ABSTRACT
The Quantified Self refers to individuals that collect data about themselves to improve health, aspects of their life and finding new life experiences. Time tracking of activities is a common data-collection habit Quantified Selfers engage for improving aspects of their life, however, they struggle engaging and understanding their data due to ineffective tools for visualisation. Studies have identified that Physical Ambient Data Visualisations are effective for this, specially Data Sculptures, which are data embedded objects with functional and aesthetic qualities that allow awareness, engagement, exploration and data sense-making for a wide range of users. This thesis explores the experience of non-expert Quantified Selfers utilising Data Sculptures for awareness of their daily activities, their usage patterns and how they appropriate them. The Data Sculptures displayed information utilising light, colours and allowed exploration and comparison of data. A one-week In The Wild study was conducted in a household in London with two non-expert Quantified Selfers using two Data Sculptures and activity trackers for collection of time-based activities. The participants collected more than 60 hours of data, 50% productivity related, the Data Sculptures were integrated into the environment, utilised individually as daily decision taking and data awareness tools. Yet, participants preferred self-comparison of data and had opposite views regarding time-based data visualisation and more importantly, concerns regarding Data Sculptures’ appropriation, as they could become invasive in households.

Author Keywords
Quantified Self; Personal Informatics; Data Visualisation; Physicalisations; Data Sculptures; Tangible Interfaces.

ACM Classification Keywords
Design, Experimentation.

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Design, Empirical.

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1. INTRODUCTION

Nowadays, thanks to ubiquitous computing and online communication it is possible to collect and access information about almost any aspects of our lives and of our environment. Data can come from several sources, either published open data from organisations and governments, as well as from individuals direct sources like micro-controllers and sensors for collecting information about their immediate surroundings, personal activities and body performances. Thanks to the existence of growingly easier data collection methods and easier access to data, it has become frequent for users to engage in all sorts of personal data gathering behaviours. These type of users are often identified as Quantified Selfers [8], which define citizens that are aware, focused and familiarised with the collection of data about themselves, especially about their surroundings, bodies and daily activities. The reason and purpose for this behaviour relates to users wanting to learn about themselves, improving their health, productivity and more. Apart from health tracking, Quantified Selfers that were interested in improving aspects of their lives, engaged in collecting their use of time through time tracking apps or calendar logging. Quantified Selfers can range from casual to frequent users, from occasionally tracking one to several aspects of their lives in a frequent fashion. For visualising their data, Quantified Selfers adopt a wide range of tools, however most utilised techniques still rely on common software like Excel and common graphs [8].

Computers, smartphones, tablets, and several other screen-based displays have become the necessary and preferred medium for managing and visualising self-collected data as it can be accessed easily through the use of software and online services, providing powerful interactive tools for displaying and visualising organised information, as well as allowing to control and compare large amounts of information at once by the use of structured and hierarchical visual cues for quantitative data [2,5]. Common tools can be graphs, diagrams, tables and several others that have become familiarised strategies for data visualisation [8]. However, because these types of common strategies still remain dependent of screen-based devices, obliges users to mediate with these types of devices in order to make sense and engage with their data [21], as well as requiring a certain level of knowledge and skill for managing data that it is not trivial for a wide range of user [17,60]. Therefore it has been identified that there is a limitation in how to access to data and how to understand it, which still demands a fairly amount of effort from the user that in consequence reduces engagement and data sense making [17]. It is not uncommon that users -especially non-expert users- after collecting data, become weary of this activity as it grew tedious and less meaningful for taking full potential of its benefits.

The raised concerns regarding this limitation in information visualisation can be explained through the economic model by Van Wijk [21,57] which identify the costs it involves, being in top level the monetary costs, followed by the perceptual, time and effort from the user. Therefore, academic work regarding information visualisation and Human Data Interaction has been focused into reducing this problematic by developing tools for the democratisation of data sense making and access through the use of novel interfaces that allow users to interact and visualise data in a way that potentially can become more engaging, less demanding and comprehensible [17]. Regarding this subject, among major opportunities identified in Human Data Interaction research is physical data visualisation and data embodiment [40,60] for better sense making and engagement of people utilising their collected data.

The reason on why physical data visualisation is important relates to research on Tangible User Interfaces (TUI) [19] and Ambient Information Systems [44]. TUI are interfaces that allow transferring the digital experience from screen-based interactions towards devices that allow richer and wider types of interactions through physical affordances, letting users to interact physically with devices in a humanly inherent and accessible way to manipulate and comprehend them, therefore contributing to more engaging, expressive and meaningful possibilities of interaction [19,21]. Additionally, because TUI afford a wider range of form factors, they possess the advantage of becoming embedded into the user’s ambient and architecture without causing a dramatic disruption of the user’s surroundings while allowing a permanent awareness and access to its interactive controls and displays [17,21].

On the other hand, work related to Ambient Information Systems focus on the research and design of information systems that are integrated into the environment of users while making them aware of data that, although not being critical for their work and life, is important for their wellbeing and general awareness. In addition, Physicalisations [23] and Data Sculptures [60] are among other existing works that have emerged in the same subject of physical data visualisation, which demonstrate that there is still not a unified concept, yet they share similar aspects regarding tangible interfaces and metaphors for data embodiment.

Investigation in physical data visualisation has provided researchers the opportunity to experiment with a wide range of possible materials and form factors, from light, water, sound, to interactive architecture, however, in spite of this body of work, there is still significant research required to identify what the benefits are for utilising Physical Visualisations in the future [21], more specifically, to addressing the needs of the Quantified Self, and investigating its possible uses in data awareness, exploration, understanding and appropriation on wider audiences [23].

In this direction, previous research regarding the Physikit [17] has provided the methodological ground for this thesis,
conducting a field study with technology probes [18] for gathering insights about use, experiences and appropriation of Physical Ambient Visualisations in households of smart citizen’s data users. Therefore, this thesis focuses through a similar methodology into understanding awareness, use and appropriation of a Data Sculpture designed for the visualisation of time-based activities, as it is the most frequent habit that Quantified Selfers engage when self-tracking for life improvement [8]. A Data Sculpture was designed as a Data Lamp, leveraging the use of light and colour for displaying information in the environment, as in the Physikit project, light was the most utilised method for mapping data [17]. In addition, the Data Lamp displays time-based information from a manual activity tracker built specially for the study, as it can promote a closer relationship with data and its prior visualisation [8].

By integrating the HCI, Natural Sciences and Design Triangulation [33], the thesis divides itself into three parts: The first one is the building of a theoretical background about Quantified Selfers habits, Data embodiment and interactivity based in proximity sensing [36]; the second part is the application and integration of this theoretical background into the designing of a technology probe with the purpose to be tested in a real life setting; finally, the third part involves an empirical study, which is a deployment of the technology probe during a week in a household in London with the purpose of collecting quantitative and qualitative data about patterns of usage, experiences, how data is perceived, manipulated, shared, compared and how the device is appropriated by the household’s members.

In conclusion, this study demonstrates and reflects upon the possible uses of a Physical Ambient Data Visualisation technology, as well as the opportunities and challenges in awareness, engagement and appropriation that can arise from its use.

2. LITERATURE REVIEW

The Quantified Self

Personal Informatics

The habit of self-collecting data is not new, long time ago when no digital technology existed, the use of written diaries for self tracking behaviours and activities was one of the common strategies for this [30]. The habit of Self-monitoring started back in 1970 within the area of research in behavioural psychology, as a mean of assessing and treating therapy patients through a self-tracking and self-reflection process with the help of clinicians in between [8,27,26]. Upon the advent of digital technology, data collection methods have evolved and become more sophisticated and precise. Research has been focused in understanding the meaning and purposes of self-tracking behaviours and how does technology enhance and modify them, as well as mapping and guiding the further advances in this subject. In and out of academic research, there are many names that define this activity: Self-tracking, Self-surveillance, Quantified Self, Personal Analytics, Self-monitoring and several others, however it is mostly known in academic research as Personal Informatics [28].

