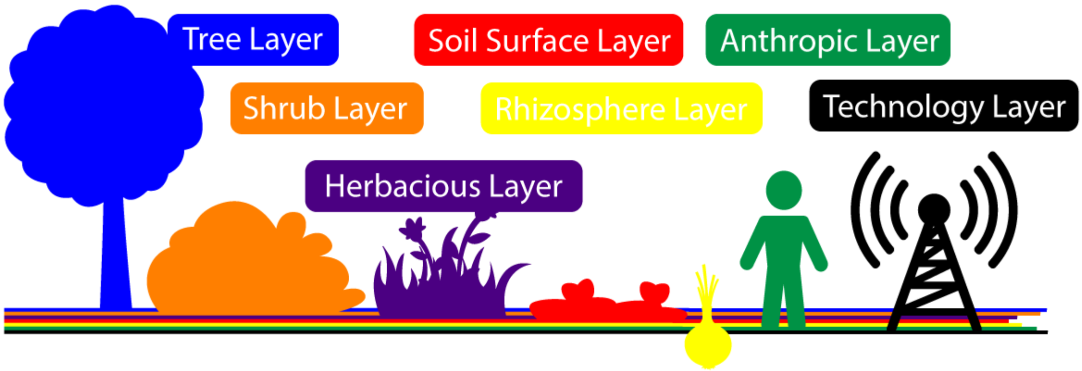


**Figure 2: Proposed augmented plant guild**

## 4.2 User Journey

Figure 3 is a user journey map detailing the proposed user journey when interacting with the artefact. The user would be made aware of the system by signage (figures 4 & 5) on the mobile device dock directing users to place their NFC-enabled phone in the dock. There was an NFC tag located on the dock which automatically launched the web application in the user's NFC-enabled mobile device browser. Alternatively, users could scan the provided QR code located on the dock first. Both NFC and QR code direct the device browser to a website, loading the web application.

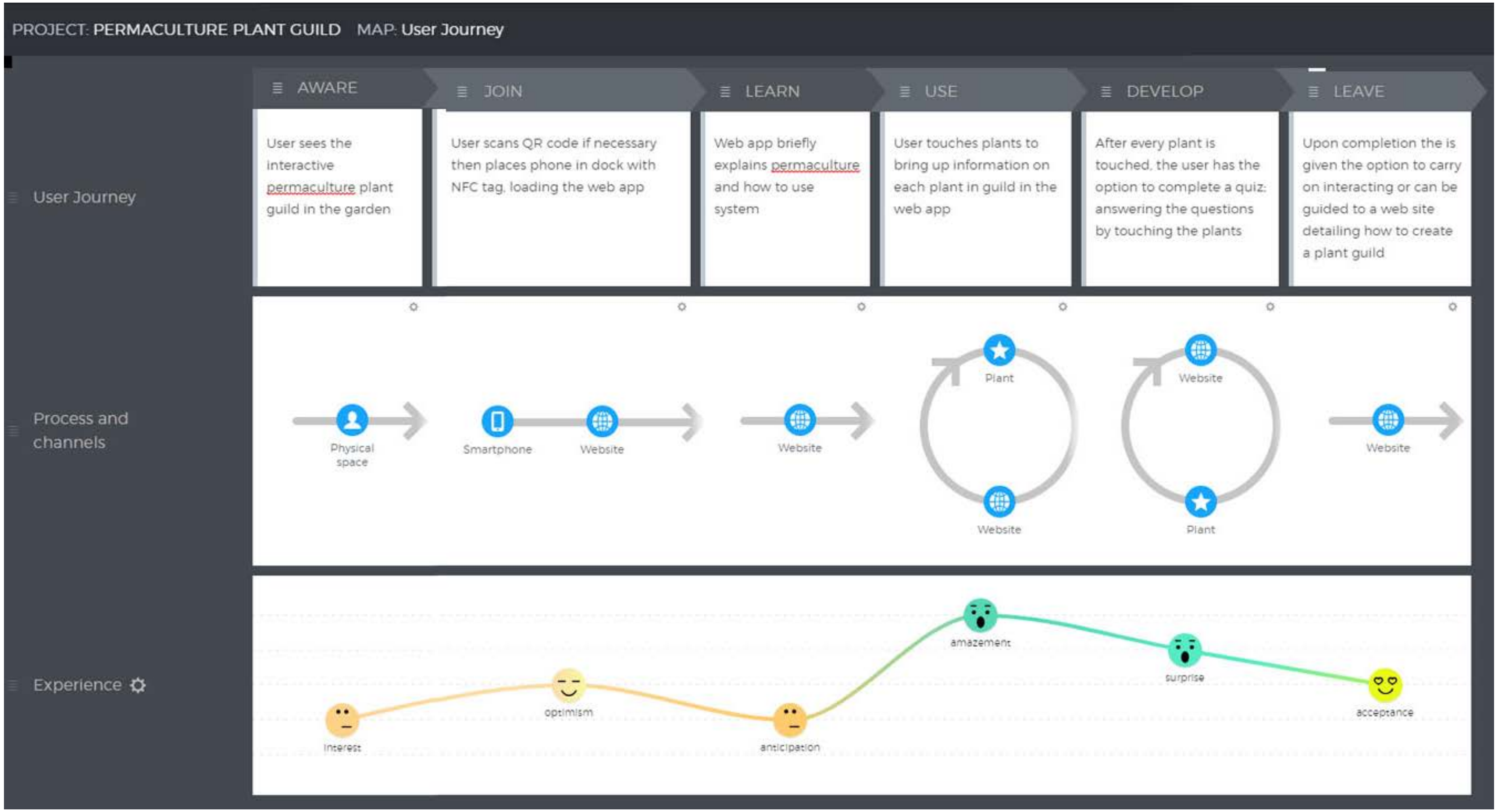


**Figure 3: User journey map**


**Figure 4: Signage on the device dock**

**Figure 5: The designed artefact**

While the app loads, the user is shown convivial, animated, alternating messages. Then information about permaculture and plant guilds is shown, as shown in figure 6.

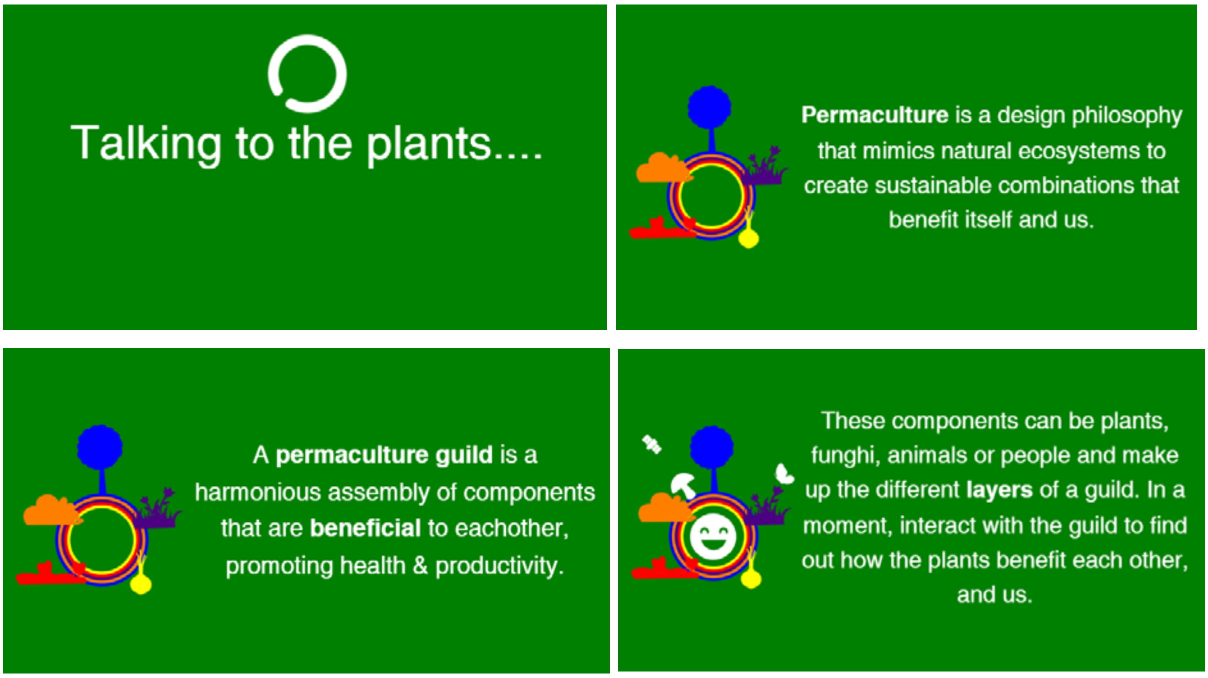


**Figure 6: Loading screen and intro screens of web app**

Afterwards, screens showing instructions are displayed. If no plant touches are detected, the user is advised to touch the soil instead (as the soil is more conductive) or directed to add water to the plants as touch sensors only work through moisture; if the soil is completely dry, functionality will not work.

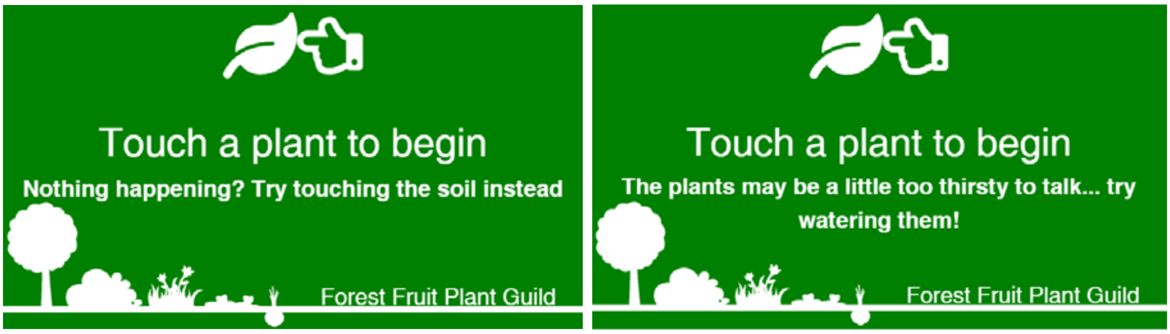


**Figure 7: Waiting for user action page**

Upon touching different plants in the plant guild, information about that plant is shown on the web application, examples shown in figure 8 & 9.


**Figure 8: Examples of plant information pages**


**Figure 9: Users interacting with the artefact**

Once all plants have been interacted with and following a set amount of time, the user is asked if they would like to test their knowledge in a quiz or continue interacting with the plants (figure 10). Users answer the questions by touching the plants.

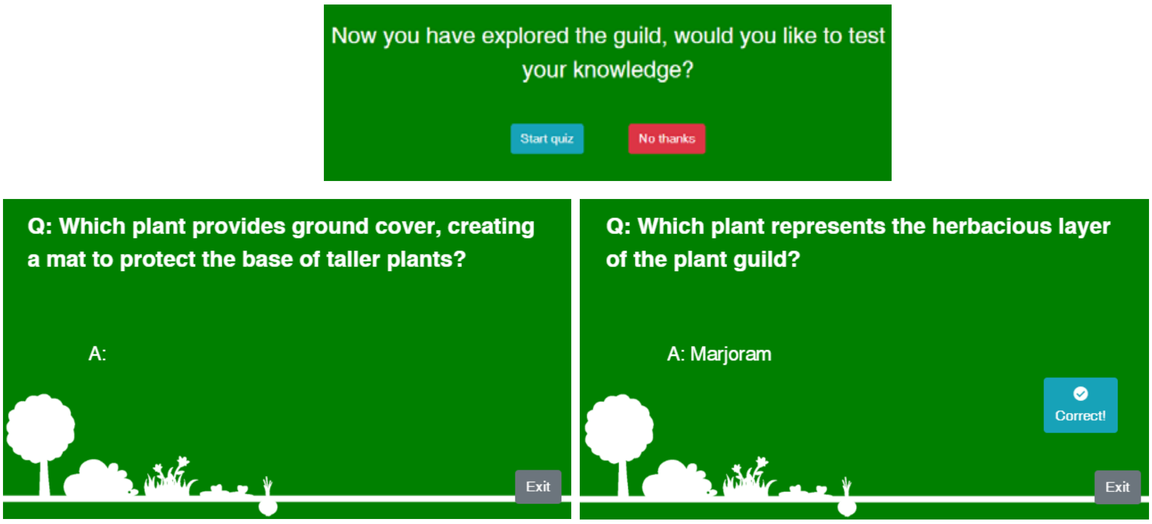


**Figure 10: Quiz pages of web app**

After answering all the questions, the user is asked whether they would like to continue interacting with the plant guild or be taken to an external website explaining how to create your own plant guild (figure 11).

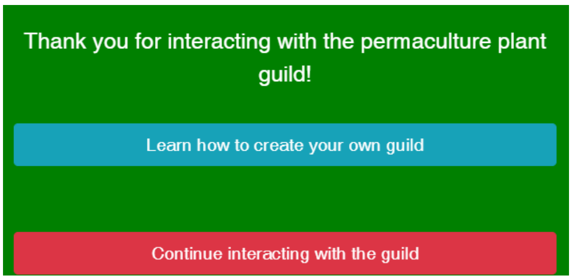


**Figure 11: Exit page of web app**

## 4.3 Physical Design

This section will detail the physical components of the artefact and why certain hardware was selected.

Components:

- Particle Photon (with headers)
- Adafruit MPR121 12-key capacitive touch sensor breakout board (with headers)
- Prototyping breadboard
- 22 AWG eco wire (several metres)
- Steel angle
- Tin/lead solder
- Printed adhesive vinyl sheet
- Micro-USB power cable
- Mobile device ‘dock’ (upcycled from 2 white plastic angled table placards)
- Five plants (apple tree, blackberry shrub, marjoram, parsnip & alpine strawberry)
- Wooden palette

Tools used:

- Soldering iron
- Hacksaw
- Hot glue gun
- ‘Helping hand’ magnifier
- Wire cutters

The Photon is a small wi-fi connected microprocessor development kit manufactured by Particle. Equipped with an integrated wi-fi chip, an ARM Cortex M3 microprocessor, 1 MB flash memory, 128 KB RAM and 18 mixed signal general purpose input/output pins, it also has built-in support for Particle’s cloud platform, Particle Cloud  (Particle, 2018). Particle Cloud allows for easy-to-implement communication of data from the Photon to a web application and vice versa. This device was chosen for its ease of IoT connectivity and its various power saving modes that allow it to operate with very low power consumption rates.

The MPR121 12-key capacitive touch sensor breakout board, manufactured by Adafruit, offers 12 channels which can be wired to anything conductive to make it touch sensitive (Ada & DiCola, 2015). It was chosen over alternatives for practical simplicity as it handles all filtering and has configurable sensitivity. It also offers an interrupt request (IRQ) output, used to send a signal to the Photon to exit sleep mode, turning wi-fi back on. The MPR121 was configured to operate on a current of 63 uA.

The Particle Photon and MPR121 were place on a breadboard for ease of prototyping and future reconfigurability. A breadboard sketch of the electronic set-up is shown in figure 12. EcoWire Hook-up Wire (22 AWG) manufactured by Alpha Wire was used for all wiring. The wire is coated in a modified polyphenylene ether (mPPE) thermoplastic which contains no halogens, phthalates, or heavy metals and meets the Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances Directive (RoHS) requirements for the elimination of hazardous substances and recyclability, and so is 100% recyclable (Alpha Wire, 2018). The dielectric properties of mPPE also make possible a reduced wall thickness so less is required, when compared to typically used PVC and polyethylene wire coatings. Five of the MPR121 touch sensor pins (numbers 3 to 7) were wired to the plants, one wire buried into the soil of each plant, and one pin (number 0) connected to a steel edge attached to the base of the device dock.

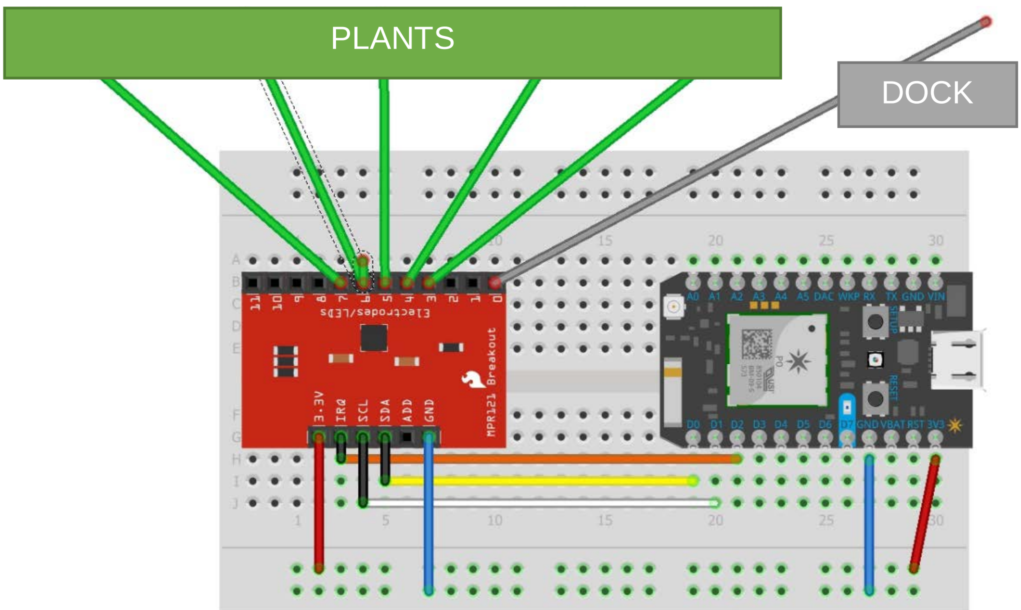


**Figure 13: Breadboard sketch of Particle Photon and MPR121 Capacitive Touch Sensor**

## 4.4 Software

This section will describe how the software on the microcontroller and web application functioned. The code for the Particle Photon can be found in Appendix G, the HTML code for the web application in Appendices 8 and the JavaScript code for the web application in Appendix I. A conceptual diagram of the system is shown in Figure 13.

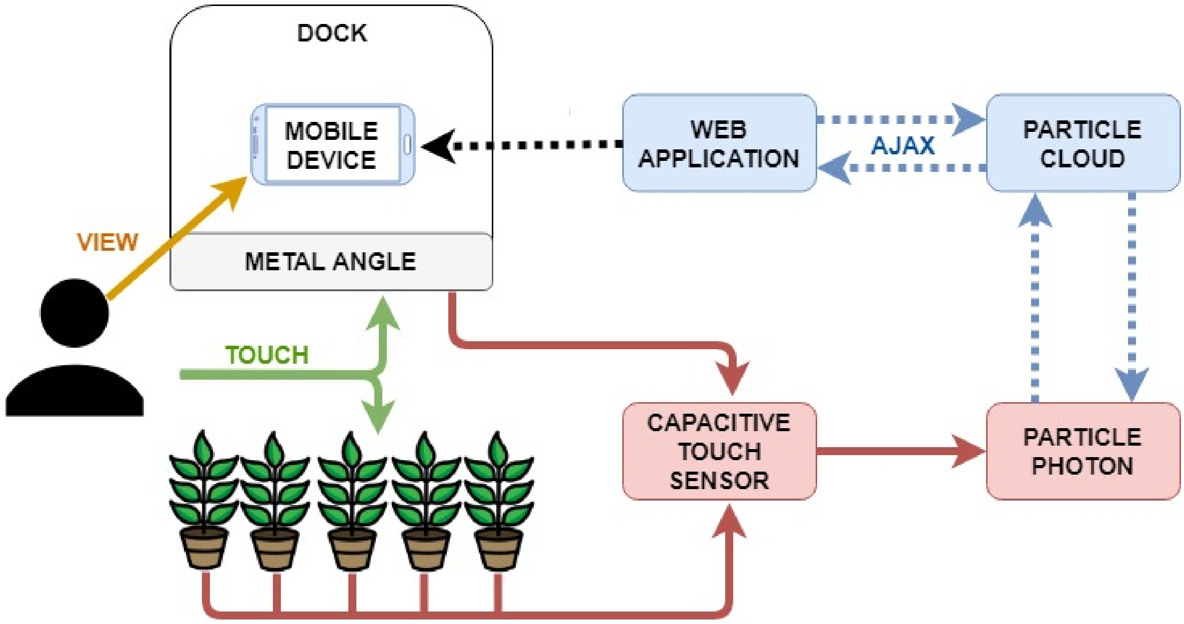


**Figure 14: Conceptual diagram of interactive plant guild**

### 4.4.1 Microcontroller

The Photon operates using the same simplified version of C++ employed by Arduino microcontrollers. It was programmed to go into ‘sleep mode’, which turns off its wi-fi module, with an operating current of approximately 1 mA (compared to an average of 80 mA when operating normally and not in sleep mode) at quiz completion and after set-up when reset. It wakes from sleep mode when the MPR121 capacitive touch sensors register capacitance changes in the plants or the metal edge on the phone dock. The code for the touch sensing functionality was a modified version of the Adafruit MPR121 Library for Arduino (*Adafruit_MPR121*, 2014/2018).

