Eco-Garden: A Data Sculpture to Encourage Sustainable Practices in Everyday Life in Households

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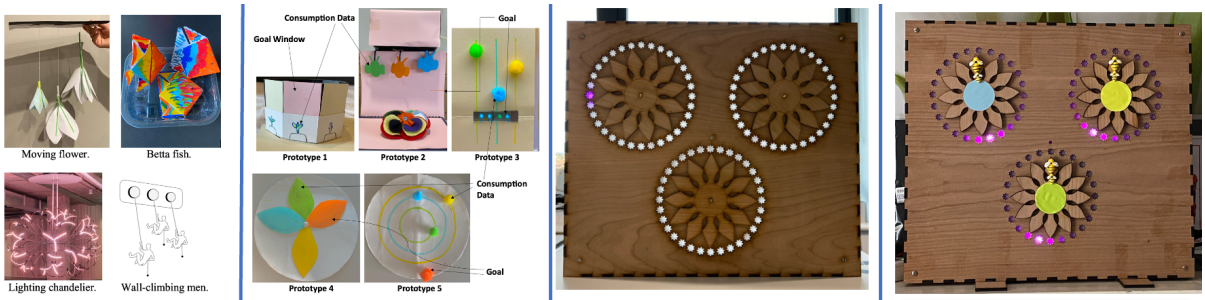

(a) Phase 1 of the research - we created two low-fidelity paper prototypes (top two) and used two images (bottom two). Each represents ways of displaying consumption data.

(b) Phase 2 of the research - we created five low to medium-fidelity prototypes. Each represents household consumption through movement and lights.

(c) Phase 3 of the research – we created a high-fidelity data sculpture representing household consumption for electricity, gas, and food waste.

(d) Phase 4 of the research – we modified the data sculpture representing household consumption for electricity, gas, and food waste.

Figure 1: Evolution of the design of Eco-Garden data sculpture through the four phases of this research: (a) Low-fidelity prototypes used in Phase 1 [35] - 'moving flowers' is a set of 3 flowers that bloom and hang from the ceiling, 'lighting chandelier' is an image that visualises a static installation with LED strips [44] (Reaction Diffusion (2022), Jason Bruges Studio. Image credit: Josh Partee), 'Betta fish' changes colour, and 'wall-climbing men' shows objects move to reach parallel targets, (b) Low to medium-fidelity prototypes created in Phase 2 [38] - Prototype 1 is a rotating cylinder displaying a gradually blooming flower, Prototype 2 is a set of three bees moving vertically down to reach a flower, Prototype 3 is a see of three spherical balls moving to reach a parallel target, Prototype 4 is a clock interface with flower petal-shaped hands, and Prototype 5 depicts circular paths on a clock interface, (c) in Phase 3, we designed the data sculpture, *Eco-Garden*, that visualises household consumption, and d) in Phase 4, we modified *Eco-Garden* and created the final prototype.

Abstract

Household consumption significantly impacts climate change. Although interventions that make households aware of their consumption exist, tailoring the design to each home's needs remains challenging. To address this, we developed *Eco-Garden*, a data sculpture designed to visualise household consumption aiming to promote sustainable practices. Eco-Garden serves as both an aesthetic piece for visitors and a functional tool for household members to understand their resource consumption. In this paper, we present the human-centred design process of Eco-Garden and the preliminary findings we made through the field study. We conducted a field study with 15 households to explore participants' experience with Eco-Garden and its potential to encourage sustainable practices at home. Our participants provided positive feedback on integrating Eco-Garden into their homes, highlighting considerations such as aesthetics, physicality, calm manner of presenting consumption data. Our Insights contribute to developing data sculptures for households that can facilitate meaningful interactions with consumption data.

Index Terms: Data Sculptures, Sustainability, Household Consumption, Ambient Information Systems.

1 Introduction

Climate change mitigation strategies require collaboration across all sectors, with around two-thirds of global emissions linked to private household activities according to consumption-based accounting [45](page 14). Eco-feedback technologies [32] have been implemented to provide feedback on resource consumption to reduce environmental impact, including in-house displays (IHD) [48], web-based apps / mobile applications [26], games [15], virtual environments [9], tangible user interfaces [12], and physical artefacts [43, 40]. Data physicalizations [24] and data sculptures [49], have shown potential to promote sustainable actions by bridging the gap between digital information and the real world, enabling a more creative and meaningful approach to looking at data [14, 13, 35, 25]. By incorporating data physicalizations [24] and data sculptures [49] into routine household tasks, we can raise awareness of consumption data [43, 40, 14]. Data sculptures, in particular, provide an overview of the data with their artistic elements that allow them to blend into the background and not obstruct the user's activities [4, 35].