Personal Informatics come from the perspective of technologies mediating the action of self-collecting data, defining these technologies as systems that help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge [28]. According to academics, Personal Informatics allow users to be aware of their data with concrete information while not depending on the process of self-reflection -because people’s memory is fragile- it offers the possibility of continuously collecting information that can either be difficult to gather or there is not enough time for doing it. Additionally, these technologies provide users, especially non-expert users, to explore and interpret data more effectively.

Quantified Self

On the other hand, the concept Quantified Self does not come from the realm of academic research and it is interesting because it’s source is a Silicon Valley community of users and technology enthusiasts that practice self-monitoring as a way of life, sharing their experiences and struggles online and offline. The founder of the Quantified Self community invites users to reflect about the purpose of personal data collection as an outward way of sharing information that involves self-awareness, self-improvement, self-discovery and self-knowledge, being self-knowledge the core action for the self, which in his words, relates to the operation centre of people’s bodies and moral compass. As he states, if people want to act more effectively to the world around them, they should know themselves better [59].

The individuals belonging to this community are an example of highly engaged Quantified Self users that continuously collect information about their everyday activities and body performances with the help of novel technologies and low-cost sensors for monitoring.

This community is an open demonstration on how new technologies are allowing enthusiasts to engage in the Quantified Self practice, testing theories through personal experiences. The Q-self community provides information on a blog and forums, sharing discussions, talks by the founders and more importantly organising meet-ups to comment and reflect about practices and experiences. This information has been helpful for academic research to understand upcoming issues from an empirical source, this is the example of the work of Choe et al. [8], which conducted a qualitative and quantitative analysis of 52 video recordings of the community’s meet-ups, finding patterns of use, types of data gathered, how they learned and the common barriers in the activity. Some of their findings are mentioned in the next sections.
Common practices and problems

Academic research has identified common practices and issues regarding personal data collection. For instance, the work of Rooksby et al. [46] on personal tracking for health, the survey of Americans’ self-tracking practices [13], Li et al. [28] stage-based model for personal data tracking, which identified several barriers that users have to address, as well as Choe et al. [8] work on Quantified Selfers’ frequent practices and problems inside this community. All the relevant habits and barriers are discussed in the next sections.

(i) Motivations

Rooksby et al. [46] identified five core types of tracking behaviours in users: Directive Tracking (Goal driven), Documentary Tracking (Documenting activities instead of changing them), Diagnostic Tracking (linking one thing to another), Collecting Rewards (Scoring point or unlocking achievement in tracking apps) and Fetishized Tracking (Pure interest in gadgets and technology). According to Fox and Dungan [13,31] a 70% of users engaged in data collection of well being and health did so, either for themselves or a loved one, being weight, diet or exercise routines the most frequently monitored. In Li et al. study [28], the most relevant categories of information to collect by their participants were finance, journaling, exercise, and general health. The reasons referred to natural curiosity, personal interest in data, discovering new tools, suggestions from a peer and trigger events. Additionally, Choe et al. [8] stated that most Quantified Selfers engaged in this habit for improving health, aspects of their lives to improve or to find new life experiences. Regarding health, some Quantified Selfers stated that they could even treat or cure health problems thanks to their collected data. On aspects of life to improve, mainly users collected their use of time (time tracking, life logging), cognitive performance (mind tests) and time spent in front of a computer (time tracking, productivity tracking software, calendar logging). On new experiences, they did not have a goal in mind, just to find patterns and common themes in the data collected. Among most popular items that Quantified Selfers reported tracking were Activity (40%), food (31%), weight (29%), sleep (25%), and mood (13%).

(ii) Data collection methods

There are two main ways to collect data, automatic or manually, also hybrid methods that combine both ways. By automatic it can either be through the use of a sensing technology like fitness wristbands, pedometers and tracking apps for smartphones and desktop. It can also be bills, bank statements, email history, phone call history and several other types of automatically collected information. By manually collected data, among most popular ones were calendar events, status updates (social networks), work activities, blog posts and several other types ranging from pictures to journals and diaries [28]. The potential of manually collected data refers to tracking a larger number of activities and data that it is not possible to gather otherwise (pain, sleep quality). In the case of Quantified Selfers that manually tracked data, they stated they felt awareness and connection with the gathered data (“intimacy with data”). It seems that people sense data not only when they are visualising it, also they feel it and understand it while collecting it [8].

(iii) Data exploration tools

Spreadsheet software like Excel is among the most common tools for data exploration and visualisation, allowing inputting data and visualising it through charts. Line and bar charts were among the most popular ways of visualising data [8]. In general, users engage in some kind of data input in these kinds of software and customise how they want to visualise it [28]. Other examples of data exploration and visualisation referred to the use of web applications that allowed mapping data in charts, such as apps from activity tracking systems like the Fitbit and others available in the market. Additionally, if users do not want to use Excel, they can input their data into web applications that offer a wide range of charts and maps to visualise it.

In case of more expert users, they referred to constructing their own types of visualisations through coding, however the visualising methods still utilised common types of charts and graphs. Other cases utilised physical or digital calendars and in rare and special cases users commented utilising novel methods, like a physical light for real-time feedback visualisation [8].

(iv) Barriers

There are several issues identified in data exploration and visualisation, mainly involving problems with insufficient skills from the users and lack of proper tools to plot data that undermine user’s motivation. The reason why it is necessary to overcome these challenges can be explained through Van Wijk economic model for information visualisation [57], which identifies that there are several costs involved, being the monetary cost the most important one, followed by perceptual cost, time and effort per user.

Most common barriers for Quantified Selfers in collection and interpretation of data referred to lack of time; motivation; unsuitable visualisation and tools for analytics; insufficient skills and knowledge to understand data; and fragmentation of data through multiple platforms [8]. Similarly, the main problem identified by Li et al. [28] related to lack of time, seconded by visualisation. Barriers within the integration and reflection stage, suggest a problematic with the available tools for exploration and visualisation in relation to organisation and transcription of data to exploration platforms. Moreover, data that has been gathered from different sources could lead to scattered visualisations. As well, other reasons relate to the interpretation of data as a consequence of not utilising the proper tools to effectively manage and explore data.
The outcomes of these issues can lead to simplification of the tracking process for an easier way to handle analysis as it has been identified that the learning curve for data manipulation and selecting an appropriate visualisation was steep [8].

However, it is necessary to mention that TUI cannot be as versatile and malleable as screen-based systems [50]. Therefore TUI does not replace previously existing systems, yet they can become expressive tools for concrete tasks, or for exploration in hybrid tangible and graphical interfaces [50]. Moreover, they can become part of the architecture, which is mostly known as Ambient Displays [58]; systems that provide access to controls, actions and information in the environment, at the periphery of the user’s attention [35].

**Data embodiment**

Human Data Interaction explores the need of humans to be at the centre and control of their data collection, analysis, interpretation and share, being visualisation and sense making the first of five holistic challenges to address. One of its focuses for solving this challenge is utilising data embodiment as a solution for data visualisation [4,11,15,40] as they are powerful tools for external cognition, which is a core cognitive process involved in sense making through the use of external representations in the real world [11,22,25]. It is known that graphical interfaces are effective as external representations [49], yet these involve few senses, mainly vision and sound, limiting the possibilities to explore, engage and understand. In contrast, physical representations allow a whole range of modes and possibilities for visual representations, like the use of spatial arrangements, objects and its affordances for exploration and leveraging natural and expressive interactions with data [22].

**Physical visualisation and ambient information systems**

The problematic and barriers discussed before are related to an active research area for the Information Visualisation community which one of its main challenges is helping the general public to effectively explore and understand their data utilising meaningful visualisations [8,21,60]. There are several approaches to these issues, and certainly there is not a solution that solves it all, infographics, digital tools for data visualisation and a whole classification of methods for data sense-making and interaction have been researched for this challenge.

However, for the purpose of this thesis, research is focused in the use of physical representations for visualisation and exploration of data as they benefit external cognition through the perception and use of external representations, leveraging natural interactions for a wider set of users [11,21,23]. In the next sections relevant literature around Tangible User Interfaces (TUI) [19], embodiment in Human Data Interaction (HDI) [4,11,40], Physicalisations [21], Ambient Information Systems [44] and the use of proximity sensing [20,36] as methods for allowing interactivity in physical data visualisation are discussed.