Once the Particle Photon is out of sleep mode, it detects changes in capacitance of the plants from physical contact. The wi-fi connected Photon then publishes this data to the Particle Cloud.

### 4.4.2 Web Application

The part of the interface displayed on the user mobile device is a single-page web application scripted using HTML5 (Appendix H), CSS (Appendix A0) and JavaScript (Appendix I). Ajax, a set of client-side web development techniques used to create asynchronous web applications, is used to update the page content. Data from the touch sensor is retrieved by the web application using an Ajax call to the Particle Cloud, with the client-side JavaScript changing the content of the web application as appropriate when a change in data has occurred (i.e. a different plant has been touched).

Included JavaScript libraries and toolkits:

- jQuery 3.3.1 (JS Foundation, 2018) – simplifies client-side manipulation, event handling, Ajax and animations in HTML.
- Bootstrap 4.1.0 (Bootstrap Core Team, 2018) – a toolkit for easy prototyping of mobile-first web applications.
- Animate.css (Eden, 2011/2018) & Morphext JS (L, 2013/2018) – jQuery plugins used for animations within web application.
- NoSleep.js (Tibbett, 2015/2018) – Prevents Android and iOS mobile displays from going to sleep.
- PleaseRotate.js (Scanlon, 2014/2018) – A script to ensure user devices are in the correct orientation and politely ask them to rotate if not.

# 5 Testing & Evaluation

This chapter will describe in detail the results of the research methods from Chapter 3, evaluating the artefact described in Chapter 4 and the making of it.

## 5.1 Results

### 5.1.1 Reflective Journal Content Analysis

As described in Chapter 4, the reflective journal was encoded and a content analysis performed on the text to reveal the basis of design decisions in the making process. Refer to Appendix D for the encoded design decision catalogue. Some design decisions had multiple bases.

**Table 2: Frequency of design decision bases**

| Code Group | Code | Design Decision Basis | Frequency |
|---|---|---|---|
| **Permaculture** | | | **30** |
| | PP1 | Observe and interact | 4 |
| | PP2 | Catch and store energy | 5 |
| | PP3 | Obtain a yield | 2 |
| | PP4 | Apply self-regulation and accept feedback | 3 |
| | PP5 | Use and value renewable resources and services | 4 |
| | PP6 | Produce no waste | 1 |
| | PP7 | Design from patterns to details | 3 |
| | PP8 | Integrate rather than segregate | 1 |
| | PP9 | Use small and slow solutions | 3 |
| | PP10 | Use and value diversity | 1 |
| | PP11 | Use edges and value the marginal | 1 |
| | PP12 | Creatively use and respond to change | 2 |
| **SID** | | | **4** |
| | SID2 | Promoting renewal and reuse | 3 |
| | SID4 | Decoupling ownership and identity | 1 |
| **UX Method** | | | **8** |

| | | | | |
|---|---|---|---|---|
| | UX1 | Competitive Analysis | | 2 |
| | UX2 | PACT Analysis | | 2 |
| | UX3 | User Journey | | 4 |
| **Other** | | | **11** | |
| | OTHER | Functional necessity or other practical consideration | | 11 |

According to Table 2 all permaculture principles had some influence in the process of designing the artefact, to varying degrees, with frequency of occurrence ranging from 1 to 5, with 30 instances of a permaculture principle informing a design decision. Of the permaculture principles, “observe and interact”, “catch and store energy” and “use and value renewable resources and services” occurred with the most frequency.

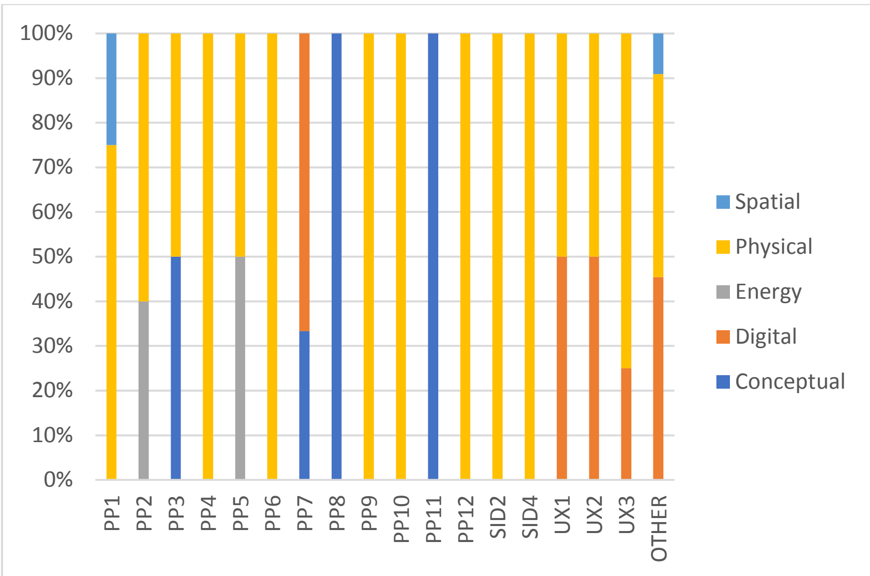


**Figure 15: The design aspects influenced as a proportion of total frequency for each design decision basis**

Figure 14 explores what aspects of design (split into categories of conceptual, spatial, physical, digital and energy) each code contributed to by percentage of total frequency. It shows that the permaculture design principles influenced a broad range of aspects of the design to some extent. Five permaculture principles (4, 6, 9, 10 & 12) seem to have influenced purely physical aspects of the design, two principles (8

& 11) influenced only the conceptual aspects, with the remaining permaculture principles having multi-aspect effects on the design.

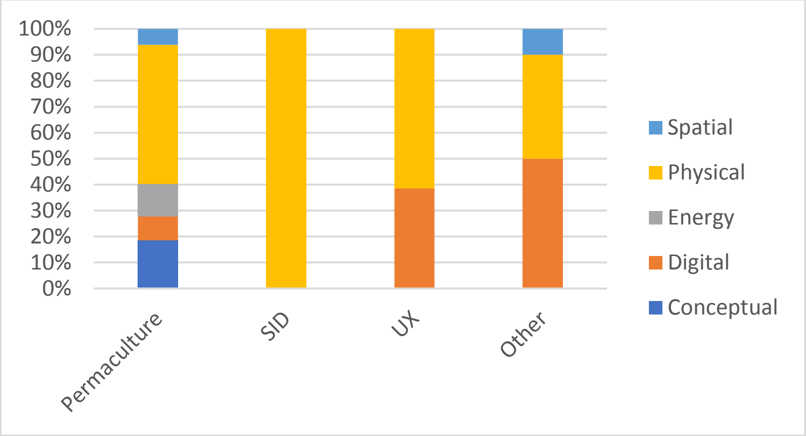


**Figure 16: The design aspects influenced by design decision grouping**

Grouping the codes into categories (permaculture, SID, UX and other), Figure 15 shows the frequency of design decisions within each category, split as a per centage by design aspect.

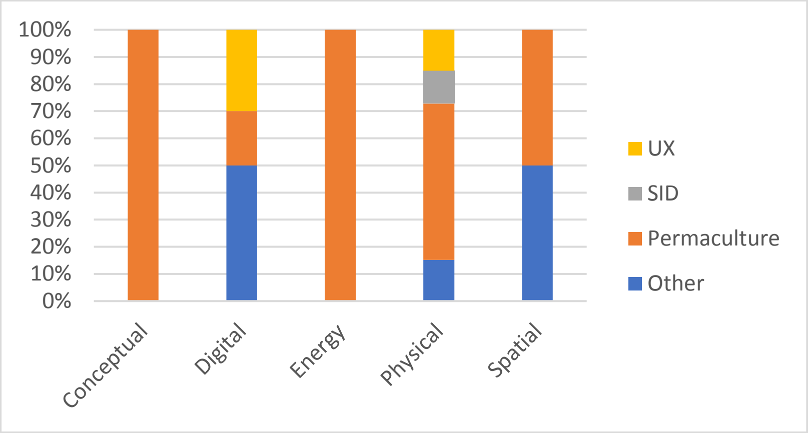


**Figure 17: Contribution of design decision grouping on each design aspect**

Figure 16 shows the percentage of design decisions by code grouping, separated by design aspect and indicates to what extent each code grouping influenced design decisions for each aspect. There is a notable lack of permaculture influence on the digital aspects of design.

### 5.1.2 Mixed-Method User Evaluation

This section will describe the results of the user testing of the designed artefact, and the interviews and questionnaires the research participants took after interacting with the interactive plant guild.

#### 5.1.2.1 Interviews

*Obtained a Yield*

One measure of success that required to be validated was that the designed system would “obtain a yield”, one of the twelve design principles of permaculture detailed in Chapter 2. One possible form of yield of benefit to the user would be gained knowledge from use of the system. The questions “did you know anything about permaculture today?” and the follow up questions “do you know more about permaculture now you have interacted with the interactive plant guild?” and “If so, what have you learned?” were used to determine if any knowledge, and thus a yield, was obtained from use of the system.

Of the 7 participants, 5 had no prior knowledge of permaculture (Participants 1 to 4 and 6). Of the 5 participants with no prior knowledge of permaculture, 4 responded in the affirmative to having gained knowledge about permaculture (Participants 1 to 4) and were then able to successfully describe one or more aspects of permaculture and how natural ecosystems function sustainably. Participant 5 who claimed to have “some” pre-knowledge of permaculture also responded in the affirmative. Participant 6 who had no prior knowledge of permaculture stated that they had only gained an “insight” into permaculture from use of the system. They also said that they were “perhaps more interested in how it works and not too much interested in the plants.”

*User Affect*

The questions “how did your experience of the interactive permaculture plant guild make you feel?” was incorporated into the interview to give an indication of the affect of using the system. Responses were as follows:

> *“I quite enjoyed it... It was impressive in terms of technical stuff and I had not seen that before.”* (Participant 1)

> *"I enjoyed it, figuring out what the plants were and what they did. I liked learning more about the individual plants and the fact that they are all edible, but also the other uses that they have, like coverage and integrating with the other plants. It's great because you're really being amongst nature and touching the plants."* (Participant 2)

> *"Quite excited, interested, like I was learning. I like that it was very accessible, the language was quite easy to understand and absorb, and it was informative. It was very novel, and I liked that element of interacting with plants this way."* (Participant 3)

> *"I liked the touching the soil and the information about the plant coming up. I felt involved. I was more involved than clicking a button or scrolling through something. Thought it was a unique approach and it worked well"* (Participant 4)

> *"I felt quite involved with my surroundings. There was quite a novelty to it. You can touch the plants, you can use your own device"* (Participant 5)

> *"I quite enjoyed it. It's cool to learn something. This type of experience could be good in a supermarket for example. I liked that they showed the nutrition, it's good to know before you eat something… it's good to get the information."* (Participant 6)

> *"I was surprised and interested and engaged. The plants were clearly interactive, they clearly did something and provided feedback. The fact you can touch a plant and it can provide feedback to you was very interesting."* (Participant 7)

Participant responses and language used indicate an overall positive valence from their experience with the interactive plant guild for all participants; three participants using the word "enjoyed" to describe how they felt about their experience. Other descriptors of positive valence included "interested" (twice), "excited", "fun" and "surprised". No descriptors of negative valence were used by participants.

*User Engagement and Connectedness to Nature*

In response to the same question regarding the user's felt experience of interacting with the plant guild, three participants described a form of engagement with the interactive plant guild; two participants described feeling "involved" and one participant described feeling "engaged" with the system. Two participants also suggested a connection beyond the system itself, with the wider space within the guild was situated. One participant described being "involved with" their "surroundings" and another described "being amongst nature".

*Future Behaviours*

Questions regarding future behaviours such as those probing whether systems such as the designed artefact would affect their relationship with nature proved somewhat inconclusive, with responses typically being vague; using words such as "potentially", "maybe" and "should" to respond. Four participants responded that they had "increased" or "more" interest in nature and/or natural ecologies. Four participants also responded in the affirmative when asked whether they would consider growing a plant guild of their own in the future, the remaining three participants in the negative.

#### 5.1.2.2 Subjective Time Perception

**Table 3: Actual time spent and time estimated interacting with the artefact by participant**

| Participant | Time Spent (m:ss) | Time Estimated (mins) | Time Estimated/Spent Ratio |
|---|---|---|---|
| 1 | 4:38 | 5 | 1:1.08 |
| 2 | 5:39 | 15 | 1:2.65 |
| 3 | 3:50 | 7 | 1:1.83 |
| 4 | 6:55 | 10 | 1:1.58 |
| 5 | 3:55 | 7 | 1:1.79 |
| 6 | 4:02 | 6 | 1:1.49 |
| 7 | 9:35 | 10 | 1:1.04 |

In the interview, participants were asked to estimate the amount of time they think they spent interacting with the plant guild, the results and the actual time spent interacting as timed by the researcher are recorded in table 3 Two participants estimated time to a fairly accurate degree. The other 5 participants' time estimates were significantly different from actual time spent interacting and thus exhibiting a distortion of time perception, suggesting high level of engagement.

#### 5.1.2.3 Questionnaire

The questionnaire provided to participants to complete is based on the revised User Engagement Scale (UES); a tool for measuring user engagement (O'Brien et al., 2018) as described in Chapter 3. These are measured using four distinct subscales in the refined UES representing the four dimensions; focused attention (FA), perceived usability (PU), aesthetic appeal (AE) and reward factor (RW). Items PU-1, PU-2, PU-3, PU-4, PU-5, PU6, PU-8 and RW-3 are reverse-weighted. The mean score for each item calculated by dividing the sum of the scores by the total number of participants is shown in Table 4 with reverse-weighted items identified with an asterisk (*). Possible mean scores can range between the values 1 and 5 where 1 indicates poor engagement, 5 indicates high engagement and 3 is neutral. All participants provided an answer for every item on the scale.

**Table 4: Mean scores of the UES from participant questionnaires**

| Identifier | Questions | Mean Score |
|---|---|---|
| FA.1 | I lost myself in this experience. | 3.86 |
| FA.2 | I was so involved in this experience that I lost track of time. | 3.86 |
| FA.3 | I blocked out things around me when I was using the system | 4.14 |
| FA.4 | I lost track of the world around me. | 3.43 |
| FA.5 | Time just slipped away. | 3.57 |
| FA.6 | I was absorbed in this experience. | 4.00 |
| FA.7 | During this experience I let myself go. | 3.29 |

| | | |
|---|---|---|
| PU.1 | I felt frustrated while using the system.* | 4.14 |
| PU.2 | I found this system confusing to use.* | 4.14 |
| PU.3 | I felt annoyed while using it.* | 4.43 |
| PU.4 | I felt discouraged while it.* | 4.43 |
| PU.5 | Using the interactive plant guild was taxing. * | 4.71 |
| PU.6 | This experience was demanding.* | 4.71 |
| PU.7 | I felt in control while using this interactive plant guild. | 4.29 |
| PU.8 | I could not do some of the things I needed to do while using the interactive plant guild.* | 3.43 |
| AE.1 | This system was attractive. | 4.57 |
| AE.2 | The interactive plant guild was aesthestically appealing. | 4.00 |
| AE.3 | I liked the graphics and images of the interactive plant guild. | 4.00 |
| AE.4 | The interactive plant guild appealed to my visual senses. | 4.14 |
| AE.5 | The screen layout of the interactive plant guild was visually pleasing. | 4.29 |
| RW.1 | Using the interactive plant guild was worthwhile. | 4.57 |
| RW.2 | I consider my experience a success. | 4.43 |
| RW.3 | This experience did not work out the way I had planned.* | 3.57 |
| RW.4 | My experience was rewarding. | 4.00 |
| RW.5 | I would recommend the interactive plant guild to my family and friends. | 4.00 |
| RW.6 | I would continue to use the interactive plant guild out of curiosity. | 4.43 |
| RW.7 | The content of the interactive plant guild incited my curiosity. | 4.57 |
| RW.8 | I was really drawn into this experience. | 4.43 |
| RW.9 | I felt involved in this experience. | 4.57 |
| RW.10 | This experience was fun. | 4.71 |

The mean score for each dimension of user engagement, indicated by the first two letters of each item identifier, were as follows: Focused Attention (FA) = 3.73, Perceived Usability (PU) = 4.29, Aesthetic Appeal (AE) = 4.20 and Reward Factor (RW) = 4.33.

An overall user engagement score is calculated by summing the mean values of the four subscales (FA, PU, AE and RW). This was 16.55 out of 20.

### 5.1.3 User Testing

Observation of the research participants provided several insights into how users would interact with the artefact and identified design problems for consideration in future development.

A significant issue was the use of NFC and QR code to access the web application. Four participants using Applie iPhone, and so unable to use the NFC tag to open the web application, were able to use the QR code instead without issue. One participant was using an older model phone with neither native QR code-scanning capability or NFC so a smartphone was provided. Two participants using Android devices, for which QR code scanning is not native and so would require a QR scanning app to use this method of entry, attempted to use the NFC tag. Both Android phones were NFC-capable however both users had NFC disabled on their devices initially so had to enable this functionality in their device’s settings to proceed.

There were also revealed issues with the transitions for the tutorial text after loading the app within the web application. Two participants found the transitions occurred too quickly for them to read all the text in time. One participant also commented on the text being too small on some pages of the web app.

The touch sensors on the plant, while robust, also had limitations. Some of the larger plants were unresponsive further away from the soil, although the web app recommending touching the plants nearer the base if unresponsive mitigated this somewhat.

## 5.2 Analysis of Results

This section will holistically analyse the data gathered in this chapter from the various research methods employed. It will aim to ascertain the validity and reliability of the data gathered and thus inferences made from them by evaluating the techniques used.

A variety of research methods have been utilised in this study; established quantitative and qualitative methods and emergent and creative methods. Using multiple mixed methods has enabled findings to be corroborated across multiple sources, improving reliability and validity. The measure of user engagement is an example of this. Engagement is a complex thing to gauge, and both subjective and objective indications required to effectively measure. The UES questionnaire provided a self-reported quantitative response of affirmed user engagement across all user engagement dimensions of focused awareness, reward factor, perceived usability and aesthetic appeal. However, this score was merely indicative that user engagement was positive. Without a lack of comparable data with other artefacts to compare against, the degree or extent of user engagement achieved could not be accurately determined by the questionnaire alone. User engagement was however corroborated by two further means; interview and subjective time perception. The interviews elicited that users were “engaged” or “involved”; phrases provided by the participants without directly being asked about engagement or similar specifically. Questionnaires and interviews, being self-reported and taking place after interaction with the artefact must also rely on participant memory recall in their responses and are susceptible to misinterpretation of questions and communication problems. Hence an objective measure was used to further validate findings. Subjective perception of time on its own indicates only one dimension of user engagement, focused awareness, so as an individual measure would not be substantial enough to affirm user engagement was achieved. However, as a corroborative objective measure, it successfully validates that user engagement was achieved.