In light of this, we designed and developed *Eco-Garden*, a data sculpture that displays household consumption aiming to facilitate collaborative interpretation and enhance the experience of understanding data. In this paper, we present the human-

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centred design process of Eco-Garden and the preliminary findings we made through the field study conducted with 15 households for five months where each household utilised the sculpture for three weeks. Aligning with prior work [43, 40, 49], we constructed Eco-Garden to visualise electricity and gas usage, and food wastage. Our work contributes to the growing body of Physical Data Visualisations in Human-Computer Interaction (HCI) research [1, 27, 40, 26, 10, 41, 14, 11, 13, 35, 23, 49]. First, we present an overview of the physical and visual experience of Eco-Garden complementing research investigating the design of physical artefacts to curtail consumption in the home context [43, 40, 20, 6, 42, 26]. Secondly, based on our findings, we discuss the usefulness of the physicality and aesthetics of Eco-Garden in terms of integration into home environments [40, 41, 49], facilitating reflection by providing a physical overview of daily/weekly consumption data and prompting sustainable actions [43, 41], and its calm manner of displaying consumption data to households to minimise the stress of information overload [43, 40, 14, 24, 13].

2 Related Work

There is a long tradition of gathering personal data and thinking back on it [29]. For instance, Ellie Harrison created art projects on her personal behaviour, such as food consumption and sneezes (http://ellieharrison.com). On the website StepGreen [1], users can share their sustainable actions and view progress charts [30]. A smartphone app called UbiGreen [2] monitors and displays environmentally friendly transport habits [16]. Li et al. [29] defined personal informatics systems as those that 'help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge'. On the one hand, Li et al. [29] identified collection and reflection as the core aspects of a personal informatics system [29]. On the other hand, they discovered that obstacles such as context and a lack of a holistic view could hinder users from appropriating and understanding their data during reflection. It is argued that frequently looking at data enables both an instant short-term reflection on current results and a more thorough long-term analysis of developing trends [41]. Li et al. [29] also discovered people frequently lack the time to sift through all of their data for reflection. Finally, it is important to support users in making meaningful transitions between their qualitative goals such as reducing household consumption, and the quantitative goals that monitoring devices help them achieve such as reducing the heating by one degree today. However, the typical setup of figures and graphs on majority of the consumption monitoring applications is not always suitable for the individual needs of the households due to their varied dynamics [35]. Therefore, we require technologies that adapt the visualisation of consumption data to the needs of the user and make it easily accessible [37].

Ishii et al. [23] introduced physical data representations through their work on 'tangible bits'. In 2008, 'Data sculpture' was first introduced by Zhao et al. [49], as 'a data-based physical artefact, possessing both artistic and functional qualities, that aims to augment a nearby audience's understanding of data insights and any socially relevant issues that underlie it' [49]. Then 'data physicalization' was described later in 2015 as 'a physical artefact whose geometry or material properties encode data' [24]. Data sculptures are an artistic form of data physicalizations that transform data into physical forms, enabling engagement and integration into social situations [49]. Data sculptures can raise awareness of sustainability concerns and enhance people's engagement through their physical presence [43, 40, 49].

While several features are being investigated in the field of data sculpting for sustainable consumption, there is still a lack of development in the application of these features to improve user experience [3]. For instance, the 'personalisation' of data presentation, as described by Lee et al. [28], might make data visualisations more captivating by tailoring the display to the individual's requirements [28]. Current visualisations frequently follow a uniform methodology, providing few or no means of tailoring layout, appearance, and information presentation to suit the daily dynamics seen in various homes [37]. While households work together to achieve collective sustainable consumption goals [46], not every member may understand information in similar ways [47]; in particular, children might not be able to grasp a data display that an adult could understand [47]. Further, it might be more helpful to provide users with a personal consumption target [3], which they are then encouraged not to exceed. Users might not fully comprehend the relationship between their activities such as washing, cooking, or entertainment, with overall consumption and its impact on the climate [37]. This emphasises the need for more engaging and understandable data visualisations that offer insights into consumption domains so users may make choices that suit their needs and preferences [2].