**Tangible interfaces**

Tangible User Interfaces (TUI) are alternative solutions to graphical user interfaces by introducing manipulation of physical artifacts and its affordances for input and exploration of digital tasks [19]. The potential of TUI is related to the possibility of introducing an ample range of gestures for interactivity that leverage inherently learned human skills like manipulation and arrangement of objects, which are some rough examples of habits that human beings start to learn in early stages of life.
that the field is just emerging and there is still little research regarding the challenges of Physicalisations, needing more work focused in Physicalisations’ future possible applications, data displaying capabilities, interactivity, and evaluation methods.

**Data sculptures**

In a similar way, Data sculptures become physical data visualisation objects focused to open the possibilities of sense making and engagement to a wider audience to explore and analyse data [60]. For accomplishing its purposes, Data Sculptures become information-oriented physical objects that possess an aesthetic and functional quality, standing in a middle ground between Tangible User Interfaces, Information Visualisation and Visual Arts by physically representing abstract information that can be perceived or manipulated for exploration and reflection.

Besides function, the importance of aesthetics in HCI concerns its proficiency to enhance usability and user experience [38,43,56]. However, in the field of information visualisation, it is still needed to understand to what extent aesthetics influence insights, therefore, Data Sculptures become important tools for addressing this challenge as well [7,60]. Closely related, the work by Zhao and Moere centres in two important factors that determine a Data Sculpture’s embodiment, defined by the distance of the embodiment metaphor from data and/or reality [60], thus this model is an important contribution for the decision of Data Sculptures’ form factors and purpose.

Regarding design, multiple examples of Data Sculptures exist, from the art world to HCI, utilising different materiality, static, interactive, embedded in the architecture, mobile, for work, creativity or leisure. One interesting example is the FizViz [52] a Data Sculpture for visualising web analytics in the office. In visualisation of self-tracked activities, the SweatAtoms [24] and the Activity Sculptures [53] allow users to explore and visualise their physical activity in 3D printed sculptures. Lastly, Jansen et al. is continually covering an updated timeline of Physical Visualisations and Data Sculptures since the first artifact made by man, towards the newest of our times [10].

**Ambient information systems / Screen-based and Physical**

Similar to the definition of Ambient Displays, according to Wisneski et al. [58], Ambient Information Systems are digital platforms that become part of the environment of users, displaying information available at the periphery of their attention while notifying non-crucial information yet important for the tasks or goals needed.

Ambient Information Systems are closely related but parallel to TUI [17]. The core essence of Ambient Information Systems is to become discrete devices deployed into the environment [44], however these depend on purpose and design dimensions, which in the outcome they can become screen-based devices if several data points are needed to be displayed. Matthews et al. and McRickard et al. introduced design dimensions for the development Ambient Information Systems, however not focusing into data representation [37,39]. Therefore the work by Pousman and Stasko [44] is relevant, which extends previous dimensions towards how systems make the user aware of data, how many data points portrays (from one to several), how and where they are deployed and how form factors are related or not to the representation of data. This approach allows focusing into data representation, flexibility and aesthetics in a simplified and straightforward method for designing Ambient Information Systems.

Pousman and Stasko defined four design dimensions and identifying four major design patterns: Symbolic Sculptural Display (a sculptural or decorative and few pieces of information), Multiple-Information Consolidators (mainly screen-based and portrays several pieces of information), Information Monitor Display (displays a peripheral aspect of a computer desktop), and High Throughput Textual Display (use of simple text and graphics for communicating information). The latter suggest that A Symbolic Sculptural Display would offer an appropriate blending between embodiment of data and Ambient Information Systems, allowing a wide range of form factors and possibilities of interaction.

**Opportunities in Physicalisations: Proximity Sensing**

One of the core challenges in Physicalisations is introducing interactive methods that can help exploring and understanding data. Most Physicalisations are static representations of data, although with the advent of sensing, actuation and digital prototyping tools, there has been a growing interest into developing Physicalisations that can become dynamic. The potential of dynamic Physicalisations relates to the possibilities of blending physical interaction and synthetic interaction (through computing), to support re-configurability of data upon interaction [23].

Certainly, the list of possible interactions with dynamic Physicalisations is large, however, the author’s interest is focused towards proximity sensing technologies, since it can leverage natural tangible and proxemic interactions beneficial for transferring information between devices. One example is Kray’s group project [36], which explored the relationship between smartphones transferring data upon a certain region, resulting in effective and intuitive actions, although there are still problems related to users not knowing which of the devices is communicating with another, invisibility of the data that is being transferred and what other methods can be effective for transferring data [36]. Another example is Jakobsen et al. research [20], which explored a taxonomy of proxemics for visualisation of information, yet its contribution was focused in screen-based systems and not Physical Visualisations, leaving space for research regarding the use of proxemics or proximity sensing as methods of interaction for data Physicalisations.
3. MAIN CONTENT

Aims and objectives

The previous literature outlines the problematic and opportunities in Personal Informatics and the Quantified Self, as well as the advantages of making data tangible, interactive and situated in the environment for enhancing data awareness and engagement for expert and novice users.

However, as it is stated in Jansen et al. [23], this is an emerging field of research and there is still much necessary investigation in relation to how could these technologies be utilised, their context of use, how they could enhance awareness and understanding and what are the social implications. There has been important investigation regarding implementation of Physical Ambient Data Visualisations in several perspectives and applications, although there is not yet design research that focuses specifically into the Quantified Self.

This thesis leverages this opportunity to understand how Physical Ambient Data Visualisations allow awareness, use and understanding of self-collected data, specifically for non-expert users. The development of a light-based prototype and its prior field study looks towards the advantages of interactive objects for the visualisation and exploration of time-based activities within the user’s environment. The goal is to allow users a constant awareness of their data that can invite them to explore and utilise it the way they consider it is convenient for them.

In the following sections the author will outline and justify the methods selected for the study.

Selected methods

For HCI, the deductive and inductive approaches are equally important and necessary, however due to the multidisciplinary characteristics of HCI design research, it cannot be treated as a natural science and thus both models are not enough to address its complex characteristics. An HCI design project is different in regard to how it develops knowledge within an iterative process that focuses on designing artifacts and people’s interactions with them.

For addressing this problematic, theHCI, Natural Science and Design Framework [33] is an approach that allows adapting research to the need of the author through the triangulation of HCI theory, design and observation. This allows to develop a theoretical background of a design projects, based on relevant HCI literature, the application of theory into an artifact and the testing of the artifact with users, within an iterative process that goes further into those three perspectives.

For this thesis, the mentioned framework is the core of the study process, which utilises HCI literature as a background for the designing of a Technology Probe [18] to be utilised and tested In The Wild [45] by real users in a real environment, with the purpose to gather insights and recommendations. The process can be seen in Figure 3.

Technology probe study in the wild

In a similar multidisciplinary direction as Mackay and Fayard [33], Technology Probes are prototype designs to be studied in relation to three perspectives: Social Sciences, Engineering and Design [18].

Technology Probes are introduced at early stages of a design process to be utilised by its target users in a real world setting for gathering insights about usage patterns, field testing the technology and gather recommendations for prior stages of the design or eliciting design ideas.

For a field study, Technology Probes need to encourage the relevant interactions that are meant to be studied, these should be flexible and open-ended in order to promote use and creativity from participants, usability can be exploratory as it is not the main goal or can be used to provoke reactions. Lastly and more importantly, these devices should log the user’s actions for prior quantitative analysis [18]. Moreover, it is necessary to mention that there is always risk in the deployment of probes as they can fail or bring unexpected results, therefore it is responsibility of the researcher to be aware, in contact and available during the study if anything fails.

For the purpose of this thesis, Technology Probes are built for the quantitative and qualitative analysis of the participants interactions to collect patterns, insights and recommendations. Quantitative data is gathered through the use of the Technology Probe and the qualitative data is gathered first through semi-structured interviews, a diary study and a participative design workshop.
The process of prototyping these technology probes is commented in the next section.