The questionnaire and interviews would have benefitted from a larger number of participants to further verify findings. Although the majority of participants were students at Edinburgh Napier University, an accurate and representative sample of participants indicative of typical visitors to the garden would need to have been established for a small participant group size.

An additional acknowledged weakness of the research was from attempting to determine effect on future attitudes and behaviours from the semi-structured interviews. While some environmentally-positive future attitudes and behaviours were indicated by several participants, a longer-term study would be required to corroborate as only participant intent could be determined. Such questions in interviews can also be affected by ‘social desirability bias’ where research participants tend to offer socially desirable responses instead of their true beliefs. A better understanding of permaculture was confirmed by the interview however whether they would adopt such philosophies in their lives remained inconclusive.

Content analysis of the reflective journal composed during development of the designed artefact indicated application of the permaculture principles throughout the design process. This was further corroborated by the interviews in which one of the measurable principles “obtain a yield” was verified. This is indicative of the permaculture principles’ generalizability and can be applied to the domains of HCI and interaction design. The content analysis analysed the areas of design the permaculture principles were strongest and weakest. They proved of most benefit for considering the space the artefact is situated in, physical aspects of the artefact, energy consumption and the conceptual, more abstract aspects of the design such as what it does, etc. Content analysis did however uncover a lack of applicability of permaculture principles to the digital components of the design, such as in the web application. Content analysis benefits from being both a qualitative and quantitative methodology and was useful in gathering data from a large qualitative dataset. However, the quality of data provided by content analysis depends highly on the data source; the reflective journal.

Time was required to learn how to create journal entries with amount and subject of detail varying throughout. Certain design activities would provoke strong journal entries, however others would prohibit, for example on days when stuck on a design problem when motivation lessened. It was useful for examining the design process at a macroscopic level and provided a valuable record of the design process, reducing the risk of post-event rationalisation. It also provided the benefit of giving an opportunity to reflect on the design process as it progressed, awareness of which aided in decision-making. The reflective journal may have benefitted from a pre-determined diary format and schedule to ensure elicitation of desired thoughts and details, although this could also have restricted the content of the journal.

The next chapter will be a discussion of the results of the evaluations in this chapter in relation to the literature review in Chapter 2 and the researcher's subjective experience of 'making' as recorded in the reflective journal in Appendix C, and attempt to answer the research questions proposed by this paper.

# 6 Discussion

This chapter will begin by considering the aims and research questions proposed at the start of this study before then discussing other relevant findings. The main research questions were:

1. In what ways can permaculture make the design of interactive systems in complex artefact ecologies a sustainable practice?

2. Can an interactive system combining environmental and digital artefacts foster engagement with nature?

3. What can be achieved by engagement with an environmental-digital artefact?

Permaculture as a design philosophy was incorporated into the research via three main approaches; Holmgrem's twelve principles of permaculture (2010), the three core ethics of permaculture (people care, earth care and fair share) and through 'making'. Content analysis in the previous chapter indicated the twelve principles' generalizability and applicability to SID, each principle contributing at least once to a design decision in the design of the artefact. Frequency of adoption and applicability for use in an HCI design context however varied from principle to principle. They were after all composed by Holmgrem with agricultural and social design in mind. Next, I will discuss each principle in regards to the first research question; including what it contributed to sustainable interaction design, design within complex ecologies and within blended spaces, and how well it mapped to the domain of HCI.

### I. Observe and interact

Probably the most generalizable principle, this is one that viewed fundamentally is required for good design in most any domain; understanding the design problem and its external factors. At this level of abstraction, this principle is already utilized in the UX design practices of interaction design and ethnography. Similarly, it advocates the use of iterative design cycles framing design as an ongoing process of evaluation and re-evaluation as used in both UX design and permaculture. It is also a principle that is multifaceted, referring to understanding the space, the people who use it and its components and how they can be used to best effect for mutual benefit, and also looking to natural and social patterns to understand how natural ecologies function in a sustainable way. The concept of understanding and utilizing the processes in natural ecosystems that make them sustainable does require some level of adaption for application in HCI; after all, technology does not naturally occur in natural, sustainable ecosystems. This method of using natural models has however been utilized in several other design domains such as product and automotive design, architecture and urban planning (Shu-Yang, Freedman, & Cote, 2004), but appears to have had less of an influence in interaction design. Imitation of natural systems is one of Blevis' principles of SID; "using natural models and reflection" (2007), so the concept is not a new one within sHCI.

The notion from this principle of understanding the wider ecologies involved was a useful tool, echoing Jung et al.'s (2008) and Coughlan et al.'s (2012) holistic view on designing for device ecologies; requiring consideration of the assemblage of artefacts, people and technologies with desirable relations and characteristics. But further to this, the principle required consideration of the space as well as the ecology. In interactive systems grounded in physical spaces, Benyon (2014) posits that blended spaces have four key descriptive characteristics: ontology, topology, volatility and agency. 'Analysis of Elements' , 'Input-Output Analysis', 'Zoning' and 'Sectoring' are commonly used research methods in permaculture (Whitefield, 2016, pp. 13-38) for designing the ontology and topology of a design space. Analysis of Elements requires the designer to describe the needs, outputs, and intrinsic characteristics of each component; describing the ontology. 'Input-Output Analysis', 'Zoning' and 'Sectoring' can be used to determine the topology. The inputs and outputs of the components can be analysed to guide the placement of the components where they will make the most beneficial relationships with other components and highest productivity. Zoning and Sectoring are methods employed to work out how to use the space to the most benefit by considering human movement and activities through and in the space, and external energies such as wind and solar.

### II. Catch and store energy

This principle promotes resilient design and minimisation of external resources and quite self-evident in its application in HCI; catch energy and be energy-efficient but can also infer promoting energy-efficient behaviour of users. Much sHCI literature focuses on this subject, although it is less prominent within SID (Nunes & Alvão, 2017). This principle was used numerous times in the design of the artefact evaluated in this study especially for design decisions relating to energy consumption and physical aspects, such as the use of the microprocessor's low-power modes.

### III. Obtain a yield

Productive systems are more likely to last, giving people reason to maintain them. In HCI this means providing a benefit to people such as a useful functionality, gained knowledge or visceral enjoyment.

In the design of the artefact this meant ensuring the system had a purpose to users at the conceptual level; providing knowledge, verified in the user evaluation, and edibles from the plants themselves. Hopefully also a widening of the users' outlook in showing what can be possible.

### IV. Apply self-regulation and accept feedback

Sustainable systems self-regulate, and application of this principle requires understanding of the positive and negative relationships in nature. Self-regulation can also be interpreted as encouraging recycling and upcycling over use of brand new materials in the making process. Accepting feedback means identifying and responding to positive and negative outcomes. In the sHCI corpus self-regulation is similar to the SID research genre of 'persuasive technologies' which in most existing literature the aim of which has been to encourage users to live more sustainably by conserving resources (Nunes & Alvão, 2017) with focus on individual change rather than societal (Brynjarsdottir et al., 2012). Brynjarsdottir et al.'s recommendation of alternatively persuading by sharing a perspective to inform and shape beliefs, rather than coercion or control, was adopted in the design of the artefact by sharing the 'permaculture view' and imparting knowledge of how beneficial relationships create sustainable systems in nature. The application of self-regulation by recycling and upcycling also echoes Blevis' SID principle of 'promoting renewal and reuse' (2007), used in the design of the artefact by upcycling some components. Accepting feedback is another concept shared between UX and permaculture design; in UX by using user testing and evaluation and the feedback from them to continue to improve the system being designed.

### V. Use and value renewable resources and services

This principle advises making the most of renewable natural resources and incorporating passive functions in nature that can provide a benefit without consumption. In HCI this can mean taking advantage of wind or solar energy. Or taking advantage of human behaviours; for example, by energy-harvesting from human movement. In the design of the artefact this principle was employed by ensuring the power consumption was low enough to be suitable to be powered by solar power and battery (although this remained untested at time of writing), and by incorporating user personal mobile devices in the design as an extension of the space the user inhabits (Farman, 2012). The use of NFC tags in the design was another example, using the electromagnetic field emitted by the NFC transceiver on the users' mobile device to power itself.

### VI. Produce no waste

In permaculture, this principle views output as an opportunity; making use of all outputs from components in order to reduce waste and pollution. In HCI this relates to the physical and material and could apply to the by-products of manufacture of physical artefacts, which was beyond the scope of this study but still a vital consideration. This principle relates to three of Blevis' SID principles (2007): "linking invention and disposal", "promoting renewal and reuse" and "decoupling ownership and identity", all focused on material disposal in SID. 'Linking invention and disposal' attempts to deal with the problem of "built-in obsolescence" described by McDonough and Braungart (2009). This was achieved in the designed artefact by ensuring as many components as feasible were modular, reconfigurable and reusable with easy transfer of ownership.

### VII. Design from patterns to details

Copying, scaling and incorporating the patterns that exist in society and nature can contribute to the design and sustainability of a system. It also means considering the ‘bigger picture’. Permaculture shares with UX an interest in design patterns and this was useful in the design of the interactive plant guild at a conceptual level (basing the artefact on an augmented plant guild) and the visual level (in the use of iconography).

### VIII. Integrate rather than segregate

The connections between components are as important as the components themselves and the components should be arranged to improve the benefits from other components, building upon the understanding gained from the “observe and interact” principle. In HCI design, this bears some similarities to Suchman’s argument for designing “working relations” rather than “discrete devices” (1993) and Jung et al.’s framework for understanding digital ecologies (2008) by focusing on ecological layers and factors, grouping them to reveal interconnections. It can also incorporate frameworks based on assemblage theory; where assemblages are dynamic wholes whose characteristics transpire from interactions and relationships between components and non-human actors are given equal ontological status to human actors. For example, De Landa’s (2002) and Hoffman and Novak’s (2018) object-oriented conceptual frameworks. This focus on relations, ontology and considering the whole gives a useful perspective for considering complex ecologies and shares a similar perspective to blended spaces. Designing for ecologies requires understanding of how to configure a variety of devices holistically to be of best use to people, other artefacts and technologies.

### IX. Use small and slow solutions

Designing to the smallest practical scale can have benefits within sHCI. Simpler, smaller systems require less material and potentially less material disposal. Avoiding unnecessary functions and components conserves resources. This principle also refers to using local resources. In a sHCI context that could be designing for local conditions rather than using “brute force” (McDonough & Braungart, 2009) and imposing universal design solutions, the application of which expends unnecessary chemicals and fossil fuel energy to make them ‘fit’. The “slow solutions” part of this principles appears at face-value to be antithetical to the aims of UX, where speed is of importance. However, interpreted as taking the long perspective in the design process to consider human and ecological health, and natural diversity, it has value to the SID agenda.

### X. Use and value diversity

Diversity in permaculture ensures a fail-safe against threats. It should also be noted that in permaculture, more diversity is not necessarily better however; the aim is to find the right balance of variety to create a productive system. In the domain of HCI and concerning devices within ecologies diversity can be problematic. This was evidenced in the user testing of the designed artefact; where a diversity of devices caused compatibility issues. Accounting for the wide diversity of screen sizes and screen ratios proved problematic, as well as software variances such as whether QR code-reading was native or if the devices were NFC-enabled. Using multiple solutions to solve one design requirement or problem also results in contradicting the principle of using “small and slow solutions”; in design of digital artefacts, accounting for diversity often means applying “brute force” to ensure a working system across devices. This issue possibly highlights how “unnatural” the design of such digital systems often are, if not just how badly conceived the current paradigm is for understanding how to design within the same ecology as existing digital technologies. For example, some of the mass-produced devices created by major technology companies may be considered ‘monocultures’ of their own; designed intentionally with some level of segregation and to not integrate completely with competitor technologies.

### XI. Use edges and value the marginal

In permaculture, the place where two ecosystems meet (the edge) is often rich in variety and more productive. The marginal can be unusual (or novel) ideas, views or components. The concept of edge, representing the changes in structure that occur at boundaries, was conceptually one that could be challenging to apply to the domain of HCI. What could be considered a boundary in this context? And how could it be utilized? Valuing the marginal was simpler to apply; embracing new technologies, concepts, views and ways of doing things; the unusual, the novel, the unconventional and the unwonted.

### XII. Creatively use and respond to change

Designing to consider change over time has its difficulties and uncertainties, both in the physical and digital spaces. Benyon's key characteristic of blended spaces of "volatility" similarly highlights this design concern (2014) and is addressed in material aspects by Blevis' SID principle of "promoting quality and equality"; ensuring longevity and robustness and that materials can be reused or recycled.

Having now considered the twelve principles of permaculture, the following will discuss the principles in their totality. Permaculture is a holistic design approach and as such these principles should be considered as a whole rather than just individually as they are not intended to be applied in isolation. It is also important to note that these are guiding principles and open to differing interpretations, necessary for some principles when mapping to a different domain to which they were intended, and so this discussion is based on my own interpretation of these principles.

As previously mentioned there are a number of correspondences between permaculture and UX, indicating suitability for creating a blend of the two conceptual spaces. There is a growing need for frameworks and for designing interactive systems that consider the increasingly complex ecologies and spaces they inhabit. While frameworks based on actor-network theory, assemblage theory and blending theory have been developed, there has been little in the sHCI corpus to apply an object-oriented and relations-based approach to creating more sustainable systems. Permaculture design requires consideration of both the relations between components and the spaces they inhabit and offers an approach that requires sustainable thinking. Viewing components as active players through the lens of permaculture opened up possibilities of what each could contribute to each other and to the natural environment compared to designing to a strict design specification of requirements.

It is through the guiding design principles, permaculture design as applied to HCI does not just promote mimicking natural ecosystems, it guides the designer towards sustainable system design by elucidating *how* to do so. From the aspects of design that emerged in the Contextual Review (Spatial, Physical, Digital and Energy), permaculture heavily influenced the Physical and Energy aspects toward a more sustainable way of being, and to some extent the Spatial. However, permaculture in this instance had a markedly lesser impact on the Digital aspects of the design. Given the small scale of the web application and thus its relatively minute ecological impact, a permaculture philosophy may not have had much of an effect. However, for digital systems on a larger scale beyond the scope of this study, ecological footprint is a growing concern. For example, internet-connected devices are predicted to produce 14% of greenhouse gases by 2040 (Andrae, 2017), and it has been forecast that U.S. data centers will require 73 TWh of electricity per annum by 2020 (Arman Shehabi et al., 2016). Put into perspective, the total electricity output from all nuclear power stations in the UK in 2017 was 70 TWh (Department for Business, Energy & Industrial Strategy, 2017).

Much of the discourse in SID and sHCI has focused on materiality and material disposal (such as Blevis' principles) or it frames sustainability as an awareness and persuasion problem; limiting the focus to controlling consumption and correcting individual behaviour. These approaches to SID, however, are limited. Controlling consumption by making people, processes and things more resource-efficient only makes them comparatively less environmentally-damaging than they were before, it does not resolve the deeper, systematic issues. Designing for behavioural change also neglects the societies the individuals inhabit, tend not to consider the complexities of real life and rely heavily on persuasion bordering on coercion. These approaches are not intrinsically bad; they can be valuable when implemented as a tool within a larger, effective system. The permaculture principles incorporate efficiency but are not limited to efficiency alone. Instead of correcting behaviour, permaculture promotes actively cultivating collaboration between people and nature; working with nature, not against nature. A permaculture model brings humans into the natural ecology.

A digital-physical artefact designed to work in synergy with nature, the interactive permaculture plant guild, was created as part of this study to explore the second and third research questions; can such a system, designed using a permaculture framework, foster engagement with nature? And if so, what can be achieved?

Central to achieving engagement is the phenomenological tenet of the body as the subjective source of experience. Our motor-sensory experiences facilitate adaptive behaviour. Dourish introduced the concept of 'embodied interaction' in the domains of HCI and interaction design arguing that physical artefacts are the place computer technology should inhabit, rather than interacting with computers via physical proxies (2001). Embodiment is also a spatial practice and it is "people interacting with and within that space that produces the sense of place and being" (Benyon, 2014, p. 30). A means to achieve engagement through embodiment with nature in the designed artefact was to use nature in the form of plants as tangible interfaces, within a 'natural' environment; a garden. TUIs offload cognitive workload, providing higher levels of emotional engagement (Alzayat et al., 2014) and exploratory tangibles in particular can facilitate learning by requiring reflection (Marshall et al., 2003).

Engagement is a complex and multifaceted concept that is more than user satisfaction. Evaluation of the designed artefact with research participants indicated the artefact achieved a level of engagement: with the artefact, the space and nature more widely. It is through activities that involve contact, meaning, emotional attachment and compassion mediated by engagement that connectedness with nature occurs, even in urban environments (Lumber et al., 2017). Connectedness to nature (Geng et al., 2015) and natural spaces (Vaske & Kobrin, 2001) has been shown to promote environmentally-responsible behaviours. However, the efficacy of the designed artefact to achieve improved behaviours is only speculative as a longer-term study would be required to verify.

# 7 Conclusion

This study has indicated that permaculture as a holistic design philosophy can contribute to discourse within sHCI and SID; especially with regards to technology embedded within physical spaces or environmental artefacts and within complex ecologies. Demonstrating permaculture as a design framework in the creation of a novel environmental-digital artefact has revealed potential for designing systems to be an agency of change towards the sustainable and to work with nature, not against nature. While user engagement with the artefact was suggested by the evaluations in Chapter 5, whether that translated to engagement and connectedness to nature and change in environmental behaviours remains speculative.

The twelve principles of permaculture used in the design were multifaceted and required consideration of important factors for sustainable design: energy efficiency, material disposal and waste, temporality and maximising the benefit of the relations between people, nature, technology and space.

## 7.1 Future Work

Further research is required to validate the theory posited that user engagement with natural objects using digital-environmental artefacts can foster an engagement and connection with nature, leading to improved environmentally responsible behaviours. To determine change in behaviour would require a longer-term study, and to validate the notion, multiple similarly designed systems would need to be evaluated as such.

The next step in further developing the application of permaculture within sHCI and SID is to repeat. Research through Design requires repeatedly investigating the same situation through multiple projects with a diversity of researchers for the best results emerge (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2013). The designing and making process, and interpretation of permaculture is based on the subjective experience of a single researcher. Multiple projects and researchers would strengthen validity and reliability of proposed results, and provide further insights into how to design more sustainable HCI systems.

Research in interaction design is a dynamic, evolving field and new technologies and shifting paradigms bring new challenges and opportunities. Major trends such as IoT, Artificial Intelligence, Augmented Reality, Virtual Reality, increasingly pervasive computing, biosynthetic materials and wearable technologies will all radically alter interaction design. Finding “nurturing solutions very different to the often outrageous initiatives that harm the environment” (McDonough & Braungart, 2009, p. 3) are necessary, solutions that possibly run counter to the foundational concepts currently used in interaction design. For example, the focus of the user in UX and HCI will need to be broadened to also consider our environment and the ecologies and spaces we inhabit.

This study presents one perspective on permaculture design’s application to HCI to hopefully inform future studies and strengthen the framing of the permaculture view and application in sHCI and SID.  By embracing the marginal we can open up HCI to new ideas and ways of making things that are necessary to disrupt the current environmentally-destructive and unsustainable paradigm.

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# Appendix A - Initial Proposal

EDINBURGH NAPIER UNIVERSITY SCHOOL OF COMPUTING
MSc RESEARCH PROPOSAL

The process of completing and reviewing the contents of this form is intended ensure that the proposed project is viable.  It is also intended to increase the chances of a good pass.  Much of the material produced while completing this form may be reused in the dissertation itself.