To integrate the consumption data more fully into someone's everyday life, we propose an alternative approach for data representation, by means of a dynamic sculpture. The rationale is that a physical abstraction of the data can encourage a different way of reflecting and engaging with the data by regular confrontation [40, 41, 22]. Further, the dynamic nature of a sculpture opens up opportunities to support changing user needs and enables feedback over time in a sustainable fashion [41].

3 Human-Centred Design And Development Of Eco-garden

3.1 Evolution of the Design

We started a project in October 2021 to investigate how physical artefacts may be designed to encourage sustainable practices in UK homes. Phase 1 involved a survey (22 responses) and 13 household interviews to understand consumption practices, values, and factors influencing consumption [37, 35, 36]. We created low-fidelity prototypes at this phase to communicate the idea of data sculptures ((a) Phase 1 in Figure 1). Building upon the Phase 1 findings, we conducted 15 household design workshops in Phase 2 [38] to understand participants' preferences and ideas for designing a physical visualisation. In this phase, we created five low to medium-fidelity prototypes ((b) Phase 2 in Figure 1). The workshops identified design considerations, features of the sculpture, size and location requirements, the need to make the sculpture abstract, and the need for child-friendly design. Participants identified electricity, gas, and food waste as the most important consumptions in their homes. Based on these findings, in Phase 3 we designed an initial version of Eco-Garden to be an aesthetically pleasing object that communicates consumption information in a friendly manner to children and adults. We also designed an initial version of a mobile app that can be used to enter the weekly target, gas usage, and food waste, and visualise consumption graphs and progress. We then conducted 14 household workshops to gather user feedback (Phase 3 in Figure 1) on the sculpture (including visibility, understandability, aesthetics) and the app (user interface, ease of use, and understandability). Finally, integrating the findings from Phase 3, we modified and designed the final version of Eco-Garden, the data sculpture and the complementary mobile app in Phase 4 (in Figure 1).

3.2 Eco-Garden

Eco-Garden (Figure 3) is a physical artefact and a complimentary mobile app that visualises household consumption data, including electricity, gas, and food waste, aiming to encourage sustainable practices. The purpose of the mobile app (Figure 2) is to allow the users to enter weekly targets, gas usage and food waste, and visualise their consumption in graphs and check the progress (the

[1] https://make4all.org/portfolio/stepgreen/

[2] https://www.ubigreen.com/en/

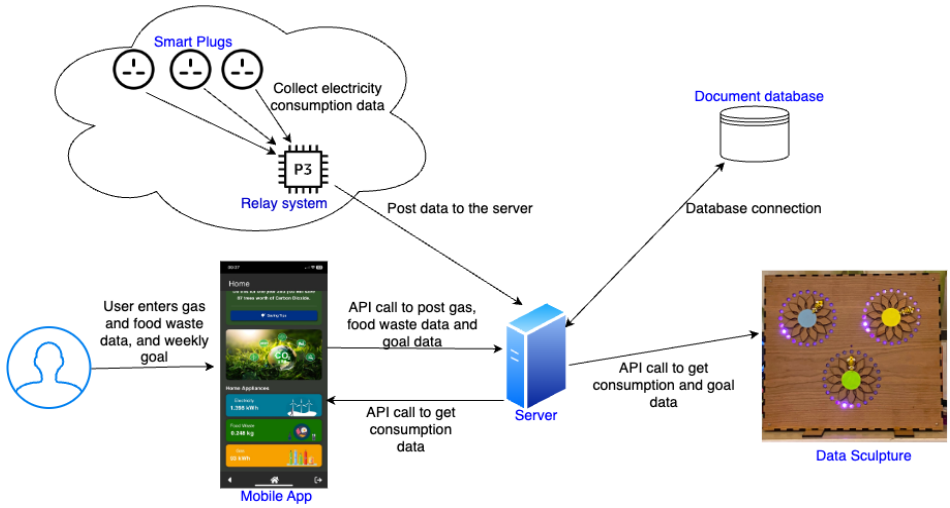

Figure 2: The system architecture diagram.