**Prototyping: digital fabrication and microcontrollers**

A prototype is a physical representation of a design or interactive system [1], a concrete tangible representation meant to be reflected on, analysed, observed or utilised, to help refining the system towards its finalised version. Fidelity in prototypes vary depending on the purpose of what they want to communicate and evaluate, these either can be offline (paper mock-ups, sketches) or online (prototypes utilising software, a computer or a microcontroller). The trade-off between offline and online is that offline prototypes are cheap, encourages more ideas (easily disposable, designers do not get attached with their ideas) and can be created by different types of people, not only researchers and programmers. Online prototypes are set in between the ideation stage and the concrete design and are necessary for evaluating more complex, interactive objects, yet they slow down the process of design significantly as they take more time and specific skills to build, as well as being much more expensive.

However, thanks to digital fabrication and the use of microcontrollers, the costs and times of building online prototypes have dropped dramatically. Thanks to 3D printing, Laser cutters and the programming of powerful microcontrollers and sensors has allowed flexibility in the use of materials, shapes, interactivity, thus reducing times and costs of development [14,23,54]. This has helped for instance, research labs, which could take them several months and a large budget for building a complex and powerful prototype to test.

Because the thesis’s study required building an online, interactive prototype to be deployed in a real world setting, the use of microcontrollers and digital fabrication was crucial.

**Semi-structured interviews**

Interviewing are necessary tools in HCI for gathering insights and needs from users. For the purpose of this study, a semi-structured interview was utilised at the beginning for gathering insights about previous experiences regarding the Quantified self and at the end to gather reflections about the Technology probe deployment.

The interviewing methods utilised were critical incident technique [12,34] and a post-experience interview [34,51]. The first is a technique to gather deep insights about previous knowledge in the subject and the latter for gathering reflections and learning regarding the experience.

**Diary study**

A diary study is a method utilised in HCI for understanding a participant’s behaviour regarding a situation, subject or artifact. Usually diary studies require for participants to answer a set of predefined questions that allow providing valuable feedback for the purpose of a project [6]. On other occasions participants are required to provide recorded feedback that can be utilised for prior discussions. Either way, some of the most usual problems with diary studies are that users often are not willing to write or perform the required feedback method because it requires more effort and usually can take them out from the main task [6].

Regarding this problematic, this study’s participants were given the option to provide feedback through daily interviews structured as a diary study questions, which they preferred in contrast to writing everyday, as they commented that would be better for them, less tiring and more concrete. From the author’s perspective, this was a good opportunity for as well conducting quick contextual inquiries [16] to gather further data about their experiences with the technology probes.

**Participatory design**

The traditional approach to designing a new technology or product sets the researcher (or designer) to interpret users needs for the creation of user requirements in the design process. Issues in this approach relate to it being one-directional (from researcher to user) and the inherent struggle to interpret persons coming from other cultural or professional backgrounds [41].

Some of the contributions to solving this problematic refer to participatory design [41] or co-creation [48], which are approaches focused to change the design perspective towards a two-directional one, this means designing with the user to allow new relationships and understandings in the creative process. Participatory design can be focused to critique the present, reflect about the future or for implementations. It is increasingly becoming adopted in HCI thanks to its benefits for engaging all the stakeholders involved in the design process, while combining and developing new applicable ideas emerging from this collaborative action [41].

For this study, Sanders et al. framework of participatory design [47] was utilised for the organisation of a mock-up and prototyping workshop as a closing session to gather insights and generating design ideas for the future. Participants coming from their previous experience and learning throughout the study, created an ideal design of their own, presented it and discussed it.
Technology probe design

For this thesis focus, a Technology Probe is built for the collection of participant’s usage patterns, insights and further design recommendations. The probe is going to be deployed and in contact with users in a real world setting during a particular amount of time.

The probe is designed as a flexible and open interpretation Data Sculpture for eliciting discussion and allowing users to decide, collect and map the time-based activities they want.

In addition, this artifact lets participants to be aware, visualise and explore data through manipulation and place it wherever it is better for them.

The following sections explain its construction based on the theoretical background and further relevant design decisions.

Data Lamps

The Data Sculpture works as a conceptual Data Lamp to be utilised indoor, it can be deployed inside a household or within a working environment depending on what purpose users want to give to it. Like a lamp, it utilises light, however in this case it is utilised along with colour for mapping and differentiating time-based data on three stripes along the surface of the Data Lamp, representing daily, monthly and yearly activities. The lamp displays the data from a manual activity tracker that works as a time logger for users to collect and input time-based data of up to five activities. In the lamp, each activity is related to a different colour and it is up to the user to decide to what colour the activities they should be mapped.

Apart from its functional and aesthetic qualities, its interactive qualities proceed from its form factors by how the lights are displayed along its affordances for allowing manual data exploration. Additionally, while the user is not explicitly utilising the lamp, it becomes discrete, lowering its light intensity while still displaying the data in the environment. Finally, for encouraging collective visualisation, that means, while utilising two different lamps with different types of data from two different users, the lamps detect each other on proximity, triggering an alternative mode of data visualisation that promotes exploration and comparison between two datasets.

In the next sections the author will explain the relevant theoretical background applied to the Data Lamp.

Quantified self

The Data Lamp utilise a manual activity tracker as time-based data input, storing a timestamp log of use and the total minutes of each activity collected. As opposed to automatic trackers, manual collection of data is utilised by Quantified Selfers as a method to become more involved and aware of the habit, as well as for having the flexibility to collect any kind of time-based data [8]. Time-based data from daily activities, were among the most utilised ways of collection from Quantified Selfers [8], therefore for this study, the author provided participants the opportunity to engage in this mode of self-collection of data to understand its use and the positives and negatives of this method in regard to Physical Ambient Data Visualisation.

The activity trackers are composed by a button and a knob, utilised for changing the state of the button into five different buttons, allowing participants to track up to five different activities. For collecting data, it was designed to work as simple as a stopwatch. The participant presses the button, a light is turned on for feedback and starts collecting the minutes of that activity, when the participant does not want to collect more of that activity, presses the button again and it stops collecting. The data is transferred wireless when the tracker is in range and on.
Embodiment model

The embodiment model of the Data Sculpture is a third perspective regarding interaction to the Physical visualisation, therefore the author added a model to understand how its interaction is not addressed and it is also important regarding how the Data Sculpture raises a functional and aesthetic quality, however the perceived like this abstract lampshade could raise notoriety as a decorative object and familiarity. It is important to comment that illumination in households support a wide variety of form factors and hence the shape in a metaphor of an abstract lampshade could raise notoriety as a decorative object and familiarity. It is known that Moere [60] that abstraction was utilised for portraying data and its form factors to elicit a real world decorative object to raise familiarity and appropriation in the participant’s household. It is known that illumination in households support a wide variety of form factors and hence the shape in a metaphor of an abstract lampshade could raise notoriety as a decorative object and familiarity. It is important to comment that although this is the purpose, aesthetics are very subjective and depend on participant’s reactions to understand if it is perceived like this [44,60]. According to the model, Data Sculptures raise a functional and aesthetic quality, however the interaction is not addressed and it is also important regarding how it makes users aware of data through interaction and discovery. Therefore the author added a third perspective regarding interaction to the Data Sculpture embodiment model present in Table 1.

### Table 1. Data embodiment model.

<table>
<thead>
<tr>
<th>Functional qualities</th>
<th>Interactive qualities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness and exploration of manually collected time-based activities.</td>
<td>Form factors that could be inserted in a common household as a decorative object that could become part of the environment. Provide users with cues for exploration and comparison of data.</td>
</tr>
</tbody>
</table>

### Physical visualisation

For the construction of the Physical Visualisation, Zhao and Moere model was utilised for the embodiment of the data [60]. The intention was developing a “far from data and close to reality” embodiment, this means abstraction was utilised for portraying data and its form factors to elicit a real world decorative object to raise familiarity and appropriation in the participant’s household. It is known that illumination in households support a wide variety of form factors and hence the shape in a metaphor of an abstract lampshade could raise notoriety as a decorative object and familiarity. It is important to comment that although this is the purpose, aesthetics are very subjective and depend on participant’s reactions to understand if it is perceived like this [44,60]. According to the model, Data Sculptures raise a functional and aesthetic quality, however the interaction is not addressed and it is also important regarding how it makes users aware of data through interaction and discovery. Therefore the author added a third perspective regarding interaction to the Data Sculpture embodiment model present in Table 1.