1. **Student details**

| | |
|---|---|
| First name | Nicholas |
| Last (family) name | Besagni |
| Napier matriculation number | 40332469 |

2. **Details of your programme of study**

| | |
|---|---|
| MSc Programme title | MSc Computing |
| Year that you started your diploma modules | 2017 |
| Month that you started your diploma modules | September |
| Mode of study of diploma modules | Full-time |
| Date that you completed/will complete your diploma modules at Napier | August 2018 |

3. **Project outline details**

Please suggest a title for your proposed project. If you have worked with a supervisor on this proposal, please provide the name.  You are strongly advised to work with a member of staff when putting your proposal together.

| | |
|---|---|
| Title of the proposed project | Symbiosis of Digital and Environmental artefacts In Sustainable  Blended Spaces Using Permaculture Design Methodology |

| | |
|---|---|
| Is your project appropriate to your programme of study? | Yes |
| Name of supervisor | Callum Egan |
| I do not have a member of staff lined up to supervise my work | |

4. **Brief description of the research area - background**

Please do not describe your project in this section. Instead, provide background information in the box below on the broad research area in which your project sits. You should write in narrative (not bullet points). The academic/theoretical basis of your description of the research area should be evident through the use of citations and references. Your description should be between half and one page in length.

User Experience (UX) design is increasingly more concerned with providing great experiences than just designing usable systems. McCarthy and Wright say experience in technology refers to the “irreducible totality of people acting, sensing, thinking, feeling, and making meaning” including their perception and sensation of the artefact in context (McCarthy & Wright, 2004). Designing for an experience requires considering the different layers of interaction, including aesthetics, pleasure and emotional engagement, in context (Benyon, 2013). With the rise of ubiquitous computing it has become increasingly important for interaction designers to understand how to implement interactive systems across an ecology of interactive artefacts, as well as multiple types of spaces; digital, physical, social and blended spaces.

Blended spaces are spaces in which the digital and physical spaces are deliberately closely integrated; where the physical and digital are completely coupled to provide a sense of presence in a different type of space (Benyon, 2014). The idea of blending two conceptual spaces to create a new blended space in design, rather than projecting from one source domain to a target domain as in the theory of metaphors in design, stems from blending theory (Fauconnier & Turner, 2008). Ed Hutchins contributes further to blending theory by positing that the use of a ‘material anchor’, where one of the input spaces is grounded in a physical, embodied experience, can stabilize conceptual representations (Hutchins, 2005), improving the blend.

Our perception is shaped by our physical ecology; the artefacts we interact with to realise our activities. The use of these interactive artefacts influence other artefacts in the ecology and cannot be fully understood in isolation (Jung et al., 2008). Physical objects in our environments become different things when they are combined with technology; their functionality expands and new relationships within our ecologies are created. The forms of interaction within these ecologies are becoming increasingly multi-modal as new technologies bring new forms of interaction which affects the user experience. For example, tangible user interfaces (TUIs) and multi-touch screen interfaces are two combinations of embodiments that are psychophysically perceived differently by users (Alzayat et al., 2014). This suggests differences at higher levels of interaction with artefacts such as emotional engagement. Blended space design aims to enable people to feel more present and engaged within blended spaces. This dissertation will seek to explore how technologies and physical objects combined at the conceptual stage to create novel artefacts can enhance this.

Sustainable Interaction Design (SID) is a field of study within Human-Computer Interaction (HCI) that posits that sustainability should be an important consideration in the design of interactive technologies. In this context, *design* is defined by Blevis as “the act of choosing among, or informing choices of future ways of being” (Blevis, 2007). The focus in this field of study is environmental sustainability; how interactive technologies can promote more sustainable behaviours and how sustainability can be used as a critical lens in their design. Five principles of SID (Blevis, 2006) that can frame design criticism and design goals are: (i) linking invention and disposal, (ii) promoting renewal and reuse, (iii) promoting quality and equality, (iv) decoupling ownership and identity and (v) using natural models and reflection.

Permaculture is a system of agricultural and social design principles that take natural ecosystems as a model for human habitats with a central aim to reduce our ecological impact (Whitefield, 2016). Natural ecosystems are sustainable and if we can understand how they work, we can apply this understanding to design sustainable systems. What makes an ecosystem work is its diversity and the beneficial relationships between its components. Permaculture goes beyond just taking direct imitations of natural ecosystems; it proposes understanding the principles on which they operate and applying them more widely to create systems that are kind to both people and planet, based on intelligent design.

Egan, Benyon & Thomson propose using permaculture as a framework for achieving principles of SID (Egan et al., 2017). Egan et al. propose blending UX and permaculture, using a garden as a material anchor within a blended space, as a means to create experiences that enable people to reflect on sustainability and foster a connection to nature, and as designers gain better understanding of UX, sustainable HCI and SID (Egan & Benyon, 2017). This project will explore using novel artefacts, combining technology with existing, natural objects, to achieve these aims using permaculture design principles.

5. **<u>Project outline for the work that you propose to complete</u>**

Please complete the project outline in the box below. You should use the emboldened text as a framework. Your project outline should be between half and one page in length.

**The idea for this research arose from:**

It was originally inspired by discussions in workshops for the Design Dialogues module, taught by David Benyon and further developed in meetings with my dissertation supervisor. Our interactions with digital technologies are becoming increasingly multi-modal and UX is now concerned with much more than simply what is displayed on a screen. With the increase in the ubiquity of interactive technologies and the Internet of Things it will also increase their ecological impact. The means to reduce this by exploring methods and principles to design interactive systems that can be more sustainable are becoming increasingly important for the world in which we live.

**The aims of the project are as follows:**

The project seeks to demonstrate permaculture as an interactive design philosophy to achieve sustainable HCI and to explore how tangible interfaces can enhance our interactions with complex ecologies of artefacts within blended spaces. It also seeks to explore how UX and sensor technologies can enhance our interactions with the physical world in a way that supports sustainability by using real world garden objects as an interface to provide more engaging experiences and create more beneficial relationships within our ecologies.

**The main research questions that this work will address include:**
How can digital spaces and gardens (as a physical space) with garden objects as both existing, organic parts of the material anchor and interface artefacts, be blended in ways that foster engagement and sense of presence? Once there is a sense of presence, what can be achieved?
Can such a system demonstrate permaculture?

**The software development/design work/other deliverable of the project will be:**
Design and implementation of an interactive system, utilising sensors and garden objects, in an interactive permaculture garden.

**The project deliverable will be evaluated as follows:**
Mixed-method evaluation:
User testing with questionnaire and/or eye-tracking glasses for psychophysiological response.
Interview.

**The project will involve the following research/field work/experimentation/evaluation:**
The project will incorporate UX and permaculture design research methods for understanding and evaluation in the design, implementation and evaluation of the interactive system including:

- Literature review to explore how materiality and haptics can affect engagement and presence, how interaction designers can achieve the principles of SID in blended spaces, and permaculture design methods.
- PACT analysis
- Case study
- Observational study
- Participatory Action Research: Interviews/focus group

**This work will require the use of specialist software:**

No

**This work will require the use of specialist hardware:**

No

## 6. References


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## 7. **Ethics**

If your research involves other people, privacy or controversial research there may be ethical issues to consider (please see the information on the module website). If the answer below is YES then you need to complete a research Ethics and Governance Approval form, available on the website:
http://www.ethics.napier.ac.uk .

| | |
|---|---|
| Does this project have any ethical or governance issues related to working with, studying or observing other people? (YES/NO) | No |

## 8. **Confidentiality**

If your research is being done in conjunction with an outside firm or organisation, there may be issues of confidentiality or intellectual property.

| | |
|---|---|
| Does this project have any issues of confidentiality or intellectual property? (YES/NO) | No |

## 9. **Supervision timescale**

Please indicate the mode of supervision that you are anticipating. If you expect to be away from the university during the supervision period and may need remote supervision please indicate.

| | |
|---|---|
| Weekly meetings over 1 trimester | Yes |
| Meetings every other week over 2 trimesters | |
| Other (what?) | |

# Appendix B – Project Plan

| Task | Subtask | Deadline | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project Proposal | | 01/06/2018 | | | | | | | | | | | | | | |
| | Initial draft | | | | | | | | | | | | | | | |
| | Review with supervisor | | | | | | | | | | | | | | | |
| | Finalise | | | | | | | | | | | | | | | |
| | Submit proposal | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Initial Research & Report | | 29/06/2018 | | | | | | | | | | | | | | |
| | Literature search | | | | | | | | | | | | | | | |
| | Literature review | | | | | | | | | | | | | | | |
| | Methodologies research | | | | | | | | | | | | | | | |
| | Technologies research | | | | | | | | | | | | | | | |
| | Initial draft | | | | | | | | | | | | | | | |
| | Review with supervisor | | | | | | | | | | | | | | | |
| | Finalise | | | | | | | | | | | | | | | |
| | Submit Initial Report | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Requirements | | 06/07/2018 | | | | | | | | | | | | | | |
| | UX research methods | | | | | | | | | | | | | | | |
| | Permaculture research methods | | | | | | | | | | | | | | | |
| | Analyse research methods | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Envisionment | | 06/07/2018 | | | | | | | | | | | | | | |
| | Experiment with technologies | | | | | | | | | | | | | | | |
| | Ideate | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Implementation | | 29/07/2018 | | | | | | | | | | | | | | |
| | Initial design | | | | | | | | | | | | | | | |
| | Build system | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Evaluation | | 29/07/2018 | | | | | | | | | | | | | | |
| | Self-evaluation | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | User testing | | | | | | | | | | | | | | | |
| | Analysis of results | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Communications | | 09/08/2018 | | | | | | | | | | | | | | |
| | Supervisor meeting | | | | | | | | | | | | | | | |
| | 2nd marker meeting | | | | | | | | | | | | | | | |
| | Ethnographic diary | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Dissertation | | 13/08/2018 | | | | | | | | | | | | | | |
| | Abstract | | | | | | | | | | | | | | | |
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| | Evaluation | | | | | | | | | | | | | | | |
| | Discussion | | | | | | | | | | | | | | | |
| | Conclusion | | | | | | | | | | | | | | | |
| | References | | | | | | | | | | | | | | | |
| | Initial draft | | | | | | | | | | | | | | | |
| | Revision | | | | | | | | | | | | | | | |
| | Submit dissertation | | | | | | | | | | | | | | | |

# Appendix C – Reflective Journal

**Week 1**

*Permaculture Principles*

As a starting point for using permaculture design as a framework, I began by considering David Holmgrem's twelve principles of permaculture design and how they might be applied to HCI, UX and interaction design:

1. Observe and interact – Good design requires good understanding of the design problem and the domain. In permaculture this means understanding the space and how it can be used to best effect, understanding the components and how they can be applied for mutual benefit and understanding the needs of the people who will be using and maintaining the space. It also means looking to natural and social patterns to understand how natural ecologies function in a sustainable way and to discover and mimic these sustainable systems. Gaining a good understanding of the design problem is a common tenet to most design philosophies and a factor of UX design frameworks and philosophies, accomplished by a number of research methods; for example, interviews with stakeholders and users, focus groups, observation, ethnographic studies, PACT analyses, requirements gathering and surveys. These methods are typically user-centred and would need other methods or expansion on existing methods to further take into account other components and the space. The notion of mimicking natural ecologies could also be applied to HCI by considering different components in ecologies and blended spaces and seeing what works well together; providing beneficial relationships between actors, spaces and components.
2. Catch and store energy – This means becoming more self-resilient and minimising the need to seek resources from the outside. For an interactive digital system which would require some sort of power supply. This can be applied by minimising energy requirements of a designed interactive system and exploring ways for it to capture its own energy.
3. Obtain a yield – This principle refers to systems that are productive being more likely to last, functioning as a reason for people to maintain and it.

This principle also refers to making use of stored energy to maximise yield. In HCI, a yield can be interpreted as the designed system providing a benefit to people. This could be a useful functionality, knowledge or an emotional benefit. It could also refer to providing an inspirational experience – widening people's outlook and showing what can be possible.

4. Apply self-regulation and accept feedback – Sustainable systems self-regulate, and application of this principle requires understanding of the positive and negative relationships that exist in nature. Accepting feedback means identifying both positive and negative outcomes and responding to them. This principle also refers to self-reliance, encouraging recycling and upcycling over purchasing new components where possible.
5. Use and value renewable resources and services – This means making the most of renewable natural resources and renewable services. In HCI, this could be harnessing solar or wind energy for example. It also means incorporating passive functions in nature that can provide benefit within a system without consumption; making use of natural processes and animal behaviours as part of the design. In a HCI context this could extend to considering human behaviours as part of the design.
6. Produce no waste – This principle views output as an opportunity. To accomplish this a well-designed system will make use of all outputs from its components to reduce waste and pollution. In HCI this could also mean using materials and components that are reusable or recyclable.
7. Design from patterns to details – Patterns exist in society and nature and these patterns can be copied, scaled and incorporated. The 'bigger picture' should also be considered in permaculture design and a variety of design methods employed in the process. In UX considering the bigger picture rather than focusing on the minutiae of the user interface can be accomplished with methods such as user flow diagrams.
8. Integrate rather than segregate – The connections between components are as important as the components themselves and the components should be arranged to improve the benefits from other components. Can integration of nature with the digital create a cooperative state? This principle also echoes 'assemblage theory'.

9. Use small and slow solutions – This means designing to the smallest practical scale; designing simpler systems and taking advantage of local resources. In HCI and UX this can mean avoiding excess and bloat in the design; avoiding unnecessary functions and components.
10. Use and value diversity – Diversity in permaculture ensures a fail-safe against threats. In a broader sense this means promoting cooperative, complex relationships between the diverse parts of a system. Valuing diversity can also be applied in UX; for example, avoiding stereotypes in the creation of personas.
11. Use edges and value the marginal – In permaculture, the place where two ecosystems meet (the edge) is often rich in variety and more productive. The marginal can be unusual (or novel) ideas, views or components. This principle reminds us that the most obvious areas or components of the system may not always be the most important or influential and these edges and marginals are opportunities. In HCI the edge could refer to the interface or touchpoints of the system.
12. Creatively use and respond to change – In permaculture this means designing to consider both expected and unexpected changes over time in natural systems. The challenge for designers is to make benefit of these expected changes and respond creatively to any unexpected ones.

*Initial Concept*

The initial concept for the project is to merge computer interfaces with the natural world, with the interface being an organic part of the environment. This will be an interactive system to be set up in the Edinburgh Napier University Merchiston campus’ Lions Gate interactive permaculture garden. Embedding plants with technology demonstrates “integrating rather than segregating” by combining the physical and natural with the digital. Using environmental objects as an interface also demonstrates “using the edge” and “using the marginal” in its novelty. It could also potentially meet some of the SID principles of: reducing personal consumption through design, fostering ownership of sharable resources, renewal of old objects and using materiality for engagement and expression.

Further future application of permaculture principles include: “observe and interact” to research and gather information before interacting and making, “produce a yield” which in this case could be knowledge about permaculture or sustainability and “design from patterns to details” by finding patterns in the permaculture space, such as a permaculture plant guild, made of layers of beneficial components and inserting a digital layer. In what ways could such a digital layer benefit the system?

Initial research into the artefact being designed was to search online for similar concepts (technology-human-plant interaction) to see what can be achieved and as a form of ‘competitive analysis’, a research method commonly employed in HCI. Examples found included:

- Talking Tree (source: http://www.creativeapplications.net/maxmsp/talking-tree-maxmsp/ retrieved: 10 May 2018) – A 100 year old tree outside Brussels was fitted with various sensors (light, ozone and dust meters), microphone, webcam and weatherstation. It was then fitted with equipment to enable to communicate with people across various social media and a website about its environmental condition and the effect of pollution on it.
- Phonofolium (source: http://www.scenocosme.com/phonofolium_e.htm retrieved: 10 May 2018) – An art installation consisting of a tree fitted with electrostatic sensors and other technology to “sing” in response to touch by visitors, creating a relationship between plants and sound.
- Phytosense (source: http://www.iaacblog.com/programs/phytosense/ retrieved: 10 May 2018) – An “interactive green façade”, this system uses swept frequency capacitive sensing and an Arduino Mega microcontroller to fade addressable LEDs when plants in a palette were touched.
- Botanicus Interacticus (source: http://www.botanicus-interacticus.com/ retrieved: 10 May 2018) – Uses sophisticated sensing technology to produce beautiful light shows in response to proximity , gesture and touch of different plants.
- Root Note (source: https://www.rebeccalieberman.com/root-note/ retrieved: 10 May 2018) – A responsive sonic garden that uses touch, moisture and light sensors, an Arduino and a computer to produce music affected by the various sensors.

- PiPlanter (source: https://www.raspberrypi.org/blog/piplanter-a-plant-growth-monitor/ retrieved: 10 May 2018) – Using a Raspberry Pi to automate some impressive functions, though is not necessarily interactive; it automates irrigation, monitors conditions such as temperature, light and humidity, and publishes results to social media.

Research of similar systems has revealed two main functional categories for plants embedded with technology:

- Interactive art systems using touch (and other sensors) to affect sound or light outputs.
- Automated systems using sensors to output information.

These systems have proved the feasibility of using touch sensors on plants as a means of human-computer interaction and the ability of such systems to output information to the Internet, and to do so using modular and reusable hardware such as an Arduino or Raspbery Pi. The use of modular and reusable hardware supports the SID principle of promoting renewal and reuse and the permaculture principle of self-regulation.

**Week 2**

*Experimental Design & Making*

Experimentation began with an 'Arduino Uno'; a microcontroller board with 14 digital input/output (I/O) pins which can provide or receive 20 mA (and of which 6 can be used as Pulse Width Modulation (PWM) outputs), 6 analog pins, a USB-B connection and a power input connection. It has an operating voltage of 5V, 32 KB of flash memory, weighs 25 g and measures 68.6 mm x 53.4 mm. It also offers regulated 5V and 3.3V output pins. The Arduino Uno can be bootloaded with new sketches written in a simplified version of C++ via the USB connection from a computer running the Arduino Integrated Development Environment (IDE). When operating, the Arduino Uno uses about 45 mA of current. It can create interactive environments by interacting with buttons, LEDs, camera, motors, speakers and a wide variety of sensors.

The modular nature and flexibility of a system made with an Arduino Uno and its easy transfer of ownership makes it suitable for reuse and repurposing once the system is redundant, reducing material disposal (fitting two SID principles).
Initial experiments consisted of successfully reading sensor measurements from a potentiometer and using them to adjust the brightness of an LED attached to a PWM pin.