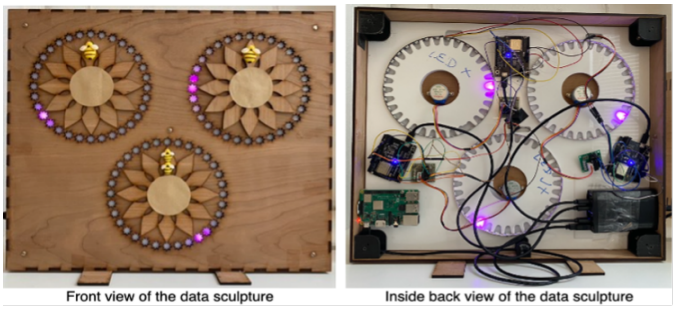

Figure 3: Eco-Garden: Three disks (each of which displays electricity use, gas use, and food waste). Bees sitting on the starting petal at the 12 O'clock position will rotate clockwise according to the home's consumption. One LED in each disk will light up to display the goal set by the user (as shown in the three disks). The inside back view (once the back panel is removed) of the Eco-Garden houses the electronic components, including the LEDs, stepper motors, ESP32 microcontrollers, and Raspberry Pi module.

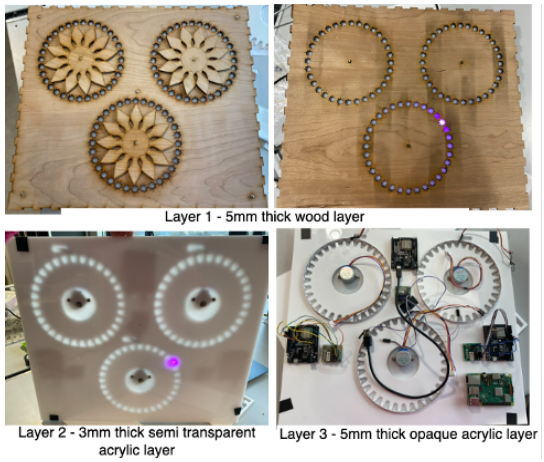

Figure 4: The three layers in the Eco-Garden prototype.

mobile app is out of scope of this paper and will be presented separately. From this point onwards, we shall use the word *Eco-Garden* to refer to the data sculpture). Eco-Garden is a 450mm x 390mm x 35mm wooden box with three disks. A flower sits on each disk, and a bee is attached to one of the petals which is considered as the beginning petal. The rotation of the disks display consumption data for electricity use practices, gas use practices, and food waste practices, which are colour-coded as blue, yellow, and green, respectively ((d) Phase 4 in Figure 1). The smaller flowers around each disk are connected to Addressable LEDs, which correspond to a configurable target set by users through the mobile app which displays detailed consumption data (mobile app is out of scope of this paper and will be reported separately). The disks follow the functioning of a traditional wall clock. Initially, Eco-Garden starts with the beginning petal with the bee, at the 12 o'clock position (representing a consumption of 0). The bees gradually rotate throughout the week to show consumption, while one lit LED in each disk shows the customised target. The bees are updated every hour. After one week, the Eco-Garden resets itself (bees rotate back to zero, and user sets a target for the new week) and continues the process with new data for the next week.

Eco-Garden has three layers and the entire prototype was laser cut while certain components were 3D printed (Figure 4); the first layer with a thickness of 5mm is wooden (cherry-veneer) along with the flowers and the back panel, the second layer with a thickness of 3mm is semi-transparent acrylic, and the final layer with a thickness of 5mm is opaque acrylic. The electronic components are placed on the third layer. The Eco-Garden has three disks, each rotated by a stepper motor, and the small flowers are connected to Addressable LED strips. The ESP32 module controls the motor and LEDs. We use TP-Link Tapo P110 smart plugs to monitor electricity consumption, while users enter food waste and gas usage on a mobile app that we designed. We wrote a Raspberry Pi-based relay program to collect electricity data from the smart plugs and send it to the back-end system, which saves it in the MongoDB database. The ESP32 modules request data from the back-end, which is then displayed by rotating the bees accordingly (Figure 2). We also provide the facility to customise Eco-Garden based on user preference for: (1) choose which consumption practice is visible on which disk and in which way (four choices were provided: a) visibility of electricity, gas, and food waste data on each disk, b) electricity usage (current and past week) and food waste across the three disks, c) electricity

data for current and past week, alongside gas data, d) electricity usage data for current and past week, and a total of all weeks), and (2) the colour of the goal LED.