The interactive quality influences the embodiment of the Data Lamp to allow its form factors to become part of the exploration of the data. In this case, the lights along its surface are displayed in a way that should encourage manual exploration of data, as seen on Figure 6. Lastly, comparison of data between two lamps is enabled by proximity sensing and manual interaction, which also influences form factors to allow these interactions to occur.

These interactive qualities will be discussed in the proximity sensing section.

### Ambient information systems

In relation to how the Data Lamp displays its data, the Pousman and Stasko model [44] was used as a complement to the Zhao and Moere model [60] utilised and primarily for the designing of the information capacity and its notification level dimensions.

Regarding information capacity, the device collects and merges data into three timeline visualisations, which is daily, monthly and yearly data from the five activities that can be collected with the tracker, therefore according to the model, it is three nuggets of information to visualise. As seen on Figure 6, timelines sum the total activity times and output the proportion of each activity compared to the total, differentiating them through contrasting colours. Red, Green, Blue, Purple and Yellow.

In addition, the notification level is designed to be subtle, as it correspond to most Ambient Information Systems, a “change blind and make aware transition” [44] that allows displaying and changing data without interrupting the user. This is achieved by displaying the information in the lowest brightness and is only lit brighter when the user transfers data from the activity tracker when it is turned on and in range.

In return and according to their defined patterns for Ambient Information Systems, the Data Lamp corresponds to a “Symbolic Sculptural Display Archetype” [44], an Ambient Information System that displays few pieces of data, representing information through a sculptural way with the intention of becoming a decorative object to be utilised indoor.

### Proximity sensing

One of the opportunities in data Physicalisation research is investigating the combination between physical interaction and synthetic interaction in order to allow Physicalisations to be reconfigurable. For instance, supporting alternative visualisations like displaying different datasets or modifying the way to visualise them [23].

Regarding this, the author is interested in exploring this subject by proposing a proximity sensing way to elicit data exploration and comparison. Therefore the Data Lamp is designed to support its data reconfiguration upon the proximity sensing of another Data Lamp. This means that
when a Data Lamp detects another, it triggers an alternative visualisation that displays the total tasks collected in a day, month and year. Although more concrete and effective possibilities of visualisation could have been designed, this functionality is developed as an open ended and less concrete method to elicit feedback from participants about how they could utilise it in the future.

![Figure 7. When a Data Lamp is on top of the other, it triggers a reconfiguration of data, displaying total activities tracked.](image)

FIELD STUDY

Participants

The study’s participants were a married couple living in a studio flat in North London, a 28 years old female (participant 1) and a 33 years old male (participant 2), both current master students and English fluent. Each had previous understanding of Quantified Self habits and engaged before in some type of self-collecting method. Participant 2 was more familiarised with data trackers and technology for utilising data collection. Both participants were currently writing their master thesis; therefore their use of time was mainly focused into studying. Participation was anonymous and required a signed consent form according to the Data Protection Act 1998. They could withdraw their data at any time if they needed to. Participants were rewarded with £10.

Materials

Two Data Lamps and two activity trackers were provided for each participant to utilise one Data Lamp and one tracker during the study. They were allowed to use them however they wanted to, this means they could place the Data Lamp where they thought would be most convenient place for them and track the activity they wanted to. In addition, there was no constraint if they wanted to use the Data Lamp somewhere else during the day, for instance, the university library.

![Figure 8. 3D printing of the prototype's form factors, laser cutting of the activity tracker and programming of circuits.](image)

The Data Lamps were physical computing prototypes built according to the theoretical background reviewed previously. Form factors were constructed utilising digital fabrication (3D printing for the Data Lamp and Laser cutting for the activity tracker). The Data Lamp’s circuits were composed by an Arduino Nano connected to a HC-06 Bluetooth an RFID tag reader and an RFID tag for the other Data Lamp to read. The lighting inside the lamp was composed by three stripes of 16 Adafruit Neopixels organised vertically along the surface of the lamp. The activity tracker’s circuits were composed by a button, a potentiometer, a led, an Arduino Uno with a Datalogger shield and an SD card to store the task times and timestamps. In addition a HC-05 Bluetooth was necessary to transfer the data wirelessly towards the Data Lamp.

The Bluetooth components from the Data Lamp and the activity tracker were configured to pair automatically upon proximity and exclusively.
**Procedure**

The study consisted in three phases and collected quantitative and qualitative data from the experience. The first phase was an introductory interview and induction to the Data Lamps. The interview’s aim was collecting data related to the participant’s knowledge about Quantified Self habits, their previous experiences and reflections from it. During the first day of use, only the activity trackers were provided to decide which tasks to track and familiarise with the activity. Then the next day, the Data Lamps were given for them to visualise the outcomes of their previous actions. During the induction, basic guidelines and possibilities of use were provided as a printed sheet with simple drawings and explanations for them to read.

Next, during the whole study they were daily interviewed on-site as a diary keeping method for gathering insights about their day-to-day experience collecting data and utilising the Data Lamp. If technical difficulties occurred during the study, the participants could contact the researcher to solve them. Throughout the study, the activity trackers logged the interactions that the participants performed with it for a prior quantitative analysis.

After the seven days of the study, a closing interview was held for collecting data about their experience, problems, learning and reflections during the deployment. Moreover, a quick think aloud was held in order to observe how they utilised the lamps and the interview session concluded with a 45 minutes participatory workshop in which participants were encouraged to reflect on the future of these technologies. The workshop consisted in envisioning ideas through making. Several different materials such as coloured acetate sheets and papers, clay, pens, wooden sticks among others were provided to them to portray their idea and present it and discuss it.

**Pilot**

Previous to the main study, a pilot was conducted during four days. The author utilised the activity tracker and kept the Data Lamp at his household and place of work while collecting data related mainly to productivity: studying, programming, writing and breaks.

The goal for conducting the pilot was to ensure that the lamps and activity trackers were working correctly and to empathize with the participants by understanding how much effort would take for them to participate. Thanks to this pilot, several technical problems and frequent doubts around the Data Lamp usage were identified, solved or communicated to the participants.

**Analysis**

Once the study was finished and the data collected, qualitative and quantitative data analysis was conducted. All the qualitative data gathered (interviews, diaries, workshop) was recorded, transcribed to a text editor and coded for thematic analysis [3] a widely used method for qualitative data analysis. This method allowed for each piece of work to identify common themes and patterns that could be important and meaningful for the study purpose. For example, problems identified, use of the Data Lamp, use of the activity tracker and more were collected and put together into larger themes for further discussion. Additionally, quantitative data analysis was conducted for the logged data from the activity tracker for identifying patterns of use. Most relevant analysis included collating total times of activities tracked per participant, types of activities tracked, total times per activity and frequent times of the day of data collection, among other types of analysis that are further discussed in the next section.

**RESULTS**

**Patterns of use**

The total amount of time tracked during the study was 62.45 hours (3747 minutes; \(x = 535.3\) minutes; min: 188 minutes; max: 760 minutes; \(\sigma = 215.6\) minutes).

Both participants collected nearly equal total times: Participant 1 collected a total of 31.1 hours of data (1864 minutes; \(x = 266.3\) minutes; min: 0 minutes; max: 514 minutes; \(\sigma = 166.7\) minutes) and participant 2 collected a total of 31.4 hours of data (1883 minutes; \(x = 269\) minutes; min: 0 minutes; max: 429 minutes; \(\sigma = 147.7\) minutes).