Some experimentation was also carried out on the 'Adafruit Circuit Playground Express'. This is another microcontroller board but with the added bonus of many additional components built-in and set in a compact disc (outer diameter: 50.6 mm; weight: 8.9 g). These built-in components include 10 mini NeoPixels (individually programmable multi-colour LEDs), a motion sensor (triple-axis accelerometer), temperature, light and sound sensors, 2 buttons, a slide switch and an infrared receiver and transmitter (which can act as a proximity sensor). The Circuit Playground also offers 8 analog alligator-clip friendly I/O pins, 7 of which can be used as capacitive touch inputs. This board has an operating voltage of 3.3 V, has 2 MB of flash storage, a microUSB port for power input and data connectivity and is Arduino IDE compatible. Power consumption is approximately 30mA.
An example of the serial output of the onboard sensors shown below, where Capsense indicates a touch sensor:

```
Capsense #3: 4
Capsense #2: 1
Capsense #0: 4
Capsense #1: 5
Capsense #12: 0
Capsense #6: 3
Capsense #9: 2
Capsense #10: 3
Slide to the left
Light sensor: 411
Sound sensor: 338
X: 0.62  Y: -2.90        Z: 8.83 m/s^2
Temperature 22.0
```

To test the validity of using touch sensing with plants, an alligator clip was attached to one of the capacitive touch inputs and the other end inserted into the soil of a basil plant pot. Serial monitor measurements were recorded in the Arduino IDE on a laptop connected via USB to the Circuit Playground while the basil plant was touched, suggesting even light touches will register and can be used to program feedback, results shown below:

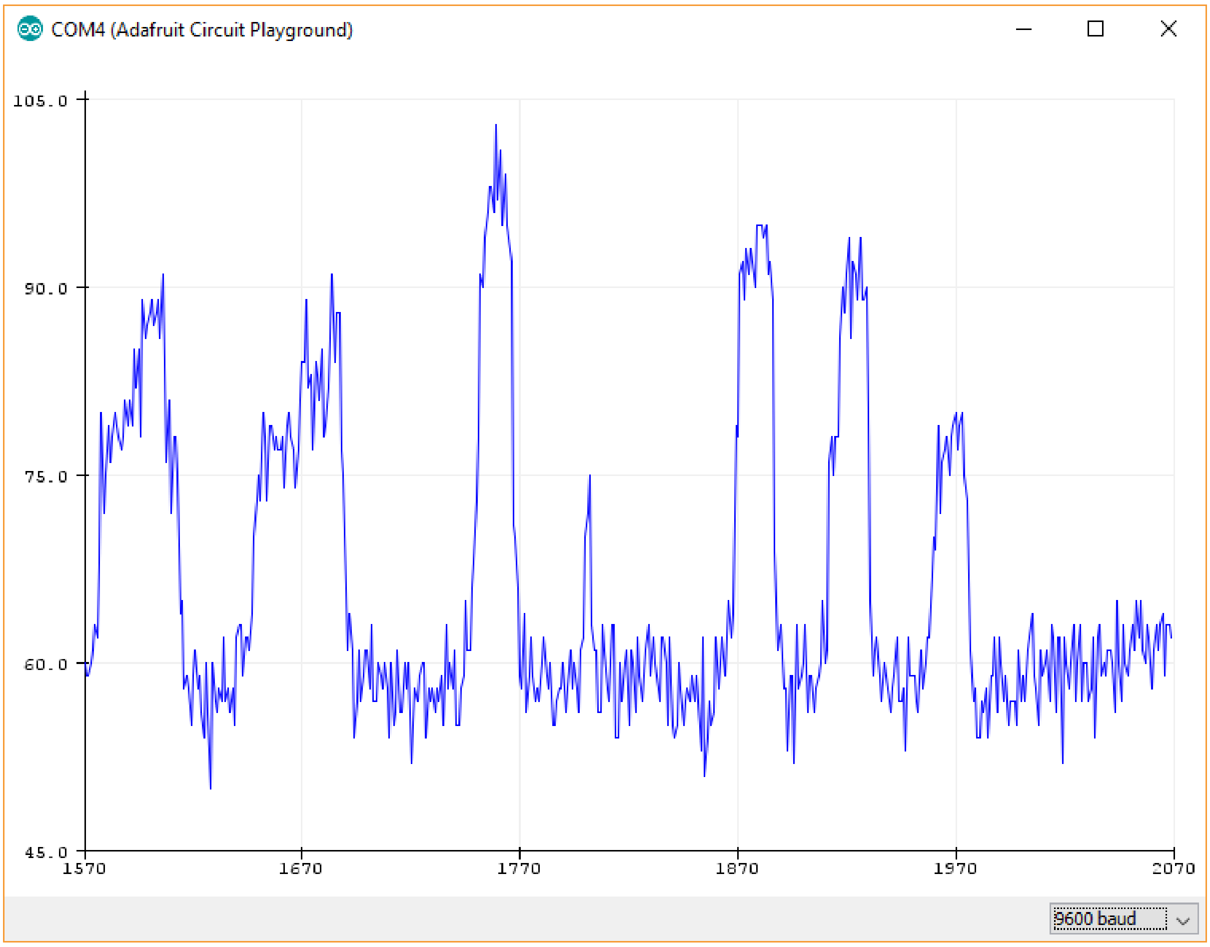


**Figure C1: Serial monitor results of testing capacitive touch sensing on basil plant**

*Considering the Space*

As highlighted by Benyon’s work on blended spaces; the space itself is also an important consideration.

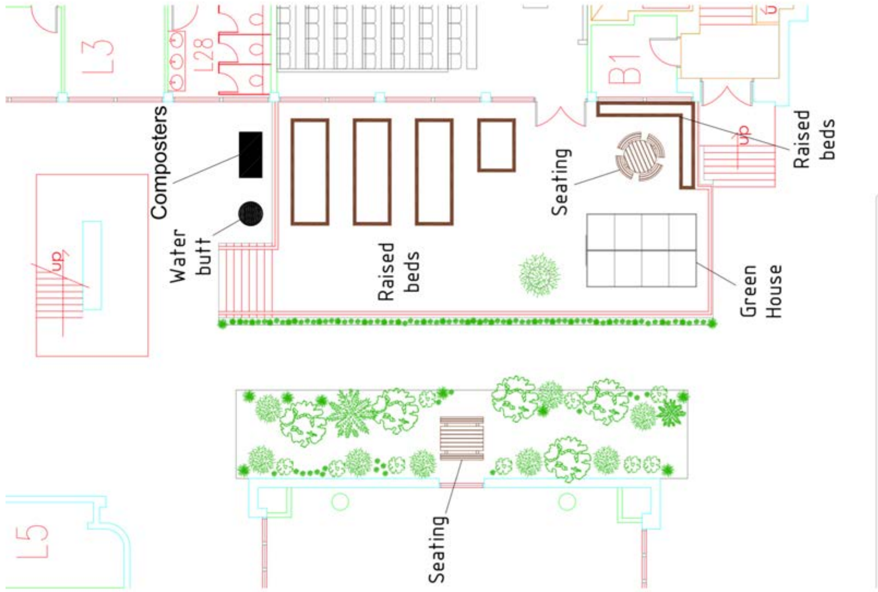


**Figure C2: Kitchen garden and rooftop allotment plan (Egan, 2017)**

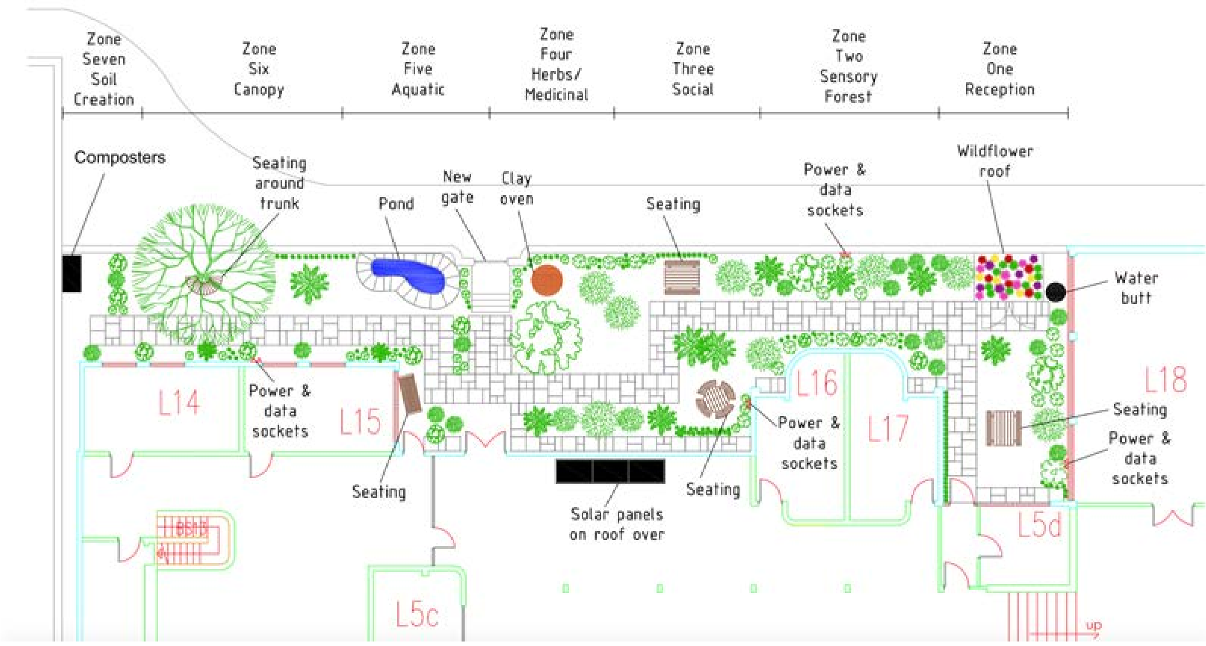


**Figure C3: Lion's Gate Garden plan (Egan, 2017)**

There are two areas within the space; the Lion’s Gate Garden and the kitchen garden and rooftop allotment. Final selection will be determined further down the line once more of the artefact is known of the features being designed.

**Week 3 7-13 June 2018**

*Literature Research*

Went back to Benyon’s description of blended spaces to gain deeper insight into blended spaces in general as well as how to apply the theory to UX and permaculture. In considering blending spaces several important factors to consider became evident; the characteristics of spaces (ontology, topology, volatility and agency) and the correspondences between them. Revisiting Egan et al.’s proposal of using permaculture as a framework further enlightened as to how to blend these conceptual spaces for the project and highlighted a few of the correspondences between UX and permaculture.

*Research Methods*

Focusing on research methods used in permaculture design I found as in UX there are a number of methods, tools and frameworks, some appropriated from other design fields. As in UX there were also design processes or cycles such as OBREDIMET. I found many similarities between processes/methods used in UX and permaculture design. OBREDIMET bore some similarities to the use of Understanding, Envisionment, Evaluation and Design stages in UX design with constant re-evaluation a feature in both. ‘Analysis of elements’ bore similarities to ‘ecosystem maps’, ‘content audits’ and ‘conceptual diagrams’ by concerning ontology and topology; ‘Observation’ to absorb the reality of the situation and to notice patterns and processes in permaculture was analogous to ‘user observation’ in UX; ‘flow diagrams’ to ‘user journey maps’ shared concepts of analysing movement through a system. Other methods used in permaculture design such as ‘random assemblies’ and ‘identification of limiting factors’ are methods that could also applicable to UX. Participatory research is also a type of research used in both domains.

Could these correspondences be used to map methods on to each other? Could new design methods be achieved by blending these spaces for use in HCI to better incorporate the permaculture ethics of ‘fair share’ and ‘earth care’ as well as ‘people care’?

**PACT Analysis**

*Research Objectives*

PACT analysis is a useful framework for thinking about a design situation, the acronym PACT referring to People, Activities, Context and Technologies (Benyon, 2013). Used in UX design to put the human at the centre of the design process, it can increase understanding of the people who use a service, the activities they undertake, the contexts within which the activities take place and the technologies used to accomplish them.

*Research Output*

People

As the garden is located on a university campus, the people most likely to visit the garden and therefore use the system being designed will be university students, staff and visitors, however members of the public will also have access to the garden. As the campus is home to the schools of Arts & Creative Industries, Computing, and Engineering & the Built Environment ('Merchiston', 2018). Around two-thirds of students enrolled at the university are mature students (age 21 or over at the time of enrolment) and around 10% of enrolled students declare a disability (Edinburgh Napier University, 2018). University staff and visitors to the campus are also a consideration. Poor spatial ability, wheelchair access and colour vision deficiency should all be considered in the design process. As subjects taught on this campus are taught in English, most potential users will likely have a strong grasp of the English language.

Activities

The service provides visitors to the garden an interactive experience demonstrating a permaculture plant guild to educate about permaculture. It is an activity that would be carried out infrequently, without time pressures and is not safety-critical. The medium used will be text and image-based so only small amounts of data would be communicated.

Contexts

Located on the Edinburgh Napier University Merchiston campus it will have fast internet access and WiFi available. Socially, it is in a public place open to students, staff and visitors. Users will also be interacting with it on their own with no interaction required with others. The system will be located outdoors making it vulnerable to all weather conditions.

Technologies

A physical input is required to tie the physical space to the digital content. Capacitive touch sensors will allow users to directly ‘select’ components. The output will consist of alphanumeric data and possibly images and video so a multimedia-capable screen will be required. Small amounts of text-based data will be communicated between users and the server.

*Actionable Output*

The PACT analysis increased my understanding of the difference in variety of potential users of the service, also that most would be technologically competent to a degree (being mostly younger people studying creative, computing or engineering subjects) and that the service will be used by differently-abled people. Context analysis also highlighted areas of consideration such as differing weather conditions would have to be designed for. Activity and Technology analysis narrowed down the forms of touchpoints the system could entail. As the system would likely be used infrequently it will need to be well-guided and intuitive to use.

*Research Review*

The PACT analysis helped to focus on how to make the system usable now that a concept had been selected by considering the variances in potential users of the system. It also raised considerations concerning the environment of the system and aided in resolving the technological requirements of the system. It also was useful in highlighting user needs in relation to the system functions and the activities users carry out.

**Week 4 Thursday 14 June 2018**

*Brainstorming Ideation*

Further discussing the project deliverable with my supervisor, we brainstormed ideas. Discussing what it should convey to users brought up the idea of showing the interconnectedness of healthy ecosystems and how people can be a beneficial part of that. The idea of a kind of jigsaw that people could complete to relay this was explored, with a reward for completion such as some kind of light or display. In this concept we would try to relay the person as the final piece of the puzzle, feeding in to UX design aims to have users at the centre of the design process.

Also discussed was creation of a small space within the garden that the system could inhabit. Given that light or display may be required, a shelter made of natural materials seemed appropriate to locate the system and user.

Materials for haptic interactions were explored; any conductive materials can become touch-sensitive such as metal or anything containing water such as plants, fruit and soil. Larger plants with thick bark may not work appropriately; testing needed. Interactive elements would also need to be conductively isolated so the wrong objects are not triggered. This could be achieved by separating with wood, glass or re-purposed plastic. Square-foot garden proposed as possible solution to this if using plants as interfaces. Separating the plants is opposed to “integrate don’t segregate” however would be necessary for touch sensing to function correctly.

*Literature Research*

Extended research into tangible computing to incorporate Marshall et al.’s classifications of tangibles as ‘ready-to-hand’ and ‘present-at-hand’. While Dourish’s work focuses on ready-to-hand, Marshall et al. propose that present-at-hand should have consideration in design, especially for learning systems. While most research focuses on children, could the same principles be applied to teaching adults about sustainability? Also came across two potential case studies to examine; Antle’s Springboard prototype which applies balance metaphors to design to teach about social justice. Also Marshall’s Ambient Wood experiment.

Came across the concepts of Humane Design and Calm Technology. Humane Design attempts to understand vulnerable human characteristics so we can design

compassionately and create design standards and business models to more closely align with our humanity. Calm Technology is a design philosophy that thinks technology should simplify complexities, not introduce new ones and help us focus on the things that are important to us.
Have also looked into senses of place and space. As UX designers are now designing experiences in blended spaces, these spaces and places should be a consideration in design. Especially interesting as I discovered a study that found a sense of place attachment can increase environmentally responsible behaviour.

*Design Decisions*

The system being designed will be a ‘niche’ within an ecology consisting of the technology and other components situated within the garden. As the interactive permaculture garden is in a state of development, volatility of the space is a consideration. Using the permaculture principle of “creatively use and respond to change” means considering how this niche will respond and take advantage of change as the garden continues to change and evolve over time. One option for this is a Bluetooth beacon to draw user attention via their mobile devices, of which several could be deployed at a later date to different zones within the garden.

**Week 5 21 June 2018**

*Brainstorming Ideation*

With the ubiquity of mobiles and considering Farman’s suggestion that work in ubiquitous computing should always consider personal mobile devices such as smartphones, maybe it should be a part of the system ecology. One option for achieving this could be making a dock for user mobile devices? Bringing the phone into the space. Also reduces the material need and energy requirements (catch and store energy) for a separate display for the system; “use and value renewable resources and services” taking advantage of the fact most people carry a smartphone (human behaviours) and “slow and small solutions”, is an additional screen in the space necessary if this is the case? Bringing personal devices into the space and ecology “uses diversity” and “integrates rather than segregates” as per the permaculture principles. It also fits the principle of “using small solutions” by simplifying the physical system being designed by removing the need for an additional display in the space to convey information.

One possible user journey as follows:

- BLE beacon gets user attention and gives instruction
- Phone placed in dock
- Web page opens on screen (QR Code or RFIC tag)
- Icons – do we need bold enough plants to capture in icons
- Audio? Tell a story? Water the plants?
- Show interconnectedness and care
- Something amusing or controversial?
- Give a bold message – everything is useful?

What is the yield of the system? Knowledge is one option. Maybe edible plants also? Is there a reward? How do we educate about permaculture? What are we demonstrating? Should have design icons for different plants or layers.
What level of affordance?
Use of QR and RFIC/NFC requires no additional energy; “use and value renewable resources”.
How will be people interact with the system? Could we track head movements to highlight the different layer of permaculture; canopy, etc. Movement or touch?
Need to get making immediately; bringing the the parts into the design space to further observe and interact.

Will also build prototype site; must consider colour, mood, psychology, engagement, iconography, typography. Also media; will there be sound or video?

*Experimental Design and Making - Hardware*
Further explored the potential of the Cypress Solar Powered IoT Device Kit. While initial experimentation explored its ability to function as a wireless sensor node, I tested it out as a means to broadcast via Bluetooth to mobile devices based on this code https://github.com/cypresssemiconductorco/PSoC-4-

BLE/tree/master/100_Projects_in_100_Days/Project050_Eddystone/Eddystone/Eddystone_EH_Kit.cydsn which had to be amended to be bootloadable using UART. This could potentially have been used to obtain user attention and guide them to a website by broadcasting. The fact they are solar powered also resonates with the permaculture principle of harvesting renewable energy. However, it raised some issues; Physical Web beacons are currently undergoing re-evaluation amongst Google, Apple and Microsoft and are not currently compatible with iOS without downloading an app for listening for Physical Web beacons. The web link broadcast by the beacon in Eddystone format must also resolve to a website with HTTPS. If a native app with Physical Web functionality built-in could be developed for the entire space however, they could be used to notify users of different zones in the garden.

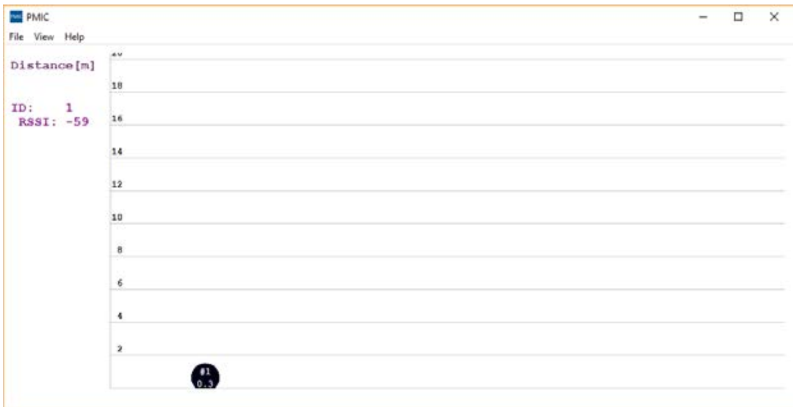


**Figure C4: Testing proximity sensing with BLE beacon**

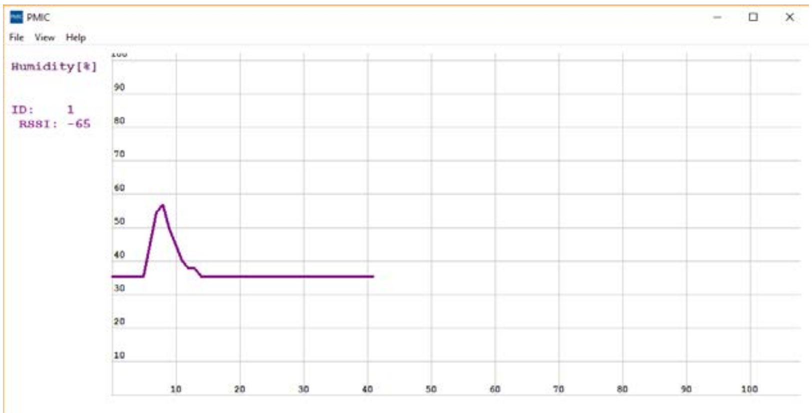


**Figure C5: Testing humidity sensor with BLE beacon**

Today I began constructing a container for the system. Given it would need to be portable a tray or box would seem appropriate. Mobility will also enable the system to better “respond to change” as the space changes. In keeping with the ideals of reuse and recycle to produce more sustainable systems, I repurposed old unused items fitting the permaculture principle of “applying self-regulation”. For the main container I found a wooden crate, moving the floor of it up a level so that the base has room to hide any electronics. I was also able to use an old tented table sign into a “dock” to situate the user device. The process of making has helped to clarify ideas for the system and how it might work, it will definitely aid in envisionment once I get some plants and objects in there.