4 Study Design

The aim of the final field study was to investigate how our data sculpture and mobile app, together called the Eco-Garden, is perceived by households and how it could encourage sustainable practices in a home context (details of the mobile app are out of scope of this paper and will be reported separately). We conducted the final field study at 15 households in Wales, UK, where each home used Eco-Garden for three weeks and provided feedback. Before the start of the study, participants were requested to read the Participation Information Sheet and sign a consent form. The field study was held between February to June 2024, with a favourable ethical opinion obtained from the ethics committee of the School of Computer Science and Informatics, Cardiff University (approval no: COMSC/Ethics/2024/001), and each household received a £25 voucher.

4.1 Participants

During the initial study (Phase 1), we used our university social media group and mailing lists for participant recruitment. We invited these participants from this previous study to the current field study. Here, 10 households (H1 to H10) with adults ranging in age from 18 to 54 years participated in the field study (Table 1). We recruited five additional households through the university email network due to attrition of previous participants. Overall, our household participants had one to four people per household, including five single-occupants, four shared homes between partners or tenants, and six family homes with children. Although we did not directly involve children, we learned about children's feedback and design interests through their parents.

4.2 Data Collection

During the field study, we conducted pre and post-study interviews and surveys, and weekly interviews with each household. We shall briefly explain these three studies and then focus on the weekly studies as we are only reporting the preliminary outcomes of the weekly interviews in this paper.

At the beginning of the field-study, participants were contacted by email to pick a convenient date for the system setup at their home. During the first visit to the participants' homes, we introduced them to the field study and its purpose. Then each home received an explanation of the Eco-Garden (data sculpture and the mobile app). Next, with participants' permission, we set up the Eco-Garden system in each home. Then we conducted an initial household interview for 30 minutes to understand households' first impressions on Eco-Garden. Finally, we set up a weekly meeting date with the households and a date for the final interview and collection after three weeks.

During the time of use, we set-up a weekly interview with the households. Each household was given Eco-Garden to use for three weeks (Figure 5). TP-Link Tapo P110 smart plugs collected the electricity data of the selected appliances. The participants reported their gas use and food wastage data via the smartphone application. We visited each home once each week and conducted an interview for 30 minutes to gather weekly feedback related to their overall experience with Eco-Garden during each week, how they engaged with the system, if everyone in the home collaborated with the system, whether the system encouraged any changes in practices or routines, and thoughts on the data presentation in the sculpture and the app. At this time, households were also reminded to set a new consumption target for the next week on the mobile app which will be visualised in the data sculpture as well.

Figure 5: Eco-Garden data sculpture at a participant's home (household H14).

At the end of the usage period of three weeks, we conducted a post-study using surveys and household interviews to gather data about households' overall experience, any changes in practices, and the usability of the technology. In this paper, we only report the preliminary results of the weekly interviews.

4.3 Data Analysis

All workshops were recorded and transcribed to conduct reflexive thematic analysis [7, 8] with the aid of NVivo (Version 1.7.1). We began the process by familiarising ourselves with the qualitative data, obtaining context and insight. Initial codes were produced to gather relevant participants' design ideas and feedback on the prototype, critically assessing the influence of personal viewpoints on code selection [7]. We iteratively reviewed the transcripts, generated codes and sorted them seven times to aid in theme identification. Initial examples of codes included "physical presence of the data sculpture as a motivator", "calm and comforting data display against energy applications", "data sculpture prompting sustainable actions", and "forgetting the sculpture". "Experiences of visualising consumption information through a physical artefact at home promoting engagement and taking sustainable action" was identified as the main concept for further exploration, as it was prevalent in the narratives of the participants. We continued to discuss, examine, and organise the data into themes until no new themes emerged. We adjusted the overarching themes and assigned sub-themes to the primary theme through discussions with the research team. We analysed the empirical material and found five main themes highlighting the participants' household practices: 1) Eco-Garden acting as a meaningful physical reminder encouraging sustainable actions at home, 2) Existing curtailment actions and new sustainable practices promoted through Eco-Garden, 3) Eco-Garden prompting whole-household engagement, including children, towards sustainable practices, 4) Discoveries and insightful realisations made through Eco-Garden about own consumption, and 5) Excitement and curiosity generated by Eco-Garden. In this paper, we only focus on the preliminary results of the first theme. We present our findings for the tangible presence of Eco-Garden and its influence on households.