Both participants selected very similar activities to track. As defined by them, Participant 1 collected Work/Study (43.1%, green colour coding), Leisure (20.5%, yellow colour coding), Housekeeping (18.5%, red colour coding), Creativity/Cook (13.3%, blue colour coding) and Physical Activity (4.7%, purple colour coding). Participant 2 tracked Studying times (57.2%, red colour coding), Leisure (20.4%,

![Figure 9. The first two pie charts from the left are colour-coded the way participants did to their activities in the study.](image-url)
purple colour coding), Personal Cleaning (13.8%, blue colour coding), Domestic Cleaning (8.6%, yellow colour coding) and Sports (0%, green colour coding). Participant 2 could track four activities, missing tracking Sport activities, as opposed to participant 1, who tracked the five activities intended to track.

![Participant 1 tracked activities per day](image1.png)

![Participant 2 tracked activities per day](image2.png)

Figure 10. Participant's tracked activities per day.

Merged overall activities according to the following classification (productivity, self-maintenance and leisure) [9,55] demonstrate in Figure 9 that Productivity (50.2%) was the most tracked kind of activity, opposed to Leisure (27.1%) and Self-maintenance (22.8%). Although both participants engaged in similar activities and completed nearly equal times, Figure 9 and 10 demonstrate that how they used their time differed significantly, especially in Productivity and Self-maintenance activities.

In Figure 11, data collection opposed to time of the day merged between participants, demonstrate that tracking times happened in every hour between 8:00 am and 3:00 am throughout the week, of course differing significantly between each day. In addition, most frequent times of the day for data collection occurred from 12:00 pm to 3:00 pm, and from 6:00 pm to 11:00 pm. Going deeper in comparison between the two participants, Figure 12 displays tracking times compared to the time of the day, showing again how their time management behaviour differed significantly in productivity.

![Participants merged timeline of tracking times](image3.png)

![Participant 1 timeline and activities](image4.png)

![Participant 2 timeline and activities](image5.png)

Figure 11. Participant’s merged tracking times.

Figure 12. Participant’s time tracking hours.
User experience

Previous experience in the Quantified Self

(i) Quantified self habits

Both participants had previous knowledge of the concepts of the Quantified Self and had engaged previously in some method of self-collecting data about themselves.

Participant 1 declared not utilising any technological method for focusing into working or studying, as it was something that happened naturally. As a data collection method, participant 2 has been writing a diary/schedule since 15 years old, declaring that apart from being useful for organising weekly activities, it had an emotional value, commenting that a digital version could not replace it, even though during some moment it was tried. In addition, participant 2 utilised another method before for medical reasons, a health app for daily collection of pain, which was crucial for the doctor’s diagnose.

Participant 2 was engaged in a self-tracking method utilising a smartphone timer as a stopwatch, tracking working times of writing and reading for a master’s dissertation. Although this method did not involve saving data or more insights about tracked activities, it allowed completing the intended daily goals for finishing the master’s dissertation. Additionally, participant 2 tracked cycling activities since the last 10 years and since 6 years ago utilising a smartphone app (Strava) [61] for tracking performance times, distances and routes for cycling sessions. Among Strava’s features, it allows comparison of times and routes with others, which participant 1 declared, it allowed improving decisions, strategies and times.

(ii) Previous visualization strategies

The participants declared that apart of the activity of collecting data about themselves, they engaged little in the visualisation of data, mainly due to personal reasons or limitations of their techniques. The timekeeping method that participant 2 utilised did not offer the possibility of saving data nor to visualise it, weekly times could be manually added and plotted on another platform, although it proved to be slow and tedious. In the case of the cycling app, this platform allowed some basic options for visualising routes, speeds and time for each segment, however more detailed information was a paid feature and the participant was not registered to it. Participant 1’s personal diary was utilised as a log of important information to access without previously intended use other than remembering important events. The medical app participant 1 used before was a self-logging platform that did not have any type of visualisation, even though it was mentioned that the platform allowed accessing easily to each daily record.

(iii) Previous strategies in data comparison

There were contrasted concepts about what comparing data meant, participant 2 did engage with data comparison through the use of the Strava app for cycling, however participant 1 had a personal reason of not wanting to engage in data comparison with others, stating that it was not a goal. The Strava app allowed participant 2 to visualise routes that other cyclist uploaded; depending on the times collected within the routes, users appear in the route’s ranking and in an overall ranking. Participant 2 mentioned this encouraged good feelings and was an incentive for cycling. This demonstrated that the participants had opposite views about comparison and competition as comparison.

(iv) Outcomes from previous quantified self habits

Both recognised the importance of personal data collection and its benefits. For participant 1, the schedule was important for remembering important personal events and the health app was helpful as an objective and accurate measurement for a medical diagnose and for medication adherence. The stopwatch method allowed augmenting the amount of study hours and the cycling app’s competition mode provided motivation for training more and achieving better cycling times.

Data Lamps use

This section explains how participants utilised the Data Lamps throughout the deployment, outlining the main findings upon the use of the activity tracker, the Data Lamp and its comparison functionalities. Before starting to outline these aspects, it is necessary to first provide a section mentioning and determining the technical difficulties that occurred during the deployment.

Technical issues

In The Wild studies [45] like Technology Probe Studies in most of the cases carry unexpected problems that researchers need to consider. Building a prototype to be deployed and used during one week in a specific place became very challenging, as it was very difficult to determine during the whole time, which issues could occur in between.

Among problems encountered there were technical issues for connecting lamps, user’s impression of the tracker being fragile, one of the lamp broke down during the ending of the study and comparison functionalities not being utilised properly. Participants had problems with plugs, even though being provided with a multi socket adaptor. This was a consequence of the size of their flat and the specific moment they were living, which required them to be much of the time together, studying and using power sources for other devices and needs.

In addition, it was mentioned not taking the tracker to other places because the participant did not want to break it.
However, the most important issue relates to participant 1’s lamp, which in the first and last day of the study it did not turn on due to an internal problem with the circuits, which did not allow to utilise properly the comparison functionality between the lamps, as well as not allowing participant 1 to visualise data at the end of the study.

This was further fixed for the closing interview, allowing exploring data again one last time.

**Places of data collection**

Places of data collection were mainly inside the participants’ flat or at their working environment. Participant 2 divided activity tracking between those two places. Sometimes the limitations of the tracking device did not allow it to be utilised outdoor, although given the possibility to carry a battery for it. For participant 1, placing the device tracker in only one visible area was helpful and convenient to remember to utilise it.

**Types of data collected**

Both participants, even though they did not organise themselves previously, collected very similar types of data, which was mainly divided by productivity, housekeeping and self-maintenance, leisure, health/sports and creative activities, with minor differences on what it meant for them.

**Activity tracker use**

In general there was a positive adoption of the technology, both participants utilised the time-based data tracker correctly during almost all days of the study, even commenting that if they could not track an activity for some personal reason, they felt they were missing an opportunity to collect data for a prior visualisation. However there were issues and opposite opinions regarding the use of this method.

Participant 1 struggled at first with adopting the data tracking habit, referring to a previous prejudice around the method of data collection. In regard to a specific issue interacting with the device, participant 1 considered that having to define only five tasks to track and remain tracking them without possibly adding a new one was too rigid.

At the end of the study, participant 1 reflected that the experience of collecting data as just “quantity” and not “quality” was something that did not matter to her. Participant 2 was more engaged since the beginning, as the method of tracking daily activities was similar to what was already doing for time-managing study times. Participant 2 declared that the action of tracking activities that normally did not considered tracking, especially housekeeping or personal hygiene, allowed making a concrete conclusion of how much time it took to perform those activities. In addition, participant 2 stated that the experience of collecting data with a device that did not provide any more feedback than allowing to store or not some time, made the experience more natural and organic.

**Data Lamp places of use**

Most utilised places were related to their working and studying activities, having their Data Lamps on their working desks. It seems that because two lamps were provided for each participant them to use it more personally than collectively. Furthermore, for participant 1, it took some days for incorporating it into her life and thus during those days the lamp was put in a transitory place around the flat (between a table and the floor). This triggered not manipulating it or utilising it for visualisation until incorporating it in a visible and easy place to reach.