*Experimental Design & Making - Hardware*

I began experimenting with the Photon, manufactured by the company Particle. It is a tiny (measuring 12mm x 11mm x 1.3mm), open-source WiFi IoT Device for creating internet-connected devices consisting of a microcontroller, an integrated Cypress WiFi chip, 18 mixed-signal I/O pins (18 can be used as Digital I/O, 8 as Analog Input, 2 as Analog Output and 9 can be used as PWM), 1 MB flash memory and easily interacts with the internet via Particle’s Device Cloud (a secure cloud platform for managing Particle IoT devices). The device requires an input voltage of 3.6-5.5 VDC and operating voltage of 3.3 V and typically uses around 80mA when the WiFi is on and 30 mA when WiFi is off. However, the Particle Photon has a variety of power-saving modes that can be implemented to reduce power consumption; current can be reduced to as little as 80 uA when in deep sleep mode, 1 mA in sleep mode or 18 mA with WiFi on and in “powersave” mode.

I was immediately impressed by the ease with which it could publish to and receive commands from the internet, initially testing this by programming an LED to be controlled via a simple web form. It was also designed to be Arduino-compatible, using the same simplified version of C++ used by Arduino’s microcontrollers, although it uses its own but functionally similar IDE, named Particle IDE.

*Choice of Microcontroller*

Going forward, the Particle Photon appears the best choice of microcontroller board for the project, compared to alternatives such as the Arduino Uno, Adafruit Circuit Playground, Cypress Solar Powered IoT Kit or other unexplored options such as the Raspberry Pi. The reasons are as follows:

- “Use small and slow solutions” (Fulfils desired functionality without excessive features or additional equipment) – The Particle Photon offers a microprocessor, WiFi connectivity, a sufficient number of I/O pins to work with and voltage output and that is more or less it. By comparison, the Arduino Uno would have required an additional piece of equipment such as a WiFi Shield (which supposedly can be quite difficult to work with) or Ethernet Shield and a wired LAN connection. Similarly, the Adafruit Circuit Playground would have required additional equipment for communication with other technology via the serial port and also had several sensors surplus to requirement. A Raspberry Pi such as the Raspberry Pi 3 Model B which offers built-in WiFi would have met functionality requirements however offered much that was surplus to requirement (1 GB RAM, a GPU, 40 General Purpose Input/Outputs (GPIO)), Bluetooth, HDMI connections, etc. The Cypress Solar Power IoT Kit fits the “use small and slow” principle more than the Particle Photon however it lacked in functionality for this purpose; while it has built-in Bluetooth connectivity, it required a data sink, such as a laptop with a Bluetooth transceiver, in a nearby location to communicate with. It also only transmits with Bluetooth every 6 seconds which would be too slow for any interaction requiring feedback for a user.
- “Catch and store energy” – Using this principle again the Cypress Solar Power IoT Kit would appear the best option. However, considering the bigger picture the kit would again require a second device to receive and communicate with; a device that would also require its own power supply. Raspberry Pis have a much higher average energy consumption rates, typically 120-500 mA with WiFi on, dependent on model. Arduino Uno, Adafruit Circuit Playground and Particle Photon have much lower average currents (around 30 – 80 mA). Arduino Uno’s ‘sleep mode’ can reduce this to 10 mA however the Particle Photon far surpasses this with its various power-saving modes; average current of 80 uA when in deep sleep mode, 1 mA in sleep mode and 18 mA in

powersave mode with WiFi on. This makes the Arduino Uno (with some modification) and Particle Photon suitable to be powered by solar panels, if coded to work energy-efficiently.

- The Arduino and Particle platforms also both benefit from being open-source and modular; they are easy to fix if broken or reuse for other purposes rather than be disposed of – fitting Blevis's SID principles of linking invention with disposal. The Particle Photon also offers easy transfer of ownership.

**Input-Output Analysis**

An Analysis of Elements was jotted down to better consider the ontology of the system. Components considered were: the land, humans, plants, the campus buildings and the technological components (Photon, touch sensor and user mobile device). Using the inputs and outputs from this, an input-output analysis was performed to further understanding of a potential topology.

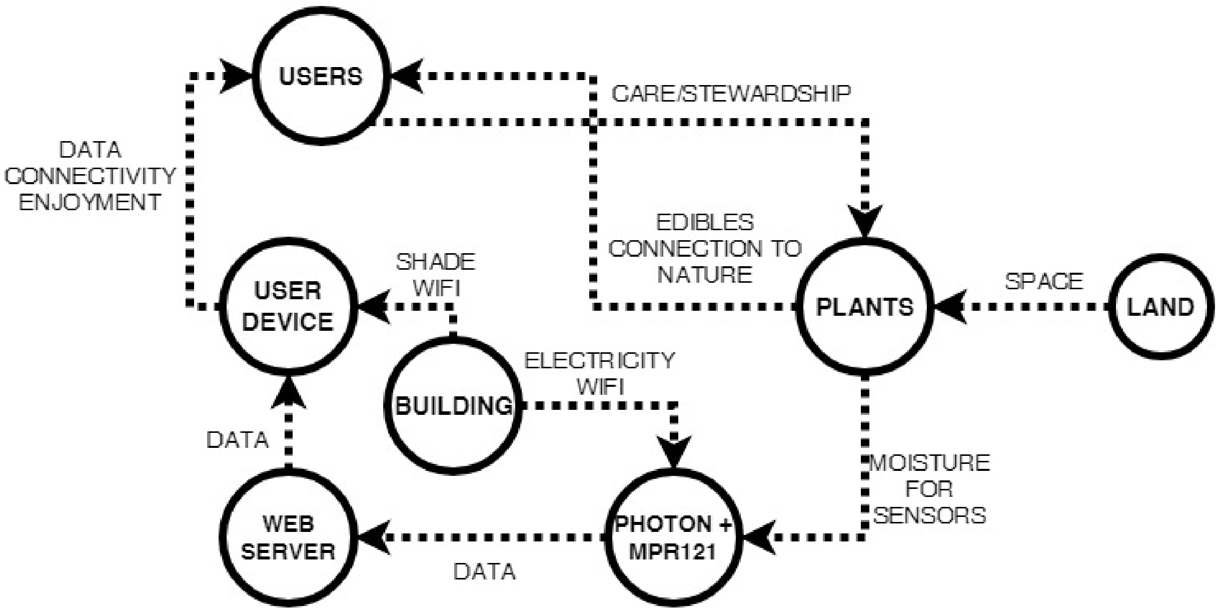


**Figure C6: Input-Output Analysis**

**Week 6 - 28 July 2018**

*Brainstorming Ideation*

To help envisage the system I used the box, dock and various plants and objects such as rocks in the garden, in varying positions and discussed possibilities, echoing the permaculture design method of “random assemblies”. Once a clearer idea was attained, I performed a cognitive walkthrough of the system. Part of the garden is provided shade by the campus buildings which made it suitable for any screen usage and use of lights. This method echoed the permaculture design method of random assembly; moving objects around in the physical space to see what could work and what part of permaculture could be demonstrated, but also was a form of cognitive walkthrough employed in UX.

The first concept we explored for the system was that of space; to make sure we know everything about the space and how the system could teach the user about the space. One idea was to lay out an old map of the garden to explain the space and its story. For example, having a pear tree sapling where a pear tree is in the wider space. This would provide a plant-based navigation through the garden. This storytelling could help foster an attachment to the place which would have the added benefit of improving environmentally responsible behaviour (ERB) as such attachments to natural resources apparently improve ERB. Exploring the space could be done by considering the dimensions of permaculture; the horizontal, the vertical, relationships and time.

Also considered was using the system to demonstrate the three principle ethics of permaculture; people care (i.e. something edible), earth care (i.e. nitrogen-fixing plants, nettles, etc.) and fair share (i.e. sharing knowledge such as how, tweets or something more frivolous such as bubbles, or a free pot with seeds in, etc.) Also considered was having a dial amongst the plants as another form of tangible, tactile interaction.

Following the session, I created a user journey map to gain a clearer perspective of the system’s flow and functionality. The need for conviviality in moments when the user is waiting or not interacting is made clear, as well as the fact the user will need to quickly be informed how to use the system and some basic permaculture knowledge to give them context before using the system.

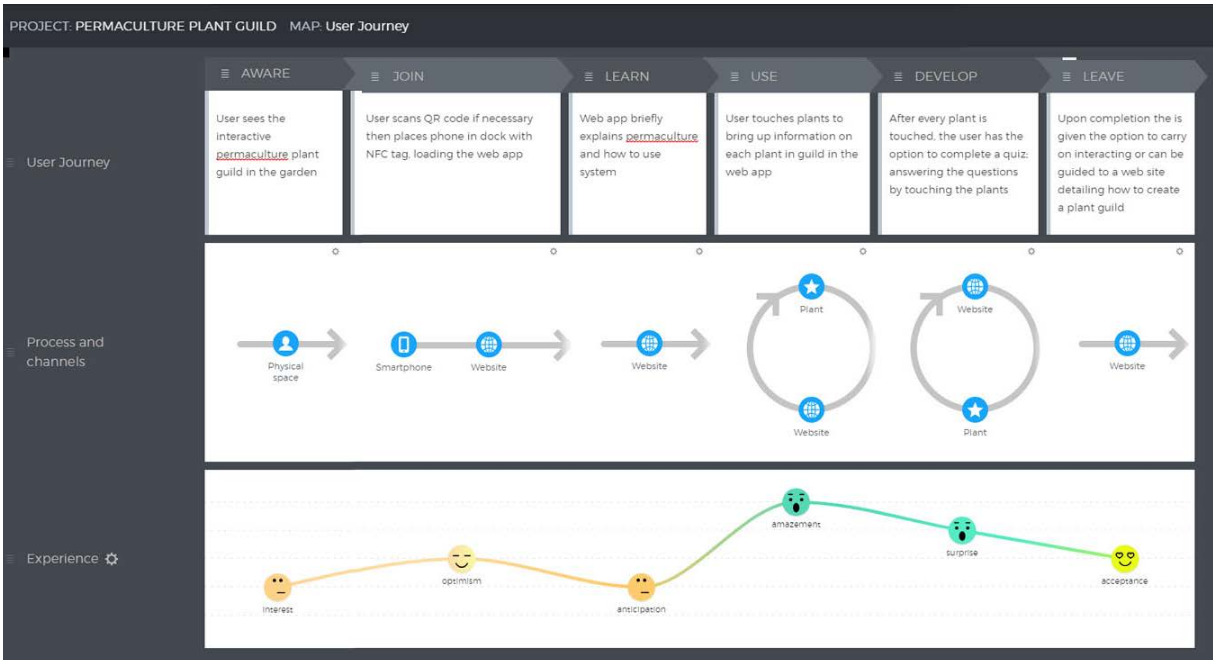


**Figure C7: User journey map**

*Graphic Design*

My first instinct for the signage on the bottom of the tray was to replicate patterns in nature. Starting with sketches using pencil and paper, these were quickly and roughly replicated in Adobe Illustrator using a tape measure for dimensions and creating patterns in black. The idea that seems to work best was a winding branch, guiding the user through the board. Also considered was a spider web reflecting the relationships between the objects and path through garden.

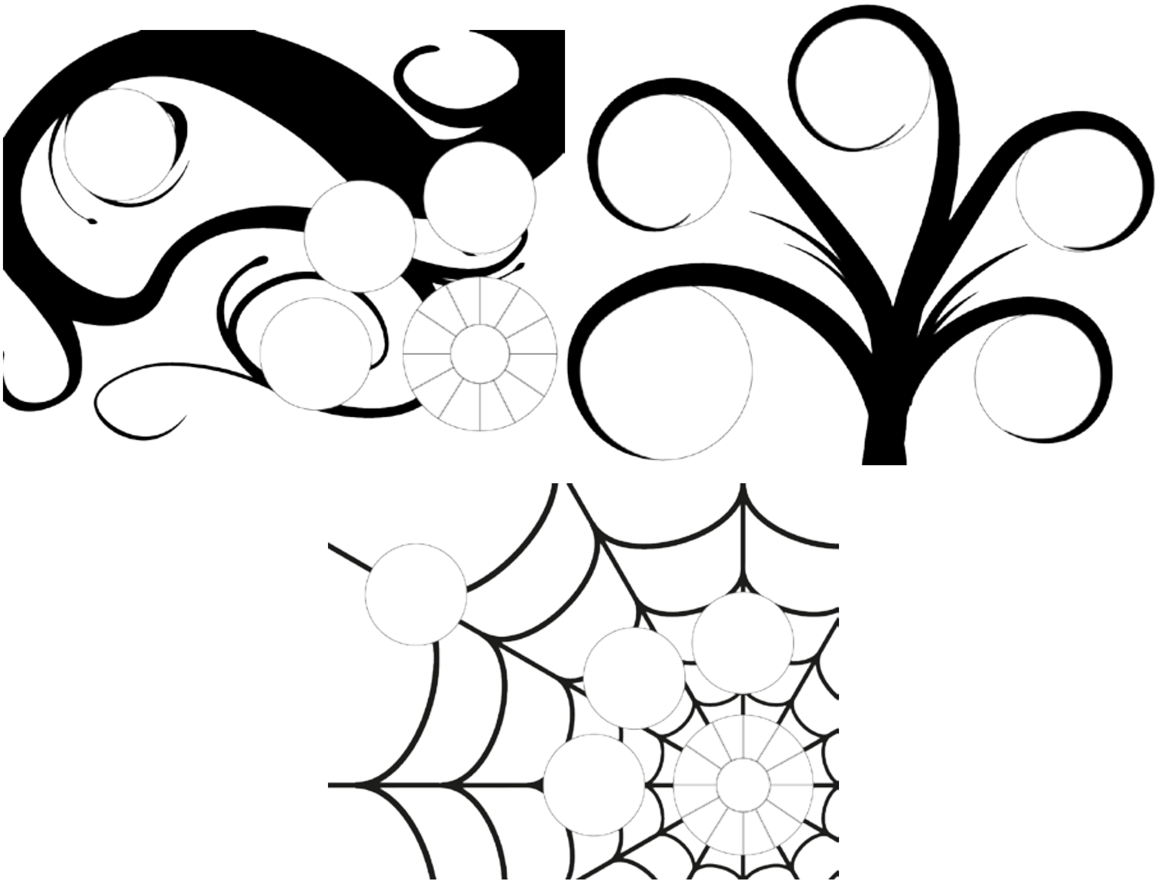

**Figure C8: Container base designs**

I have also created a graphic for the mobile phone dock, instructing the user to place the phone there. Also incorporated brief instructions; that the NFC tag will only work with NFC-enabled phones, so an also provided QR code would need to be used by devices that are not NFC-enabled. The dock also provides an opportunity to provide aesthetics and branding in the physical space for the system.


**Figure C9: Design for device dock**

*Hardware Testing*

Finished the soldering of the Adafruit MPR121 touch sensor breakout board using soldering iron and tin/lead solder. Unlike with the Adafruit Circuit Playground, touch via a test basil plant was not registering. The breakout board and provided software library were designed for direct physical touch through metallic objects. I have worked around this and improved sensitivity by increasing current through the touch sensor wires to 32 uA from 16 uA. As each sensor is read independently in turn, the total average power consumption of the board will be only be 16 uA higher (and not 12 times 16 uA). Tested the Photon with the MPR121 and was successfully able to update a basic web page whenever a different sensor pin was touched. Schematic of Photon and MPR121 shown below:

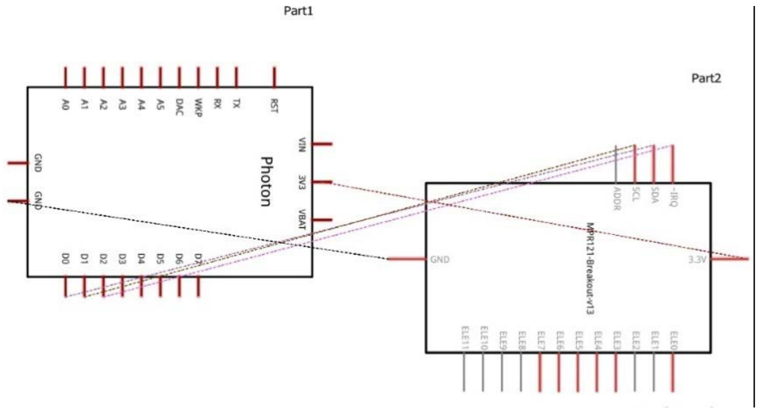


**Figure C10: Schematic of electronic setup of artefact**

*Web App Development*

I have further developed a web app to be displayed on user mobile screens using Twitter's bootstrap JavaScript library. To enable ease of visibility large icons and text, and high contrasts have been used to account for screen glare (for outdoor conditions as highlighted in PACT). A loading screen felt necessary to give the touch sensors time to recalibrate; touch sensing can be volatile, affected by temperature, humidity, etc. Convivial, changing messages and animations are displayed on loading screen to ensure user does not get agitated. Loading screen may also be necessary if a low-power mode can be introduced into the physical system when not in use; a few seconds will be required for the Particle Photon to reconnect to WiFi at which point sensors can recalibrate. Using AJAX to check the status of the Particle Photon API and which sensor was last touched successfully changes the page displayed.

**Week 7 - 5 July 2018**

*Brainstorming Ideation*

Having demonstrated the touch sensors interacting successfully with the web application, possible content was discussed. Sound was one possibility, which could be played through the user device. Video content could also be displayed. Focusing on functionality it was decided it should either be a demonstration of a simplified plant guild or a puzzle or mixture of both. Giving the player a reward of some seeds would fit with the permaculture ethic of 'fair share'. Additional to plants was the idea of having something representing technology in the crate, such as a microchip, to highlight the negative as well as beneficial effects of technology; such as informing the user of the toxicity of chemicals such as bromides in nature used in their manufacture and asking the user to reflect on what ways technology could be beneficial to ecosystems.

Plants for use in the simplified guild were decided so can now be fully researched to flesh out how to portray their relationships, beginning with an input/output analysis. They are as follows:

- Fruit tree layer – pear tree
- Shrub layer – honeysuckle
- Rhizosphere layer – wild garlic or potato
- Herbacious layer - comfrey
- Soil layer – arctic strawberries

Potentially the additional layers of:

- Animal layer
- Funghi layer
- Digital layer?

*Hardware*

Initial experiments with a Tower Pro Micro Servo to provide motor functions for the system. Seemed to struggle with the 3.3V output offered by the Particle Photon and may require an additional 5V supply. Not desirable for keeping energy consumption minimal as servos require a lot of electrical current. Also tested a potentiometer which gave clear changes in output on rotation and can be used to detect rotation of a dial which could be another useful form of input from the user.

For wiring I have chosen 22AWG EcoWire Hook-up Wire; its manufacturer AlphaWire claim it is fully recyclable due to its non-halogenated insulation that contains no heavy metal pigments (source: http://www.alphawire.com/en/Products/Wire/EcoGen/EcoWire).

Have also tested the capacitive touch sensitivity with the 22 AWG eco wire and a basil plant, with the Particle Photon plugged into a laptop with a serial monitor running in Command Prompt which was successful. I then tested each I/O pin on the MPR121 touch sensor breakout board; tests with pins 0, 1 and 3 to 11 worked successfully, however pin 2 seems not to respond, probably due to bad soldering or damage to the breakout board when attempting to do so.

*Graphic Design*

Finalised the print for the dock with the addition of a graphic representing the layers of a plant guild to further convey to the user what the plants represent in the physical space. Also explored further ideas for the base of the tray. Reflecting on nature, I experimented with a spiral design inspired by nature as a means to ‘make use of the edge’ and make the most of the space.


