Econundrum: Visualizing the Climate Impact of Dietary Choice through a Shared Data Sculpture

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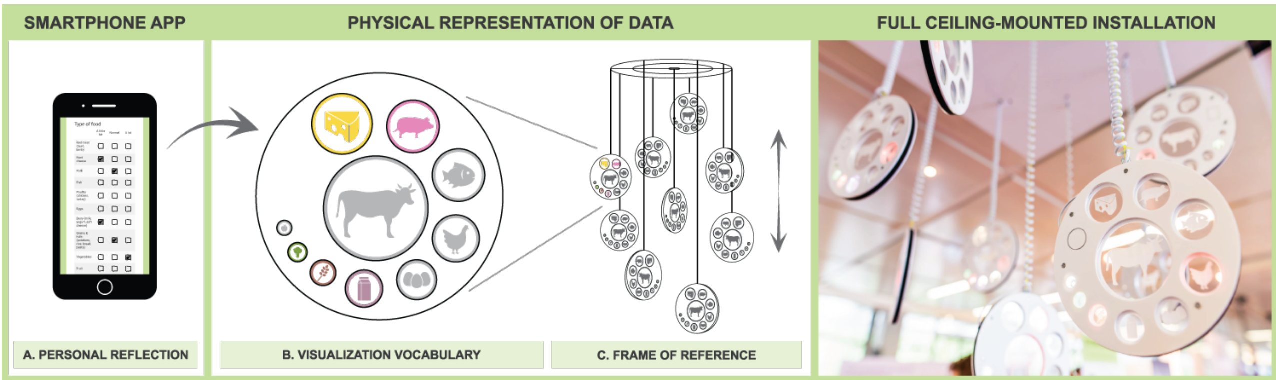

Figure 1. *Econundrum*: the application allows people to submit consumed food types, which are shown on an individual disk, using color and surface area to reveal relative carbon emissions, and can be compared to others in the physical data sculpture.

ABSTRACT
While there is a strong relationship between climate change and human food consumption, it is challenging to understand the implications and impact from an individual perspective. The lack of a shared frame of reference, that allows people to compare their impact to others, limits awareness on this complex topic. To support group reflections and social comparison of the impact of people's food consumption on climate change, we designed *Econundrum*, a shared physical data sculpture that visualizes carbon emissions resulting from dietary choices of a small community. Our three-week field study demonstrates how *Econundrum* helped people (i) understand the climate impact of various food types, (ii) reflect on the environmental impact of their food choices; and (iii) discuss the relation between climate impact and food consumption with others. Our study shows how a shared physical data sculpture mediates a complex topic to a community by facilitating the social dynamics in context.

Author Keywords
Data Sculpture; Social Interaction; Sustainable HCI; Climate Change.

CSS Concepts
• **Human-centered computing ~ Human computer interaction (HCI)**; User studies; Visualization;

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INTRODUCTION
There is a strong relation between climate change and the production, transport, waste and consumption of food [11]. At least 25% of all man-made carbon emissions are directly associated with our food system [62]. More sustainable diets, e.g. reducing the consumption of meat and dairy, are recognized to be an effective and systematic way to reduce annual personal carbon emissions [63] and eventually decrease global dietary carbon emissions [3,13,31,54,61]. For many people this connection between the immense scale of climate change, and the food they consume every day is hard to grasp [7] and there are few actionable guidelines for helping people make their diet more sustainable [63]. The unpopularity of sustainable behavior can also be understood by the concept of *social dilemmas*, as environmental issues represent a situation in which individual and collective interests are in conflict [18]. The lack of a frame of reference to compare personal data to other people or communities makes it difficult or even impossible to understand one's individual impact. People are therefore reluctant to change as the impact of their diet change might be unclear or perceived to be small [18].