**Use and interaction**

This section comments the remarks made from the participants regarding the Data Lamp’s form factors, its use for exploration and modes of visualisation, outlining their experiences and issues with it. In general, both participants stated that they could use and understand the way the Data Lamp displayed their collected data.

Both suggested that the Data Lamp’s form factors were attractive and invited to manipulate it and rotate it for visualising its data, although the wiring was sometimes a constraint for it and thus remained more static. They had considerations about the form factors not allowing visualising all data at once. As well, they suggested that sometimes data transfer was slow, and could cause some frustration. It was also mentioned that the light feedback became invasive as they commented that their flat’s size was not conditioned for devices like this.

Regarding data collection and visualisation, they commented on how during the day they were thinking how their current activities were going to be visualised in the Data Lamp, creating a mental sketch of how the collected data would appear eventually.
P2 - “Part of what was interesting for me about yesterday is that the cumulated activities in the lamp changed, as it put a block of light related to leisure, as it was a whole day of collecting that data, which for instance, before, in the week I think it had only one light on and now it has a much larger presence.”

There was a relationship between the colours utilised and the type of activities mapped to it. For participant 2, red coding was utilised for remembering crucial activities, for participant 1 it was utilised for less meaningful activities that were not related to the main goal to complete, like a sign of stop and instead focussing in the main activity (study), for which it was mapped to green as a metaphor of continuation, flow. In contrast, for participant 2, green was related to outdoor activities, however during the study, this activity could not be collected. Participant 1 mapped physical activity to a favourite colour (purple), which was something that participant 1 wanted to be more present in the visualisation. Other activities and colours in general were mapped randomly, but these previous example demonstrate that there was a conscious and unconscious relationship to color-coding.

Sometimes visualisation could become redundant when only one major activity was collected in a day, meaning that the daily visualisation would only portray one whole colour and no other type of activity to visualise and compare its proportion. Because of this, they both felt the need of collecting more different types of activities daily and when they did, it proved more engaging for them.

P2 - “I think it is nice, because I can now start to feel how a distribution of time with different extensions and the proportional graph can help you a lot (for understanding).”

Regarding the type of visualisation utilised, both considered that the cumulative view of the entire task was more engaging even though the daily visualisation was considered as an immediate feedback of how they were doing during the day.

P2 - “Actually, I think the daily visualisation becomes more meaningless for me because during the day I collect data and then having to go and check how it changes sometimes it doesn’t happen much. I think seeing the week cumulative visualisation makes more sense to me now.”

Moreover, it was declared that the lamp’s cumulative visualisations allowed them to reflect on how to balance their activities throughout the week. For instance, if they saw that there was very little of one colour, they could pick up that activity in order to change the visualisation.

The discrete Ambient Data Visualisation was adopted and understood for what its functionality was, as a background type of interaction of awareness to data and remembering to collect other types too and visualising the outcomes.

P1 - “I think is a central lamp’s function. It is very important for it to be something that not only gives feedback while is collecting but also to have a passive function of displaying the collected data so far. And to give continuity to its presence in the place that it’s located. Its there remembering you about it.”

Interesting was the situation of participant 1, that the lamp did not work especially during the last day of the study, stating that when no visualisation was available, it became frustrating and the activity times tracking process grew meaningless during that day.

At the end of the study, participant 2 reflected upon how the visualisation allowed understanding timing differently, commenting about how time passes quickly and can be visualised all at once.
P2 - “Basically this idea that a week can be visualized as a very short measure of time. ...for example, I wanted to do more physical activities because I was being lazy but I needed to study a lot and because of this I wasn’t able to do it and then I realized how quick a week goes by without doing the activity you wanted to do. That was the main learning for me.”

Comparison and proximity sensing use

One of the main issues upon the use of proximity sensing between both lamps to compare data was the outcome example, which was not informative enough, therefore it was not sufficiently engaging to be utilised even though the proximity sensing comparison was acknowledged as an interaction that invited manipulation and leveraged curiosity in data exploration.

Another problematic that appeared regarding comparison is that it requires collecting and coding the same type of data in order to not engage in translation, which makes it more difficult, however it has been suggested that comparison of data between two users could become conflictive if it is not utilised with precaution, for instance, comparing housekeeping responsibility times between each other.

Participant’s proposed prototypes

Participants engaged in the creation of future technologies for visualising Quantified Self’s data, both proposals were very much oriented to personal struggles with the Data Lamps and most ideas came as a continuation of the previous experience, despite the opportunity of exploring other options.

The following figure and table show their proposals divided by core concept, idea and functionalities. It is necessary to mention that because these are exploratory ideas, some functions could be not mentioned or considered.

<table>
<thead>
<tr>
<th>Prototype</th>
<th>Participant 1</th>
<th>Participant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Concept</td>
<td>Smaller form factors, portability and exploration of data through manipulation.</td>
<td>Reconfiguration of data and exploration of history.</td>
</tr>
<tr>
<td>Idea</td>
<td>A small cube that is possible to carry wherever it is needed and displays time-based data of activities tracked from an app or activity tracker.</td>
<td>A removable dome for the top of the Data Lamp as an activity tracker. When it is on top data can be explored, rotating the dome, triggering daily, weekly, monthly, yearly and overall view of data. It utilises lights and colours.</td>
</tr>
<tr>
<td>Function</td>
<td>Exploration of data through manipulation. Physical Visualisation utilising colours and brightness. Each face of the cube is an activity, each face shines a different colour and when a face shines brighter it is because more time was dedicated to that activity.</td>
<td>Shows real time collection of time-based activities, showing when collecting occurred and when not, leaving visible spaces for reflection. Also allows easy access to previous months and weeks for self-comparison.</td>
</tr>
</tbody>
</table>

Figure 15. (Left) Participant 1 – (Right) Participant 2

Table 2. Participant's proposed designs divided by core concept, idea and function.

4. DISCUSSION

Experience and engagement

It can be said that one participant was more engaged than the other. Both utilised the lamps during the study, tracking several hours of data for visualisation and surprisingly, of very similar activities, which could be a consequence of both living together. However, in spite of the similarities and the continuous use of the technology probes, there were clear differences and opposite reactions about the overall experience.
Participant 1 concluded that it became difficult to relate to the habit of time-based collection, being not crucial for self-understanding, preferring analogical and more “flexible” methods already utilised. Regarding the use of the Data Lamp, participant 1 acknowledged its utility for awareness and understanding, however had concerns about how a device with these qualities could be integrated in a household without being invasive, concluding no being yet convinced about the real utility of having personal data available around the environment of a house.

Participant 2 certainly adopted the modality of collecting time-based data, engaging with the Data Lamp’s form factors and visualisation modes, declaring that in contrast to previous experiences, the technology probe allowed reflection about the use of time and its perception. More specifically, participant 2 utilised the lamp as a method for balancing weekly activities and tracking activities that did not track before, while reflecting about how the cumulated data displayed on the lamp allowed understanding of how quickly a week can go by.

Differences could relate to participant 1 being a documentary tracker, without intention of changing or improving activities and participant 2 a goal tracker [46]. These methods can be very opposite, as one is exploratory and the other is target directed. Certainly the visualisation of time-based activities can become shallow for someone that explores another type of data-tracking habit, especially if it is exploratory. The type of data users want to collect and what questions they want to answer influence largely in the experience, this refers to the work of Li et al. [29] an interesting list of the motivations and questions that users of personal informatics seek. It can be technical as well, mainly related to the use of light intensity and colours in the visualisation, or whether utilising lights as visualisation could be especially invasive in small households. Regarding this problematic, further evaluation on types of Physical Visualisations in contrast to its environmental context and size would prove to be necessary to research.

Certainly, several factors could be involved in why a user would want or not to incorporate a technological solution for self-collecting and visualising data, however previous interpretations on what Quantified Self mean to users can define the limits they impose to this habit and the artifacts associated to it.

**Use, awareness and understanding of data**

Both participants acknowledged the benefits of having a Physical Ambient Visualisation device that continuously made them aware of their data. The lamps were used during the day and half of the time they were utilised as a productivity tool, situating it around their working desks for exploration and visualisation of their most crucial tasks. This matches to Quantified Selfers’ improvement of lives, which relates time-based activities to productivity [8].