**Figure C11: Design for device dock with plant guild included**

*Web App Development*

Further development of web app accomplished; applying plant guild graphics to the website has enabled me to use it as a 'key' to identify each plant as a layer component in a permaculture plant guild. Have also applied individual colours to each layer to further highlight differences between them; made use of bright colours used to ensure easy visibility in bright conditions. Ensuring consistent and aesthetic layout across the variety of potential mobile device screen sizes provided some difficulties; ensuring all items on screen are relative to the viewport size proved the best way to achieve this after user testing on several devices and using Google Chrome's Developer Tools.


**Figure C12: Prototype of plant information page**

*Testing*

From testing the web app, I realised phone display was going to sleep when screen not touched for periods of time. Have added NoSleep.js; a javascript library that mimics a video file playing to stop the screen going to sleep when screen not touched.

Also tested the touch sensing with several plants in the garden. I have increased the sensitivity again by upping current through sensor wires to 63 microAmps; the highest value allowable for the MPR121 breakout board as per its documentation (source: https://cdn-learn.adafruit.com/downloads/pdf/adafruit-mpr121-12-key-capacitive-touch-sensor-breakout-tutorial.pdf).

**Week 8**

*Design Decisions*

Have discard crate as it was too constricting and no longer provided a use; it did not provide a yield.  The electronics are compact enough to be located under the phone dock, which can also provide waterproofing. I have decided to use a palette from garden instead.

From further testing of the web application and lack of time left to ensure it looks presentable when the phone is in portrait I have implemented the pleaseRotate.js javaScript library that prompts the user to rotate their phone if in the wrong orientation.

Final testing of the touch capabilities reveals the sensing is not as sensitive as desired on some of the larger plants. Some plants lack touch sensing at their extremities, however touching the base of every plant and its soil functions correctly. Results of the parts that respond to touch as follows:

- Apple tree: 20 cm of stem from base and soil
- Black currant: 10 cm of stems from base and soil
- Marjoram: 10 cm of stems from base and soil
- Alpine Strawberry: whole plant and soil
- Parsnip: whole plant and soil

Finally have decided implemented the sleep function in the Particle Photon to conserve energy when the artefact is not being interacted with, making the artefact suitable to be powered by a solar-powered battery pack: “use and store energy” and “Use and value renewable resources and services”.

# Appendix D – Codified Design Decisions

**Table D 1: : Codified design decisions for content analysis of reflective journal**

| Code | Week | Design Decision | Category | Weighting |
|---|---|---|---|---|
| PP8 | wk 1 | Plants as interface | Conceptual | 0.5 |
| PP11 | wk 1 | Plants as interface | Conceptual | 0.5 |
| PP3 | wk 1 | Provide knowledge | Conceptual | 1 |
| PP7 | wk 1 | Make system an interactive plant guild | Conceptual | 1 |
| SID2 | wk 1 | Use of modular hardware | Physical | 0.5 |
| PP4 | wk 1 | Use of modular hardware | Physical | 0.5 |
| PP1 | wk 2 | Using touch sensing on plants | Physical | 0.5 |
| UX1 | wk 2 | Using touch sensing on plants | Physical | 0.5 |
| UX2 | wk 3 | System will need to be waterproofed | Physical | 1 |
| UX2 | wk 3 | Multimedia screen required to output information | Digital | 1 |
| OTHER | wk 4 | Conductively isolated plants | Physical | 1 |
| PP12 | wk 4 | BLE Beacon to draw user attention | Physical | 1 |
| PP2 | wk 4 | Solar Powered BLE Beacon | Energy | 0.5 |
| PP5 | wk 4 | Solar Powered BLE Beacon | Energy | 0.5 |
| PP2 | wk 5 | User to use own mobile device | Physical | 0.25 |
| PP5 | wk 5 | User to use own mobile device | Physical | 0.25 |
| PP9 | wk 5 | User to use own mobile device | Physical | 0.25 |
| PP10 | wk 5 | User to use own mobile device | Physical | 0.25 |
| OTHER | wk 5 | Web application | Software | 1 |
| UX3 | wk 5 | Physical signage to direct user | Physical | 1 |
| UX3 | wk 5 | Dock to hold user device | Physical | 1 |
| UX3 | wk 5 | QR/NFC tag to direct user to web app | Physical | 0.5 |
| PP5 | wk 5 | QR/NFC tag to direct user to web app | Physical | 0.5 |
| UX3 | wk 5 | Icons to represent plants and layers | Digital | 0.5 |
| PP7 | wk 5 | Icons to represent plants and layers | Digital | 0.5 |
| PP3 | wk 5 | Provide edibles in plant guild | Physical | 1 |
| PP12 | wk 5 | Container to enable mobility | Physical | 0.5 |
| OTHER | wk 5 | Container to enable mobility | Physical | 0.5 |
| PP4 | wk 5 | Repurposed old items for dock and container | Physical | 0.5 |
| SID2 | wk 5 | Repurposed old items for dock and container | Physical | 0.5 |

| | | | | |
|---|---|---|---|---|
| PP1 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| PP2 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| PP4 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| PP9 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| SID2 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| SID4 | wk 5 | Particle Photon as the microcontroller | Physical | 0.1666667 |
| PP1 | wk 6 | Location of artefact within garden | Spatial | 1 |
| OTHER | wk 6 | Shaded area to allow screen use | Spatial | 1 |
| OTHER | wk 6 | Touch sensing breakout board (MPR121) | Physical | 1 |
| OTHER | wk 6 | Loading screen on web app | Digital | 1 |
| OTHER | wk 6 | Increased touch sensitivity | Physical | 0.5 |
| PP1 | wk 6 | Increased touch sensitivity | Physical | 0.5 |
| UX1 | wk 6 | High contrast colours in web app | Digital | 1 |
| OTHER | wk 6 | Use AJAX to update web app display | Digital | 1 |
| OTHER | wk 6 | Use Bootstrap for mobile-first web app | Digital | 1 |
| PP6 | wk 7 | EcoWire for wiring | Physical | 1 |
| PP2 | wk 7 | Not to use a servo motor in system | Physical | 0.5 |
| PP9 | wk 7 | Not to use a servo motor in system | Physical | 0.5 |
| PP7 | wk 7 | Graphic representing layers of guild | Digital | 1 |
| OTHER | wk 7 | IncreasedMPR121 current for improved sensitivity | Physical | 1 |
| OTHER | wk 8 | Rotate phone notification in web app | Digital | 1 |
| PP2 | wk 8 | Sleep mode to conserve energy | Energy | 0.5 |
| PP5 | wk 8 | Sleep mode to conserve energy | Energy | 0.5 |

# Appendix E – Interview Guide Questions

Participant No _______ Time spent ____________

How much time do you typically spend interacting with nature?

How much time do you think you spent interacting with the plant guild just now?

How did your experience of the interactive permaculture plant guild make you feel?

What did you like about it? Why?

Is there anything you disliked? Why?

What did you think of interacting physically with the plants to navigate the application?

Did you know anything about permaculture before today?

Do you know more about permaculture now you have interacted with the interactive plant guild? If so, what have you learned?

How has interacting with the plant guild affected your interest in how nature and natural ecologies work?

Has it affected how much time you will interact with nature in the future? How?

Would you use similar systems implemented in a garden or park near where you live?

Would it encourage you to spend more time interacting with nature?

In the future would you be interested in planting your own plant guild?

Do you think you could make your own?

Is there anything else you'd like to tell me?

# Appendix F – Participant Info & Consent Form

**Symbiosis of Digital and Environmental Artefacts in Blended Spaces Using Permaculture Design as a Framework**

My name is Nicholas Besagni and I am a postgraduate student from the School of Computing at Edinburgh Napier University. As part of my degree course, I am undertaking a research project for my Masters dissertation. The title of my project is: Symbiosis of Digital and Environmental Artefacts in Blended Spaces Using Permaculture Design as a Framework.

This study will explore using permaculture design philosophy in the design of an interactive system and in what ways it can contribute to designing more sustainable interactive systems. It will also seek to explore what such a system can achieve in terms of user engagement and enhancing interactions with nature.

I am looking for volunteers to participate in the project. There are no criteria (e.g. gender, age, or health) for being included or excluded – everyone is welcome to take part.

If you agree to participate in the study, you will be asked to interact with an interactive permaculture plant guild via physical interaction with the plants and a web application on a mobile device. There will then be a questionnaire and an interview where you will be asked questions to gain further insight into your experience with the interactive plant guild. The session will take place in the Lions Gate permaculture garden at the Merchiston Campus of Edinburgh Napier University. The researcher is not aware of any risks associated with this activity. The whole procedure should take no longer than 20 minutes. You will be free to withdraw from the study at any stage, you would not have to give a reason, and it will not affect your treatment (if applicable).

All data will be anonymised as much as possible, but you may be identifiable from tape recordings of your voice. Your name will be replaced with a participant number or a pseudonym, and it will not be possible for you to be identified in any reporting of the data gathered. All data collected will be kept in a secure place (stored on a pc that is password protected) to which only Nicholas Besagni has access. These will be kept till the end of the examination process, following which all data that could identify you will be destroyed.

The results may be published in a journal or presented at a conference.

If you would like to contact an independent person, who knows about this project but is not involved in it, you are welcome to contact Dr Michael Smyth.  His contact details are given below.

If you have read and understood this information sheet, any questions you had have been answered, and you would like to be a participant in the study, please now see the consent form.


**Contact Details**

| | | |
|---|---|---|
| Nicholas Besagni | Callum Egan | Dr Michael Smyth |
| Project Researcher | Project Supervisor | Independent Advisor |
| 40332469@live.napier.ac.uk | callum.egan@napier.ac.uk | m.smyth@napier.ac.uk |
| 07484825399 | 0131 455 2790 | 0131 455 2733 |

## Edinburgh Napier University Research Consent Form

Symbiosis of Digital and Environmental Artefacts In Blended Spaces Using Permaculture Design as a Framework

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to be a participant in the research project on the topic of using permaculture in interface design to be conducted by Nicholas Besagni who is a postgraduate student at Edinburgh Napier University.
2. The broad goal of this research study is to explore using permaculture design philosophy in the design of interactive systems. Specifically, I have been asked to interact with an interactive plant guild, complete a questionnaire and participate in an interview regarding the experience which should take no longer than twenty minutes to complete.
3. I have been told that my responses will be anonymised. My name will not be linked with the research materials, and I will not be identified or identifiable in any report subsequently produced by the researcher.
4. I also understand that if at any time during the session I feel unable or unwilling to continue, I am free to leave. That is, my participation in this study is completely voluntary, and I may withdraw from it without negative consequences. However, after data has been anonymised or after publication of results it will not be possible for my data to be removed as it would be untraceable at this point.
5. In addition, should I not wish to answer any particular question or questions, I am free to decline.
6. I have been given the opportunity to ask questions regarding the session and my questions have been answered to my satisfaction.
7. I have read and understand the above and consent to participate in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

Participant's Signature                                        Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

Researcher’s Signature Date

# Appendix G – Particle Photon Code

Particle Photon .ino code – Modified version of Adafruit Touch Sense Library (*Adafruit_MPR121*, 2014/2018)

```
// SYSTEM_THREAD(ENABLED);
// include modified version of MPR121 library
#include "Adafruit_MPR121_Edit.h"

Adafruit_MPR121 cap = Adafruit_MPR121();

// Keeps track of the last pins touched so we know when plants are 'released'
uint16_t lasttouched = 0;
uint16_t currtouched = 0;

// set page to home
 int currentitem = 12;

 // set wakeup pin as D2 - connected to IRQ (interrupt request) pin on MPR121
int wakeUpPin = D2;

void setup() {
    // declare function for sleep mode
    Particle.function("photonSleep",photonSleep);
    // serial for debugging
  Serial.begin(9600);

  while (!Serial) {
    delay(10);
  }
  // print to serial for debugging
  Serial.println("Testing Adafruit MPR121 Capacitive Touch sensor");
  // publish to web API
  Particle.variable("currentitem", &currentitem, INT);
  if (!cap.begin(0x5A)) {
    Serial.println("Adafruit MPR121 not found");
    while (1);
  }
  Serial.println("Adafruit MPR121 found");
}

void loop() {
  // Get the currently touched items
  currtouched = cap.touched();

  for (uint8_t i=0; i<12; i++) {
```

```
    // it if is touched and wasnt touched before
    if ((currtouched & _BV(i)) && !(lasttouched & _BV(i)) ) {
      Serial.println(i); Serial.println(" touched");
      currentitem = i;

      delay(2000);
    }
    // if it was touched and now isnt
    if (!(currtouched & _BV(i)) && (lasttouched & _BV(i)) ) {
      Serial.println(i); Serial.println(" released");
    }
  }

  // reset state
  lasttouched = currtouched;



  // put in a delay
  delay(10000);
}




// check for call to put wifi to sleep
int photonSleep(String command) {


    if  (command=="off") {
// sleep until touch sensed
System.sleep(wakeUpPin, CHANGE);
        return 1;
    }
    else {
        return 0;
    }
}
```

# Appendix H – Web Application HTML Code

## Code for: index.html

```html
<!DOCTYPE html>
<html lang="en">
  <head>
    <!-- Required meta tags -->
    <meta charset="utf-8">
    <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-
fit=no, maximum-scale=1.0, user-scalable=0">
      <meta name="apple-mobile-web-app-capable" content="yes">

      <meta HTTP-EQUIV="Pragma" CONTENT="no-cache">
<meta HTTP-EQUIV="Expires" CONTENT="-1">

    <!-- Bootstrap CSS -->
    <link rel="stylesheet"
href="https://stackpath.bootstrapcdn.com/bootstrap/4.1.0/css/bootstrap.min.css"
integrity="sha384-
9gVQ4dYFwwWSjIDZnLEWnxCjeSWFphJiwGPXr1jddIhOegiu1FwO5qRGvFXOdJZ4"
crossorigin="anonymous">
    <!-- Site CSS -->
    <link rel="stylesheet" href="css/site.css">
    <!-- Font Awesome icons -->
    <link rel="stylesheet"
href="https://use.fontawesome.com/releases/v5.1.0/css/all.css" integrity="sha384-
lKuwvrZot6UHsBSfcMvOkWwlCMgc0TaWr+30HWe3a4ltaBwTZhyTEggF5tJv8tbt"
crossorigin="anonymous">
    <!-- Morphext & Animate CSS -->
    <link rel="stylesheet"
href="https://cdnjs.cloudflare.com/ajax/libs/animate.css/3.5.2/animate.min.css">
    <link rel="stylesheet" href="css/morphext.css">

    <title>Permaculture Plant Guild</title>
  </head>
  <body>
      <div class="container-fluid h-100 w-100">


          <!-- Loading screen -->
          <div id="loading" class="h-100 w-100">
              <br>
              <i class="fas fa-circle-notch fa-spin display-1"></i><br>
              <strong><span class="display-4" id="loadingMessage">Welcome,Talking
to the plants....,They say 'hello'...</span></strong>
```

```
        </div>


        <!-- Tutorial screen -->

        <div class="hidden h-100 w-100" id="tutorial">

            <div class="h-100 tutorialGuildImage" id="tutorialGuild">
            <img src="images/tutorial_guild.gif" class="tutorial-img-fluid"
id="tutorialImage">
            </div>
            <div class="tutorialGuildText h-100" id="tutorialGuildText">
                <span id="tutorialText1"><strong>Permaculture</strong> is a
design philosophy that mimics natural ecosystems to create sustainable
combinations that benefit itself and us.
                </span>
                <span class="hidden" id="tutorialText2">A <strong>permaculture
guild</strong> is a harmonious assembly of components that are
<strong>beneficial</strong> to eachother, promoting health &amp; productivity.
                </span>
                <span class="hidden" id="tutorialText3">
                These components can be plants, funghi, animals or people and
make up the different <strong>layers</strong> of a guild. In a moment, interact
with the guild to find out how the plants benefit each other, and us.
                </span>

            </div>

        </div>


        <!-- Begin screen -->

        <div class="hidden h-100 w-100" id="begin">
            <span id="beginPointer"><i class="fas fa-leaf"></i><i class="far fa-
hand-point-left"></i></span><br>
            <span class="beginText">Touch a plant to begin</span><br>
            <strong><span id="beginHelpText"> , ,Nothing happening? Try touching
the soil instead,The plants may be a little too thirsty to talk... try watering
them!, </span></strong>
        <div class="guildImage w-100" id="guild">
            <img src="images/guild_white.gif" class="img-fluid">
            </div>
            <div class="guildLayerName w-50">
            <span>Forest Fruit Plant Guild</span>
            </div>
        </div>
```

```
            <!-- Plant info pages -->



            <!-- Tree Layer -->
            <div class="plantPage  h-100 w-100" id="page3">
                <div class="plantName">
                <span><strong>Gala Apple Tree</strong></span>
                </div>
                <div class="plantDetail plantDetailParent">
                    Benefits:<br>
                    + Gives shade to smaller plants within the guild. <br>
                    + When larger the tree will slow down rain, encouraging water to
infiltrate the soil.<br>
                    + Provides us with apples to eat; high in fibre, Vitamin C and
antioxidants.<br>

                <div class="plantDetail">
                              <br>
                    <br>
                    <br>
                </div>
                    </div>
                <div class="guildImage w-100" id="guildTree">
                <img src="images/guild_tree.gif" class="img-fluid">
                </div>
                <div class="guildLayerName w-50">
                <span><i class="fas fa-seedling fa-2x" id="seedlingTree"></i> Fruit
Tree Layer</span>
                </div>
            </div>



            <!-- Shrub Layer -->
            <div class="plantPage  h-100 w-100" id="page4">
                <div class="plantName">
                <span><strong>Baldwin Blackcurrant</strong></span>
                </div>
                <div class="plantDetail plantDetailParent">
                    Benefits:<br>
                    + Provide food and shelter to wildlife, promoting
biodiversity.<br>
                    + The nectar from their flowers attracts beneficial insects to
the guild.<br>
```

```
                    + Has edible berries that are very high in vitamins, minerals
and antioxidants.

                <div class="plantDetail">
                              <br>
                    <br>
                    <br>
                </div>
                    </div>
                <div class="guildImage w-100" id="guildShrub">
                <img src="images/guild_shrub.gif" class="img-fluid">
                </div>
                <div class="guildLayerName w-50">
                <span><i class="fas fa-seedling fa-2x" id="seedlingShrub"></i> Shrub
Layer</span>
                </div>
            </div>




            <!-- Herb Layer -->
            <div class="plantPage  h-100 w-100" id="page5">
                <div class="plantName">
                <span><strong>Marjoram</strong></span>
                </div>
                <div class="plantDetail plantDetailParent">
                    Benefits:<br>
                    + Has a strong scent which confuses pest insects' ability to
find host plants in the guild.<br>
                    + Its bright flowers attracts bees, butterflies &amp; other
beneficial insects.<br>
                    + Is a tasty herb for use in cooking. <br>
                    + Is also a medicinal herb &amp; can be used to provide relief
from colds.

                <div class="plantDetail">
                              <br>
                    <br>
                    <br>
                </div>
                    </div>
                <div class="guildImage w-100" id="guildHerb">
                <img src="images/guild_herb.gif" class="img-fluid">
                </div>
                <div class="guildLayerName w-50">
                <span><i class="fas fa-seedling fa-2x" id="seedlingHerb"></i>
Herbaceous Layer</span>
```

```
            </div>
        </div>





        <!-- Ground Layer -->
        <div class="plantPage  h-100 w-100" id="page6">
            <div class="plantName">
            <span><strong>Alpine Strawberry</strong></span>
            </div>
            <div class="plantDetail plantDetailParent">
                Benefits:<br>
                + Provides delicious, edible fruit, high in Vitamin C.<br>
                + Excellent for providing ground cover, creating a mat to
protect the base of taller-stemmed plants.<br>
                + Suppresses unwanted weeds and prevents the growth of
grass.<br>
                + Protects soil from erosion.<br>
                + Attracts animals that feed on the berries.

            <div class="plantDetail">
                          <br>
                <br>
                <br>
            </div>
                </div>
            <div class="guildImage w-100" id="guildGround">
            <img src="images/guild_ground.gif" class="img-fluid">
            </div>
            <div class="guildLayerName w-50">
            <span><i class="fas fa-seedling fa-2x" id="seedlingGround"></i>
Ground Cover Layer</span>
            </div>
        </div>



        <!-- Rhizosphere Layer -->
        <div class="plantPage  h-100 w-100" id="page7">
            <div class="plantName">
            <span><strong>White Gem Parsnip</strong></span>
            </div>
            <div class="plantDetail plantDetailParent">
                Benefits: <br>
                + Attracts wasps that lay eggs in the larvae of other pest
insects and feeds on them.<br>
```

```
                  + Their sap contains a toxin which deters herbivores, protecting
the guild.<br>
                  + Its roots are edible, containing high levels of minerals such
as calcium, potassium, manganese, magnesium, phosphorous, zinc, and iron.<br>
                  + Has a number of purported health and medicinal benefits for
people such as improving heart health.

              <div class="plantDetail">
                            <br>
                  <br>
                  <br>
              </div>
                  </div>
              <div class="guildImage w-100" id="guildRhizo">
              <img src="images/guild_rhizo.gif" class="img-fluid">
              </div>
              <div class="guildLayerName w-50">
              <span><i class="fas fa-seedling fa-2x" id="seedlingRhizo"></i>
Rhizosphere Layer</span>
              </div>
          </div>


          <!-- Quiz Mode -->

          <!-- Quiz ask -->
          <div class="w-100 h-100 hidden" id="quizStart">
          <span class="quizQuestion"><br><br>Now you have explored the guild,
would you like to test your knowledge?<br><br></span>
              <input type="button" id="startQuiz" class="btn btn-info"
value="Start quiz"  onclick="quizQ1()">   <input type="button"
id="stopQuiz" class="btn btn-danger" value="No thanks" onclick="resetPages()">

          </div>



          <div class="w-100 h-100" id="quizContainer">

              <!-- Quiz Q1 -->
              <div class="question w-100 font-weight-bold" id="question1">
                  Q: Which plant provides ground cover, creating a mat to protect
the base of taller plants? Touch the correct plant to answer.
              </div>
              <div class="answer" id="answer1">
                  <br>
                  A: <span class="hidden" id="q1a1">Arctic Strawberries</span>
                  <br>
              </div>
```

```
                <!-- Quiz Q2 -->
                <div class="question w-100 font-weight-bold hidden" id="question2">
                    Q: Which plant represents the herbacious layer of the plant
guild?


                </div>
                <div class="answer hidden" id="answer2">
                    <br>
                    A: <span class="hidden" id="q2a1">Marjoram</span>
                    <br>
                </div>

                <!-- Quiz Q3 -->
                <div class="question w-100 font-weight-bold hidden" id="question3">
                    Q: Which plants provide edible fruit, roots or leaves?


                </div>
                <div class="answer hidden" id="answer3">
                    A: <span class="hidden" id="q3a1">Gala Apple Tree</span>
                    <br>
                    A: <span class="hidden" id="q3a2">Blackberry Shrub</span>
                    <br>
                    A: <span class="hidden" id="q3a3">Marjoram</span>
                    <br>
                    A: <span class="hidden" id="q3a4">Arctic Strawberries</span>
                    <br>
                    A: <span class="hidden" id="q3a5">White Gem Parsnip</span>
                    <br>
                </div>




                <div class="quizFeedback">
                    <br>
                    <span id="incorrectAnswer" class="hidden btn btn-danger"><i
class="fas fa-times-circle"></i><br>
                    Try again</span>
                    <span id="correctAnswer" class="hidden btn btn-info"><i
class="fas fa-check-circle"></i><br>
                    Correct!</span>
                </div>

                <div class="guildImage w-100" id="guildQuiz">
                <img src="images/guild_white.gif" class="img-fluid">
```

```
                </div>
                <div class="guildLayerName w-50" id="quildQuizName">
                <span><input type="button" id="stopQuiz1" class="btn btn-secondary"
value="Exit"  onclick="resetPages()"></span>
                </div>




        </div>
            <div class="w-100 h-100 hidden" id="quizComplete">
            <span class="quizQuestion"><br><br>Thank you for interacting with the
permaculture plant guild!<br><br></span>
                <a href="https://permacultureapprentice.com/creating-a-food-forest-
step-by-step-guide/" class="btn btn-info btn-lg btn-block">Learn how to create
your own guild</a><br>
                <input type="button" id="stopQuiz2" class="btn btn-danger btn-lg
btn-block" value="Continue interacting with the guild"  onclick="resetPages()">

            </div>





        </div>

    <!-- jQuery first, then Popper.js, then Bootstrap JS -->
    <script
  src="https://code.jquery.com/jquery-3.3.1.js"
  integrity="sha256-2Kok7MbOyxpgUVvAk/HJ2jigOSYS2auK4Pfzbm7uH60="
  crossorigin="anonymous"></script>
    <script
src="https://cdnjs.cloudflare.com/ajax/libs/popper.js/1.14.0/umd/popper.min.js"
integrity="sha384-
cs/chFZiN24E4KMATLdqdvsezGxaGsi4hLGOzlXwp5UZB1LY//20VyM2taTB4QvJ"
crossorigin="anonymous"></script>
    <script
src="https://stackpath.bootstrapcdn.com/bootstrap/4.1.0/js/bootstrap.min.js"
integrity="sha384-
uefMccjFJAIv6A+rW+L4AHf99KvxDjWSu1z9VI8SKNVmz4sk7buKt/6v9KI65qnm"
crossorigin="anonymous"></script>
    <!-- Morphext JS -->
      <script src="js/morphext.js"></script>
    <!-- NoSleep JavaScript -->
    <script src="js/NoSleep.min.js"></script>
    <!-- PleaseRotate JavaScript -->
    <script src="js/pleaserotate.min.js"></script>
```

```
    <!-- Site JavaScript -->
    <script src="js/site.js"></script>
  </body>
</html>
```