Eco-feedback mechanisms that increase awareness of water or energy use are well established (e.g., [23,24,48]), however methods and tools to build awareness of sustainable food choices in the context of environmental impact are underexplored. Although some related work explores visualizations of food miles [38], food waste [20,42,59] and organic food consumption [64], these do not focus on the immediate and direct relation between personal food consumption and carbon emissions causing climate change [17]. To address this awareness problem, Clear et al. [16] argue that, because of the social nature of food, people can be effectively engaged by leveraging their social circle to become more open to different perspectives on food consumption. By explicitly designing artifacts for local communities and social settings, people are given a frame of reference to compare their consumption, but also have direct access to peers to discuss and share reflections [2]. As suggested by Lim et al. [42], an effective means to increase awareness is to provide people with *both* eco-feedback visualizations and tools for social comparison. This opens up questions on how to meaningfully encode and present environmental data to a small group of people, and we examine (i) how people understand and interpret these visualizations and their personal data, (ii) how they make a personal connection to the bigger topic of climate change, and (iii) how social interaction within a community helps to obtain a deeper understanding of a complex topic.

Our work explores the use of *Econundrum*, a shared data sculpture [65] designed to make people within a small community aware of the carbon emissions resulting from their food choices. *Econundrum* visualizes food consumption data contributed by individuals in a physical shared form factor. The installation (Figure 1) is designed to entice curiosity and exploration [34], increase social interactions and discussion [25,37], and afford peripheral interaction [1]. Through committing personal data to this shared data sculpture, people are provided with a shared frame of reference that allows them to (i) explore their own food consumption in relation to others, (ii) examine the direct relation between food types and carbon emissions, and (iii) discuss and compare the impact of their personal food intake with their direct social circle.

We contribute a design approach and set of design principles that illustrate how a complex topic can be visualized in a peripheral and physical form factor to elicit group reflection. Our approach builds directly on recent work on sustainability [5,37,41] that argue and demonstrate that the adoption of the ideas around sustainability is directly influenced by group dynamics and social interactions [5,37]. As translating these ideas into a physicalization are non-trivial, we present our approach using high-level awareness layers (page 3), concrete design principles grounded in prior work (page 4), and a system design showing how our design principles can be operationalized to implement the awareness-building layers (page 4). We deployed *Econundrum* in a three-week in-the-wild study in a community of eight people who shared a workspace and monitored their experiences. We reflect on the system's ability to mediate social interactions and facilitate collective awareness and reflection on the relation between food consumption and climate change.

RELATED WORK

Social interaction

We examine the effects of a *shared* physical installation, as prior research indicates there is value in social sharing and comparison when engaging people with a topic [24,30,51]. For sustainability, it is important to approach people collectively, as only the actions of many will affect environmental issues [41]. Also, a social frame of reference helps people in building an understanding of an otherwise abstract topic [21]. Further, when designing for social influence, different mechanisms can be taken into account, e.g. people's natural tendency to (i) evaluate their opinions or abilities by comparison and (ii) strive for uniformity within a community [21].

To provide data for this comparison between people we can draw from the quantified-self area [58]. Technological advances in sensor-based systems are enabling people to track data about themselves including physical activity, food consumption and sleep. 'Lifelogging' is mostly an individual activity but it is recognized that the social aspect could play an important role [23,29,51]. An example is the exploration of how social media plays a role in behavior change of groups regarding their ecological footprint [44]. Social sharing extends beyond just publishing data to social networks [51], however it is important to consider privacy concerns, as sharing beyond the digital world might imply giving up your privacy and revealing personal information about yourself to others [29]. Especially when talking about the topic of climate change, it is relevant and important to explore how group action and change can be supported by social sharing.