5 Findings

In the following subsections, we report the households' experiences of visualising consumption information on the data sculpture, and varied perspectives related to the design of Eco-Garden. We report the preliminary findings of the weekly interviews of the field study in this paper. We discovered five main themes in the weekly interview. Out of these, we shall report the preliminary findings of one theme in this paper, which is the tangible presence of Eco-Garden serving as a physical reminder leading to consumption monitoring, prompting sustainable actions, and enhanced engagement.

Table 1: Participant demographics information.

Household	Household Type[1]	Members in the house	# of participants	Age ranges	Gender. Male-M, Female-F
H1	SH	2	1	25-34	F
H2	SO	1	1	35-44	F
H3	SO	1	1	25-34	M
H4	NF	4	1	25-34	F
H5	SH	2	2	25-34	M, M
H6	SO	1	1	25-34	M
H7	SO	1	1	35-44	M
H8	SO	1	1	35-44	M
H9	SH	2	2	35-44	M, F
H10	NF	4	2	25-34	M, F
H11	NF	4	1	35-44	F
H12	NF	4	2	35-44	M, F
H13	SH	2	2	35-44	M, F
H14	NF	3	2	35-44	M, F
H15	NF	4	2	35-44	M, F

[1]Household Type (NF - Nuclear family, SH - Shared house between partners or tenants, SO - Single Occupant)

5.1 Early Challenges in Interpreting the Bee's Movement and Setting Initial Consumption Targets

While the households had major positive feedback, they also mentioned facing certain challenges with the sculpture in the first few days of the field study in terms of making sense of the bee's movement against the small flowers around the disk: *"sometimes I need to count the number of small flowers the bee that's currently on, so then when I know the bee is at the 5th circle because there's no numbers. Then after two hours or tomorrow if it moves, I know how much more it had moved from yesterday. Maybe I think numbers will make it easy to keep a note. But then others will also understand the numbers. So maybe covering the small flowers with different colours? Just so I know, for example, now it's on the Purple circle"* (household H4). Further, participants also mentioned that setting the target consumptions for the first week was a challenge as they were not aware of their average consumption at the start of the study: *"first week it was difficult because I didn't know exactly how am I consuming. So it's difficult to set the goal for the first week, but the second week we have seen what I've did through this week and I can interpret the consumption"* (household H15). Although the novelty was somewhat challenging in the initial few days, our participants mentioned that Eco-garden was a positive way to look at their consumption data.

5.2 Calm and Comforting Visual Display: Participants' Positive Reactions to Visual Data Representation in Eco-Garden

Participants mentioned that the visual representation of data on the sculpture through the movement of the bees and the LED light for the consumption target, was a calm and comforting way of getting to know their consumption data. For instance, we came across household H6 who mentioned that *"It is a cute little way of seeing my data. I think if it was more scary or more shocking or if it was more in my face like 'you've used 15% of your power usage in the day', I feel like that would have been too much of a shock and stressful. So just seeing the bee move like 'Ohh wow, that moved a lot further than I thought'. It was a nice sort of change of pace compared to the alarming emails that my energy supplier sends me"*.

5.3 Physicality and Periphery: Tangible and Aesthetic Appeal of Eco-Garden Over Traditional Visualisation Devices

Household H4 explained that the physical presence of the sculpture and its aesthetics makes it much more pleasing than the smart meters and applications given by energy providers: *"I think having that physical version of something is nice to see. (...) So having that physical version of something means I don't need to go on my phone and then load up an application to view things. (...) My favourite thing about it is just having it there physically because if you go to your energy supplier and say, 'hey, give me a physical tracking system', they'll give you a little screen, a digital version and it would just be a number on a screen. But this is something nice to look at."*. Interestingly, although Eco-Garden was physically present at home on the kitchen counter-top, household H5 mentioned that they forgot about it after some time and only looked at when needed: *"I forget that the device is there at home. But when I want to see my usage, I look at it"*.