# Appendix I – Web Application JavaScript Code

Code for: js/site.js

```
// Declare global variables with initial values
var currentPage = 0;
var loadingDone = 0;
var visitedPage3 = 0;
var visitedPage4 = 0;
var visitedPage5 = 0;
var visitedPage6 = 0;
var visitedPage7 = 0;
var quizStage = 0;
var q3a1 = 0;
var q3a2 = 0;
var q3a3 = 0;
var q3a4 = 0;
var q3a5 = 0;

// Replace Device ID and Access Token with those assigned to Particle Photon
Device
var photonDeviceID = "Device ID";
var photonAccessToken = "Access Token";


// Prevent mobile device from sleeping using NoSleep.js
var noSleep = new NoSleep();

function enableNoSleep() {
  noSleep.enable();
  document.removeEventListener('touchstart', enableNoSleep, false);
  document.removeEventListener('orientationchange', enableNoSleep, false);
}

// Enable wake lock.
document.addEventListener('touchstart', enableNoSleep, false);
window.addEventListener('orientationchange', enableNoSleep, false);


// Fetch current touched object
 $.ajax({
  url: "https://api.particle.io/v1/devices/" + photonDeviceID +
"/currentitem?access_token=" + photonAccessToken,

}).done(function(data) {
    currentPage = parseInt(JSON.stringify(data.result));
});
```

```
$.post("https://api.particle.io/v1/devices/" + photonDeviceID +
"/photonSleep?access_token=" + photonAccessToken,
    {
        photonSleep: "off"
    })


// Loading screen messages
$("#loadingMessage").Morphext({
    animation: "bounceIn",
    separator: ",",
    speed: 2000,
    complete: function () {
    }
});

// Make loading screen disappear
var loadingFadeOut = function() {
  $("#loading").fadeOut("slow").delay(1000);
    setTimeout(tutorialFadeIn, 1000);
};

setTimeout(loadingFadeOut, 5500);

// Tutorial page
var tutorialFadeIn = function() {
    $("#tutorial").addClass("animated fadeInDown");
    $("#tutorial").removeClass("hidden");
    setTimeout(tutorialTextChange1, 9000);
};

var tutorialTextChange1 = function() {
    $("#tutorialText1").fadeOut(250);
    $("#tutorialText2").delay(500).fadeIn(500);
    setTimeout(tutorialTextChange2, 9000);
};

var tutorialTextChange2 = function() {
    $("#tutorialText2").fadeOut(250);
    $("#tutorialText3").delay(500).fadeIn(500);
    $("#tutorialImage").delay(2000).attr('src','images/tutorial_guild2.gif').fadeI
n("slow");
    setTimeout(tutorialFadeOut, 9000);
};

var tutorialFadeOut = function() {
    $("#tutorial").removeClass("animated fadeInDown");
    $("#tutorial").fadeOut("slow");
```

```
    setTimeout(beginFadeIn, 1000);
};

// Begin screen appear
var beginFadeIn = function() {
  $("#begin").addClass("animated fadeInDown");
  $("#begin").removeClass("hidden");
    loadingDone = 1;
};

// Begin screen hand shake
var beginHandShake = function() {
    if($('#begin').is(':visible')){
    $('#beginPointer').removeClass().addClass('shake
animated').one('webkitAnimationEnd mozAnimationEnd MSAnimationEnd oanimationend
animationend', function(){
      $(this).removeClass();
    });
    }
  };

setInterval(beginHandShake, 8000);

// Begin screen help text
var beginHelpText = function() {
    $("#beginHelpText").Morphext({
    animation: "fadeIn",
    separator: ",",
    speed: 5000,
    complete: function () {

    }
});
};
setTimeout(beginHelpText, 33500);


// Plant Touched Page Refresh
function refreshPage() {
    // check user has seen begin page
    if (loadingDone === 1) {
        // AJAX call to see what has been touched
$.ajax({
  url: "https://api.particle.io/v1/devices/" + photonDeviceID +
"/currentitem?access_token=" + photonAccessToken,

}).done(function(data) {
    // Logic to control what page user sees
    var previousPage = currentPage;
```

```
    currentPage = parseInt(JSON.stringify(data.result));
    if (currentPage !== previousPage && currentPage !== 0 && quizStage === 0) {
        // change displayed div
        if($('#begin').is(':visible'))
        {
            $('#begin').fadeOut(500);
        }
        $("#page" + previousPage).fadeOut(500);
        $("#page" + currentPage).delay(250).fadeIn(500);
        // log plant as visited
        switch (currentPage) {
        case 3:
            visitedPage3 = 1;
            break;
        case 4:
            visitedPage4 = 1;
            break;
        case 5:
            visitedPage5 = 1;
            break;
        case 6:
            visitedPage6 = 1;
            break;
        case 7:
            visitedPage7 = 1;
            break;
        }
        // check if all pages visited, load quiz
        if (visitedPage3 === 1 && visitedPage4 === 1 && visitedPage5 === 1 &&
visitedPage6 === 1 && visitedPage7 === 1) {
            setTimeout(loadQuiz, 12000);
        }
    }
    // Quiz Question 1
    else if (currentPage !== previousPage && quizStage === 2) {
        if (currentPage === 6) {
            $("#correctAnswer").addClass("animated flipInX");
            $("#correctAnswer").removeClass("hidden");
            $("#q1a1").addClass("animated flipInX");
            $("#q1a1").removeClass("hidden");
            setTimeout(quizQ2, 3000);
        }
        else {
            $("#incorrectAnswer").addClass("animated flipInX");
            $("#incorrectAnswer").removeClass("hidden");
            setTimeout(function () {
                $('#incorrectAnswer').addClass('animated fadeOutUp');
                $('#incorrectAnswer').removeClass('flipInX');}, 3000
```

```
                );

        }
    }

        // Quiz Question 2
    else if (currentPage !== previousPage && quizStage === 3) {
        if (currentPage === 5) {
            $("#correctAnswer").addClass("animated flipInX");
            $("#correctAnswer").removeClass("hidden");
            $("#q2a1").addClass("animated flipInX");
            $("#q2a1").removeClass("hidden");
            setTimeout(quizQ3, 3000);
        }
        else {
            $("#incorrectAnswer").addClass("animated flipInX");
            $("#incorrectAnswer").removeClass("hidden");
            setTimeout(function () {
                $('#incorrectAnswer').addClass('animated fadeOutUp');
                $('#incorrectAnswer').removeClass('flipInX');}, 3000
                );

        }
    }

        // Quiz Question 3
    else if (currentPage !== previousPage && quizStage === 4) {
            $("#correctAnswer").addClass("animated flipInX");
            $("#correctAnswer").removeClass("hidden");

        switch (currentPage) {
            case 3:
            $("#q3a1").addClass("animated flipInX");
            $("#q3a1").removeClass("hidden");
                q3a1 = 1;
                break;
            case 4:
            $("#q3a2").addClass("animated flipInX");
            $("#q3a2").removeClass("hidden");
                q3a2 = 1;
                break;
            case 5:
            $("#q3a3").addClass("animated flipInX");
            $("#q3a3").removeClass("hidden");
                q3a3 = 1;
                break;
            case 6:
            $("#q3a4").addClass("animated flipInX");
```

```
            $("#q3a4").removeClass("hidden");
                q3a4 = 1;
                break;
            case 7:
            $("#q3a5").addClass("animated flipInX");
            $("#q3a5").removeClass("hidden");
                q3a5 = 1;
                break;
        }
        if (q3a1 + q3a2 + q3a3 + q3a4 + q3a5 === 5) {
        setTimeout(quizComplete, 3000);
        }
    }
});
    }
    else {
        return;
    }
}

setInterval(refreshPage, 500);

// Begin quiz

function loadQuiz() {
    quizStage = 1; // stops AJAX call refreshing page to that of plant touched
    $("#page" + currentPage).fadeOut(500);
    $("#quizStart").delay(600).fadeIn(500);
}

// Begin quiz buttons
$("#startQuiz").onclick = quizQ1;
$("#stopQuiz").onclick = resetPages;
$("#stopQuiz1").onclick = resetPages;
$("#stopQuiz2").onclick = resetPages;

function resetPages() {
    visitedPage3 = 0;
    visitedPage4 = 0;
    visitedPage5 = 0;
    visitedPage6 = 0;
    visitedPage7 = 0;
    quizStage = 0;
    $("#quizStart").fadeOut(500);
    $("#quizContainer").fadeOut(500);
    $("#page" + currentPage).delay(600).fadeIn(500);

}
```

```
// Quiz page transitions
function quizQ1() {
    quizStage = 2;
    $("#quizStart").fadeOut(500);
    $("#quizContainer").delay(600).fadeIn(500);
    $("#question1").removeClass("hidden");
    $("#answer1").removeClass("hidden");
}

function quizQ2() {
    quizStage = 3;
    $("#question1").fadeOut(500);
    $("#answer1").fadeOut(600);
    $("#question2").delay(500).fadeIn(500);
    $("#question2").removeClass("hidden");
    $("#answer2").delay(600).fadeIn(500);
    $("#answer2").removeClass("hidden");
    $('#correctAnswer').addClass('animated fadeOutUp');
    $('#correctAnswer').removeClass('flipInX');
}

function quizQ3() {
    quizStage = 4;
    $("#question2").fadeOut(500);
    $("#answer2").fadeOut(500);
    $("#question3").delay(500).fadeIn(500);
    $("#question3").removeClass("hidden");
    $("#answer3").delay(500).fadeIn(500);
    $("#answer3").removeClass("hidden");
    $('#correctAnswer').addClass('animated fadeOutUp');
    $('#correctAnswer').removeClass('flipInX');
}

function quizComplete() {
    quizStage = 5;
    $("#question3").fadeOut(500);
    $("#answer3").fadeOut(500);
    $("#quizContainer").fadeOut(500);
    $("#quizComplete").delay(500).fadeIn(500);
    $.post("https://api.particle.io/v1/devices/" + photonDeviceID +
"/photonSleep?access_token=" + photonAccessToken,
    {
        photonSleep: "on"
    })

}
```

# Appendix J – Web Application CSS Code

Code for: css/site.css

```
/* CSS Document */

/* Fonts */
@font-face {
font-family: "Helvetica";

src: url("fonts/Helvetica.eot");
    src: url("fonts/Helvetica.ttf") format('truetype'),
}

@font-face {
font-family: "Helvetica Bold";
src: url("fonts/HelveticaBold.ttf");
}

html, body {
    margin: 0;
    height: 100%;
    color: white;
}

body {
    background-color: green;
    text-align: center;
    font-family: Helvetica;
    font-size: 7vh;
}

container-fluid {
    margin: 0;
    height: 100%;
    overflow: auto;
}


h1 {
    font-size: 20vh;
}

    /* PleaseRotateStyling */
    #pleaserotate-graphic{
        fill: #fff;
```

```css
    }

    #pleaserotate-backdrop {
        color: #fff;
        background-color: #008000;
    }

#loading  {
    background-color: green;
}

/* Class to hide divs on load */
.hidden {
    display: none;
}

.tutorialGuildText {
    margin: 0;
    display: flex;
    align-items: center;
    font-size: 7vh;
    width: 70%;
}
.tutorialGuildImage {
    padding: 0;
    margin: 0;
    float: left;
    width: 30%;
}
.tutorial-img-fluid {
    width: 100%;
    max-height: auto;
    position: relative;
    top: 50%;
    transform: translateY(-50%);
}


#begin {
    padding-top: 3vh;
}
#beginPointer {
    font-size: 20vh;
    line-height: 20vh;
    display: block;
}

.beginText {
    font-size: 12vh;
```

```css
}

.beginHelpText {
    font-size: 10vh;
}

.plantPage {
    display: none;
}

.plantName {
    text-align: left;
    width: 100%;
    font-size: 15vh;
    line-height:15vh;
    padding-top: 5vh;
    padding-left: 5vh;
}
.plantDetail {
    width: 85%;
    text-align: left;
    float: right;
    font-size: 4vh;
    padding-left: 6vh;
}

.plantDetailParent {
    width: 100%;
}

.guildImage {
    position: fixed;
    bottom: 0;
    left: 0;
    margin: 0;
    text-align: left;
    display: flex;
    align-items: flex-end;
    background-repeat: repeat-x;
    background-size: auto 100%;
    z-index: -1;
}
#guild, #guildQuiz {
    background-image: url("../images/guild_bg.gif");
}
#guildTree {
    background-image: url("../images/guild_tree_bg.gif");
}
```

```css
#guildShrub {
    background-image: url("../images/guild_shrub_bg.gif");
}
#guildHerb {
    background-image: url("../images/guild_herb_bg.gif");
}
#guildGround {
    background-image: url("../images/guild_ground_bg.gif");
}
#guildRhizo {
    background-image: url("../images/guild_rhizo_bg.gif");
}

.guildLayerName {
    position: fixed;
    bottom: 0;
    right: 0;
    padding-bottom: 5vh;
    text-align: center;
    color: #ffffFF;
    align-items: flex-end;
    font-size: 7vh;
}

#quildQuizName {
    text-align: right;
}
#seedlingTree {
    color: #0000ff;
}
#seedlingShrub {
    color: #ff7f00;
}
#seedlingHerb {
    color: #4b0082;
}
#seedlingGround {
    color: #ff0000;
}
#seedlingRhizo {
    color: #ffff00;
}


#quizStart {

    vertical-align: middle;
}
```

```css
#stopQuiz{
    margin-left: 8vh;
}

#stopQuiz1 {
    margin-right: 3vh;
}

#quizContainer {
    display: none
}
.question {
    height: 35%;
    align-items: center;
    padding: 4vh;
    text-align: left;
}

.answer {
    height: auto;
    padding-left: 23vh;
    text-align: left;
    float: left;
    width: 65%;
    font-size: 6vh;
}

.quizFeedback {
    float:right;
    height: auto;
    width: 35%;
}

/* guild image size fix */
.img-fluid {
      max-height: auto;
      width: 50%;
    }
```