Eco-feedback

In order to design a visual language that makes sense in the context of sustainability we can draw from work on eco-feedback systems: *"Eco-feedback technology provides feedback on individual or group behaviors with a goal of reducing environmental impact"* [23]. Research on eco-feedback technology shows overlap with personal informatics as similar motivation techniques are used in the design of the technologies such as information, goal-setting, comparison and feedback [23]. Information can be abstract or concrete, either through visualizations or text, with the aim to better inform people and stimulate environmentally friendly behavior. Similar to personal informatics, it is recognized that social sharing and comparison is underexplored regarding sustainable behavior [23]. Eco-feedback displays on water and energy usage such as Coralog [39], HEMS [55], EnergyWiz [48] and the water displays [24] show the implementation of motivation techniques in different ways. Coralog [39] is an ambient display providing abstract information on energy consumption by visualizing the health of coral reefs. HEMS [55] and the water displays [24] use a more traditional representation of bar graphs and textual feedback. Lastly, EnergyWiz [48] socializes energy-related feedback by allowing comparison with others via social media. Example eco-feedback on food are EcoPanel [64], Social Recipes [42], BinCam [59], EatChaFood [20] and Food Qualculator [17]. However, most visualizations are screen-based interfaces aimed at individual users. In contrast, we leverage social sharing and comparison, in addition to individual data, to highlight the changing dynamics between people.

Data sculptures

A data sculpture is *"a data-based physical artifact, 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"* [65]. A data sculpture conveys data-related insights while encouraging people to reflect on social and cultural impacts associated with the dataset. They make data tangible, allow for physical interaction, and embed data in physical space close to the (social) context. Attempts have been made to physicalize information for awareness and social sharing in sustainability. Tidy Street [5,60] depicted energy usage data of households in a street using graffiti, and showed that people are more motivated and likely to change their behavior when engaged as a community [60]. Similarly, Squeezy Green Balls [37] is a physical installation that engages people with environmental issues by piquing curiosity and explorative behavior.

In line with these studies, we argue that data sculptures are an effective means to raise awareness of climate change as it creates a connection to an abstract topic by physically visualizing it in users' direct surroundings. Several physical art installations have been created on sustainability and climate change, e.g. Orbacles [46] and Ice Watch [35], for which natural elements such as birds and blocks of ice were used. Perhaps, one of the main provoking properties that these works share is the ephemeral character of these installations as they create a link to natural phenomena resulting from climate change [19]. While art installations are created with the goal to provoke, their physicality and location convey a powerful message that can be leveraged to create social dynamics to facilitate engagement with sustainability.

DESIGNING FOR SUSTAINABILITY

The difficulty of adopting more sustainable food consumption behavior can be understood by different mechanisms. First, for many people there is not a clear connection between the immense scale of the impact the food system has on our climate, and the food they consume every day [7]. Second, understanding the effectiveness of reducing meat consumption has been shown to directly affect people's willingness to do so [7]. Lastly, the historical unpopularity of sustainable behavior can be understood by the concept of *social dilemmas*, as environmental issues represent a situation in which individual and collective interests are conflicted [18].

In line with Knowles et al. [41] we argue that sustainable behavior could be effectively targeted from the climate change perspective, providing a clear narrative to unify, inform and engage people and communities. Reflecting on the limitations of current persuasive sustainability research, as discussed by Brynjarsdottir et al. [10], we aim to approach designing for sustainability alternatively. Firstly, we aim to design a system which is less about prescribing behavior and more meant as *"a provocation or boundary object for eliciting issues of sustainability"* [10]. In this way it *"may encourage users to reflect on what it actually means to be sustainable in a way that makes sense in the context of their own lives"* [10]. Therefore, food consumption, as it is a vital component in everyday life, is an opportunity for sustainable HCI to transform the complex and abstract construct of climate change towards a more tangible and social concept [16].

A second suggestion of Brynjarsdottir et al. [10] is to target beyond the individual, as the understanding of complex topics such as sustainability is constructed, shaped and embedded in social norms. Complementary, Paulos et al. [47] propose to utilize our personal mobile phones for sensing and collective action and did early explorations on new approaches for community participation. Persuasive sustainability could therefore benefit from going beyond the individual and engage a community, on both individual and collective level, to support reflections on climate change. Providing information on a community level, can manifest in a social comparison process, in which the members naturally try to reach uniformity with the ones perceived as equals [21].