In addition, manual exploration of data occurred, however the lamps remained static, which can be explained by the size, form factors or metaphor (lamps affordances could be perceived as objects to be permanently placed in one area of a household) [42]. Participants utilised the lamps personally rather than collectively, this means the data was being only utilised by the “owner” of the lamp, which relates to previous finding from Houben et al [17]. One of the reasons for this could be related to participants coding similar tasks with different colours, suggesting that to understand each other’s visualisations they should first know what the colours for each other meant. Another possibility would have been collecting the same data in the same way.

An interesting insight about the use of “personal” Data Lamps relate to their potential to become “mirrors” that communicate each person’s feelings regarding how they have been spending their day, week or month. For instance, one person could know why the other is irritable because the lamp shows that it has been a week for that person of not doing any creative activity.

For both participants, the Data Lamp increased its utility when more data collection days passed and different activities were tracked, as the cumulated view of all activities (month/year) proved to be the most utilised section of the visualisation. The daily data visualisation was not as utilised because of the moment of intense study they were in, which reflected it on the lamp as nearly only one type of data throughout the day, thus becoming redundant and stressful for them.

In addition, permanently displaying data in the ambient allowed confirming decisions [29,32]. For instance, when participant 2 visualised a large proportion of the work/study light on the lamp, this allowed deciding to change to another activity without remorse. This also occurred backwards, when visualising there was a large proportion of light from another type of activity that was not work, the visualisation feedback caused feelings of guilty. This explains how a “balancing” between activities occurred with the participants thanks to how the lights reacted to their activities, which encouraged taking action.

Upon comparison of data, insights suggest there was more interest in improving this in relation to self-comparison rather than a collective activity, which was stated that comparison of time-based activities were subjective and could become a source of conflict. For instance, comparing responsibility times at home or even at work could increase tension. However, both stated that in the long term, with more data gathered it could prove to be more important, but yet to see in a longer period of collection times.

Rather than collective comparison, more means of self-exploration were suggested, regarding a deeper and interactive way to access and select time sets and to compare with them. This could relate to our common understanding and familiarity to more complex screen-
based visualisation tools rather than Physical Ambient Visualisations, which have clear limits to how much data to portray. However, in order to address necessities like this, more research is needed in the development of dynamic Physical Visualisations [23] for supporting these kinds of explorations. Upon collective comparison, Data Lamps could be a medium for actively warn and invite users to understand about themselves in relation to the activities previously tracked.

Integration into the environment

There were concerns related to how these artifacts could be adopted in people’s personal space, examples regarding this related to form factors design and its interaction with the user. For instance, it was observed and understood that a small household could not be the best scenario for a Physical Visualisation utilising a continuous feedback with light and colour. Even though design decisions were aware of this scenario and brightness in ambient mode was set at the lowest when the lamp was inactive, the main issue was how this visualisation became invasive in a small place. This contrasts to Houben et al. experience with the Physikit, which could be related to how light visualisation was utilised, for instance, lighting up for notifications rather than for a continuous visualisation of data [17].

Participant 1 at the beginning of the study did not engage initially with the Lamp, not giving it a proper place for visualisation for the first days, which undermined the relationship with it. However, with more days passed, assigning a visible place for the Data Lamp and more activities tracked, participant 1 could re-establish the interaction with it.

Lastly, there was worry regarding how these kinds of devices could be utilised in the future as the action of constantly collecting and visualising data at home or other places could incite users to become “super rational beings”. Therefore it is suggested that there should be a clear limit to how to integrate these types of devices.

Future work

Physical Ambient Data Visualisation and time-based activity tracking could be tested in more productive environments, like an office, for externalising each individual’s productivity and time management. In addition, they could be utilised for education, for instance, teaching young kids to learn about how they use their time. The purpose of these explorations should be focused in the social implications of these systems, how they could be utilised and what are the main concerns that are raised.

Moreover, explorations in type of data, data displaying flexibility, form factors, visualisation modes and interactivity are needed for data awareness, sense-making and more importantly to understand the potentials of these interactive systems.

Limitations

A major constraint in this thesis and study is that more time and resources were needed to perform a longer study, for instance, two weeks and at least one more household as a sample to evaluate would have been very significant for a more complete exploration.

Another limitation relates to the approach taken for the designing of the prototypes, especially not being able to use batteries, which limited interaction with the Data Lamps. Also, Bluetooth for wireless transmission of data was unstable; another solution would have been utilising an online app for data collection with smartphones and then the data to be transmitted online through WIFI to the Data Lamps.

5. CONCLUSION

This thesis is an exploration of how Physical Ambient Data Visualisations for Quantified Selfers can allow them awareness of their data in their households, what is the use given, and how they appropriate these systems in their environment.

A Technology Probe study was conducted for this purpose, where two prototypes of Physical Ambient Data Visualisations (Data Lamps) were built and deployed in a household in London inhabited by two non-expert Quantified Selfers that interacted with them during a week. Participants tracked hours of activities times and the Data Lamps displayed it into the environment with proportions of light and colour, allowing perceptual, manual exploration of data and comparison.

The study demonstrated awareness of data and differences in engagement and acceptance. The lamps were utilised individually, mainly for productivity, as a daily decision-taking and data awareness tool. Regarding form factors, these allowed perceptual, manual exploration and were accepted as part of the environment. However, concerns were raised regarding adoption and purpose of time-based data collection for activity visualisation and comparison with others, and more importantly, how these kinds of devices could become invasive, especially in small households.

This contributes that, despite of allowing data awareness and exploration, Physical Ambient Data Visualisations should be discreet and could tackle flexible purposes, displaying other types of data and visualisations that could blend better into the environment and for the user’s need and the characteristics of the environment or household.
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APPENDIX 1: CONSENT FORMS

DIVISION OF PSYCHOLOGY AND LANGUAGE SCIENCES

Informed Consent Form for Participants in Research Studies

Title of Project: Data Sculpture for quantified self – A study into physical ambient data visualisation and activity tracking

This study has been approved by the UCL Research Ethics Committee as:
[Project ID No]: UCLIC/1415/005/ICRI/ROGERS/CAPRA/HOUBEN

Participant’s Statement
I .............................................................................................................. agree that I have:

 laden the information sheet;

 had the opportunity to ask questions and discuss the study;

 received satisfactory answers to all my questions or have been advised of an individual to contact for
 answers to pertinent questions about the research and my rights as a participant and whom to contact in the
 event of a research-related injury.

 understand that my participation will be audio/video recorded and I am aware of and consent to the analysis
 of the recordings.

 understand that I must not take part if I am not physically able to do the tasks

 For the following, please circle “Yes” or “No” and initial each point.

 - I agree for the audio recording to be used by the researchers in further research studies
   YES / NO  initial: _____________

 - I agree for the pictures to be used by the researchers for teaching, conferences, presentations,
   publications, and/or thesis work
   YES / NO  initial: _____________

 I understand that I am free to withdraw from the study without penalty if I so wish. I understand that I consent to
 the processing of my personal information for the purposes of this study only. I understand that any such
 information will be treated as strictly confidential and handled in accordance with the provisions of the Data
 Protection Act 1998.

 Signed: ___________________________  Date: ___________________________

 Investigator’s Statement
 I ..............................................................................................................
 confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably
 foreseeable risks or benefits (where applicable).

 Signed: ___________________________  Date: ___________________________

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APPENDIX 2: STUDY INDUCTION SHEET

This week you will be introduced to the devices and their capabilities. The devices will be deployed at your house during one week. You can compare your day-to-day activities either in situ or put them close together and let the devices to simply compare the types of tasks you have done during the day/month/year.

In both a working environment and a more relaxed one, the devices can be used to measure productivity times comparisons. A combination of productivity and leisure could also determine to utilise the devices at the office and then at home. Then you can take it home during the weekend or for the end of the day to reflect and compare with your flatmate/partner how the day has been.

This are a few examples of how these devices could be utilised on a day-to-day basis. However, you are free to use it the way you think it suits you best and can make the most of the technology.

Thanks.