5.4 Physical Notifications to Monitor and Encourage Consumption Reduction: The Tangible Presence as a Meaningful Reminder Prompting Sustainable Actions

We came across household H2 who explained that the tangible presence of the data sculpture made them more conscious about consumption. They compared this to having to move through pages in a mobile app: *"Actually having that object in front of me lets me think more consciously about the usage (...) Having the bee moving and also the object here set up in front of me - it makes it easy for me to notice everything on a daily basis compared to other devices like apps"*. It was evident that the data sculpture provided a way of quickly understanding the consumption levels at home. For instance, household H5 described this as *"I can see the consumption for all the three categories in one look"*. This quick understanding lead the participants to be more aware of their consumption and get to know about usages that they were not mindful of before. As household H6 mentioned that *"I mean physically seeing the bee rotate scared me a bit because, I expected it to only move one tick but it had moved like four in the first day of using it. Then I thought about it and it was a Sunday and obviously, I used my desktop a lot on a Sunday. So I'd seen it jump a huge way through on that day and it was like 'oh God wow I use quite a lot of electricity in comparison here'."*.

Getting to know their consumption at-a-glance through the sculpture, in turn, prompted immediate sustainable actions in our participants. Household H1 described how they were able to realise that they had left the computer switched for several hours which they would not have known if not for the bee's movement on the sculpture: *"I had the PlayStation on and I didn't realise the com-*

puter was on. I saw the bee spin in the hour. It did its little spinning thing and I went 'oh God, why is that spinning so much?' Then I realised my computer was on and I went turned it off. If I didn't have that spinning bee, I would have just left the computer on sucking up electricity for the next 3-4 hours. So it's been positive in the pure fact of it giving me that physical notification. It gives me that sudden shock factor of 'oh God, I've used a lot of electricity. Let me go and fix that now'". However, our participants also noted that they did not engage with Eco-Garden as much by the third week as they had already learned the device consumption: *"I didn't look at it often later on because I have already learnt what it is telling me. Now I know how much I use. So I only look at it when I want to"* (household H10).

6 Discussion

In this research, we investigated how allowing users to connect their consumption data through a physical representation can foster reflection and integration in daily life, act as a meaningful reminder of consumption data, and encourage sustainable actions at home. Our field study showed how 15 participants utilised Eco-Garden in a home setting. Every participant stated Eco-Garden was a useful solution that was aesthetic and informative. Eco-Garden allowed for continuous but unobtrusive exposure to household consumption data and could be used to both facilitate and manipulate the moment and occasion at which participants interacted with their data. Eco-Garden made consumption data more accessible and prompted participants to link the rotation of the bees to their activities during the week.

6.1 Physical Presence and Aesthetics: Usefulness of Eco-Garden against Traditional Visualisations by Blending into Home Environments

During the field study, we observed that the physical presence of Eco-Garden assisted with monitoring, understanding and discussing household consumption. Our participants preferred the physicality and the aesthetically pleasing features of the Eco-Garden, over traditional digital tools such as smart meters provided by energy companies [37, 35]. The physical presence and artistic design of the sculpture were more engaging and integrated into the home environment, enhancing user interaction and awareness [43, 40, 41]. Our participants found Eco-Garden less obtrusive compared to their mobile device [41, 5]. They indicated that they could observe or ignore the system whenever they wanted. Although Eco-Garden had an unavoidable physical presence, participants had the feeling they had the choice to look at it whenever they want. Household H5 mentioned that despite the sculpture's physical presence being somewhat forgettable in daily life, it becomes the focal point when they need to check their energy usage. Aligning with Rasmussen et al. [39], this indicates that while the sculpture blended seamlessly into the home environment, it remained functional and useful as a visual feedback tool when needed. The physicality of a data sculpture such as Eco-Garden can allow for continuous but unobtrusive exposure to information and could be used to both facilitate and manipulate the moment and occasion at which people interact with their data dependent on the context it is placed in.