The challenges of adapting sustainable behavior can be understood by three different mechanisms: (i) unawareness of the relationship between food and climate, (ii) ignorance of the effectiveness of reducing meat consumption, and (iii) conflicting individual and collective interests. Strategies to tackle these are to (i) facilitate reflection over the prescription of behavior and (ii) target beyond the individual. Applying these strategies could make people (i) aware of the relation between climate change and food consumption, (ii) reflect on the impact of their own dietary choices and (iii) understand their impact in relation to others. Following these reflections on designing for sustainability, we argue that technology should support three layers of information:

Layer 1 – Personal Reflection: Through personal daily data collection and reflection tools (e.g., *a smartphone application*), people can track their personal climate impact over time. Personal tools help reflect on the individual connection to a complex topic, while preserving privacy and allowing people to appropriate the data input approach.
Objective: collect individual data over time

Layer 2 – Visualization Vocabulary: To demonstrate the individual impact of food consumption, a visual language is needed that provides a shared vocabulary that can be understood by different people or communities without it being prescriptive. Visualizing and communicating the effect of changes in portion, diet, or food choices helps people become aware of the relative impact of that change in a constructive manner.
Objective: visualize individual impact and change

Layer 3 – Social Frame of Reference: To unite individual and collective interests and provide a frame of reference within a community, a comparative visualization combines both individual and collective impact to allow for social comparison and discussion within the community. This social frame of reference contextualizes individual impact or change within a broader community, leading to reflection.
Objective: contextualize individual impact in a community

An effective system for building awareness on the relation between food consumption and climate change needs to support and address all three layers, as it will allow for personal reflection as well as social comparison and dynamics.

ECONUNDRUM

The goal of *Econundrum* is to increase people's understanding of the relation between their personal food consumption and climate change by engaging them as a community. By explicitly contextualizing people's personal data in a shared representation, *Econundrum* aims to help them build *environmental awareness***:** the ability to reflect on oneself in relation to others regarding environmental impact created by personal life choices. *Econundrum* (Figure 1) is an ambient data sculpture that aims to: (i) help people understand the connection between their personal dietary choices and its climate impact (*layer 1*), (ii) show how different food types create different climate impacts (*layer 2*) and (iii) facilitate social interactions on the topic within a community (*layer 3*).

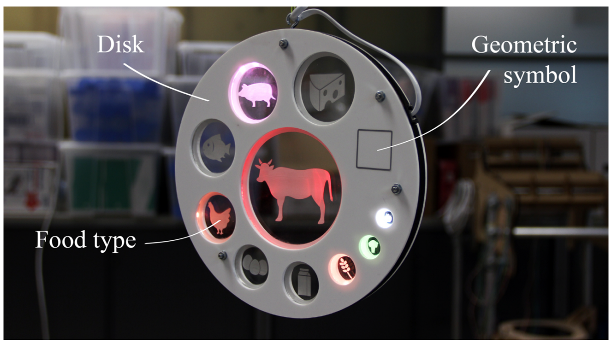

Figure 2. Visualization disk to represent the (breakdown of) individual climate impact.

Design Principles

Empirical work on public installations has demonstrated how they can be beneficial in mediating social engagement with sustainability topics [37,60], by providing tangible information in context that allows for both *individual reflection* and *social comparison*. Inspired by these findings, we designed *Econundrum* to provide tangible information for both the individual and community within a semi-public context. *Econundrum* is based on five core design principles derived from our analysis and experience with prior work on semi-public installations [26,32,33,52] and by operationalizing the ideas of Knowles et al. [41] and Lim et al. [42], to support the three layers of information:

D1. Public and Co-located – To foster group reflection and encourage the *"water-cooler effect"* [25], the system needs to be co-located with the community. Placing the system in a semi-public space will allow social activities and interactions around the system while preserving a 'safe' and private space not accessible to everyone [9]. By placing the system in close proximity of the physical space of the community it can facilitate social interactions around the system in context.