6.2 Reflective Awareness and Sustainable Actions: The Impact of Tangible Data Sculptures on Household Consumption

Our findings showed how the physical presence of the sculpture lead towards reflecting on one's own actions during the day/week. This aligns with literature on data sculptures stating that the visual presence leads to reflection and discussion [43, 40, 41]. Further, the physical presence of the sculpture acted as a reminder to keep a check on household consumption. Aligning with Stegers et al. [43], household H2 emphasised that having the object in front of them made them more conscious about their usage compared to navigating through pages in a mobile app. The tangible nature of the sculpture, with the bee moving, enabled easy daily observation and prompted a quick understanding of consumption. This suggests that the data sculpture acted as a meaningful reminder [33, 19] allowing for reflection and decision-making on regular practices at home to reduce consumption. For instance, the visual cue provided by the spinning bee prompted participants to take action, preventing further unnecessary electricity consumption [40, 41]. Also, households expressed how they could grasp the consumption for all categories at a glance, indicating the clarity of Eco-Garden in conveying information. This immediate understanding led participants to become more aware of their consumption patterns, even for areas they had not previously considered. For example, household H6 described being shocked by the bee's movement, realising the extent of their electricity usage, particularly on a day when they used their desktop extensively. In addition, eco-feedback is found to be encouraging energy savings in short-term, however, it is argued that they do not provide long-term interactivity and lead to relapse behaviours where people go back to their previous consumption behaviours [34, 21]. As our participants got to use the system for three weeks, there is an opportunity to conduct a more longitudinal study to understand the persistence of the eco-feedback of the Eco-Garden. Consistent with previous findings [34], our participants mentioned decreased engagement with the sculpture by the third week, as they became accustomed to their regular consumption patterns. However, participants mentioned that Eco-Garden was still useful to have in the home. This underscores the need for a longitudinal study to fully understand the sustainability of such interventions. Nonetheless, questions about the scalability of data sculptures arise, particularly concerning the cost and effort required to produce them in small numbers for extended use across multiple households. Further investigation into these aspects is necessary to evaluate the feasibility and impact of moving from prototyping to producing data sculptures.

6.3 Calm and Comforting Manner of Presenting Household Consumption Data

Our participants described the representation of consumption information on Eco-Garden as a calm way of getting to know their personal consumption [37, 35]. As noted by household H6, the sculpture offered a 'calm' and 'cute' way that reduces the panic and stress of getting to know consumption data, contrasting it with more aggressive or alarming notifications provided by their energy provider. Participants appreciated that the bee's movement offered a gentle, less intrusive way to stay aware of their energy usage. This feedback highlights that Eco-Garden's design provided a mild alternative to the typically stark and alarming notifications from traditional energy suppliers. The bee's movement and the gentle glow of the LED light offered a more pleasant and engaging way for participants to stay informed about their energy consumption, making the experience less stressful and more integrated into their daily lives. Indeed, physicalizations, with their tangible and visual representations of data [40, 14, 24, 13], have shown potential as stress-reduction tools when compared to screen-based displays [43, 40, 14]. By encouraging passive awareness of consumption data through physicalizations, people may find it less necessary to actively search for information on a screen, which might lead to a more stress-free approach to consumption tracking [14]. Nevertheless, a few of our participants found it challenging in the first few days to set their weekly target and identify the meaning of each small flower around each disk. The visual encoding of a data sculpture is argued to cause confusion when it is first presented, however, it becomes clearer when it is used for a few days [43]. This initial confusion underscores the need for intuitive design and the poten-

tial benefit of a brief orientation period t to help users interpret the data presented by the sculpture.

7 Reflections on Study Design- Limitations and Future Directions

Although our study did not include a large representative sample of UK homes, similar sample sizes are commonly used in qualitative research (see [9, 18, 31, 17]). The participants in our study represented a range of backgrounds, household sizes, and locations. We used snowball sampling, in which current participants helped find and recommend potential participants, to recruit three families that are not connected to the university. However, future research may benefit from including participants from a wider range of backgrounds and cultures. We were also able to contextualise better because the field study was conducted in the participants' homes. In addition, future research could benefit from directly involving children in the design process of a data sculpture as we explored children's design preferences through their parents. As our participants used Eco-Garden for three weeks, future research also needs to explore the long-term interaction with eco-feedback provided through data sculptures in a home context.

8 Conclusion

This paper explores the experience with and the potential of Eco-Garden, a data sculpture visualising household consumption data, to encourage sustainable practices. We conducted a field study with 15 households to gather participants' experiences on visualising consumption information on Eco-Garden for three weeks. Our findings revealed that the physical presence and the aesthetics of a sculpture can lead to continuous monitoring and reflection of own consumption. We discuss the potential of Eco-Garden to prompt immediate sustainable actions and foster new practices. We suggest that the physical form of information visualisation on Eco-Garden is a calm way of getting to know consumption data.

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