D2. Physical – As traditional screens and displays are prone to display and interaction blindness [34], the system needs to provide clear visualisations that are understandable and discoverable. Using simple physical representations (or data sculptures) that leverage shape, color and light will pique interest and curiosity so people can *"spend time and effort exploring and understanding important and complex data"* [36].

D3. Peripheral – To allow for peripheral interaction [1] with the system, the information should be of abstract nature [52] and unobtrusively present in the environment, but readily available at relevant moments. This will facilitate in remembrance and recall on the information, support spontaneous social interactions in context and allow for observation at a glance [45].

D4. Individual datapoints – To support both an individual and collective connection with the system, individual representations of data should be used for each participant. This will foster a personal connection and responsibility to one component, while allowing for comparison with others of the community [49].

D5. Hybrid of private-public data – A personal application allows for private and real-time input of data, after which the user can immediately observe the feedback in the semi-public setting. Splitting the input and output modality fosters both privacy when providing data as well as bringing together the community when observing the outcomes on the shared system [5].

System Components

The system is composed of three main components: a **smartphone application** for individual data collection (Figure 1A), custom designed **visualization** disks that use a new visual language to show the relation between personal food consumption and climate impact (Figure 1B), and an overall ceiling-mounted **installation** for all visualization disks that supports direct visual comparison between users (Figure 1C).

Each visualization disk represents individual data of one user that was manually collected using the smartphone. This disk uses a visual language (using colored LEDs) to break down the data into different food types. The highlighted food types per disk indicate the composition of the impact of that individual (Figure 2). Each disk is connected to the ceiling-mount installation using a cable, allowing for the adjustment in height. The physical height of the disk encodes the overall level of impact of the person represented by that disk. The higher the disk is, the less carbon emissions, while lower indicates more carbon emissions. We discuss the details of the design of *Econundrum* and explain how it encourages climate awareness by social interaction.

Layer 1 Personal Reflection – Smartphone application

When using *Econundrum*, people contribute individual dietary data through a smartphone application (Figure 3). The smartphone allows for remote and on-site interaction. When entering data, users first indicate which meal was consumed; breakfast, lunch, dinner or snacks (based on MyFitnessPal [22]). They indicate which of 10 food types (Figure 4) were consumed during the meal. To increase granularity, users indicate portion size of each food type – a little bit, normal, a lot – resulting in a more realistic estimation of their *carbon footprint*. Users enter each meal and have the option to make

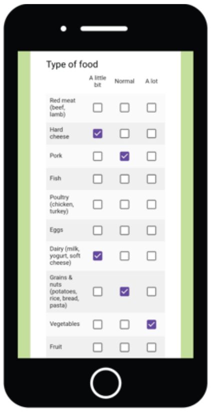

Figure 3. Application.

entries for 'yesterday' in case they forgot. If the meals of yesterday were not submitted before noon a reminder was sent. The use of a personal smartphone for data collection provides flexibility in monitoring food intake, while preserving privacy when doing entries to the system (*D5: providing a hybrid of private-public data*). Furthermore, the process of entering data provides a first level of reflection on personal food consumption [14].

Layer 2 – Visualization Vocabulary: Disk design

The second step in supporting reflection is by translating the personal data of each user into a visual language that reflects the climate impact. When a user submits data using the application, the data is directly translated to climate impact and depicted on the corresponding disk by updating its colors and height (*D2: physical representation of data to provide immediate feedback in the environment*). The climate impact resulting from a user's consumed food is established using the food's carbon footprint or *foodprint* [6]; the carbon emissions as a result of the production chain of a product. We use existing data on carbon emission equivalent per serving of different food products to establish the relative climate impact of the 10 food types included in the system [12,56]. Figure 4 shows a visual language we constructed using the value of red meat (the highest impact food) as a unit of comparison: one serving of red meat results in the same amount of carbon emissions as 3 servings of cheese, 5 servings of poultry, 36 servings of vegetables, or 60 servings of fruit. In total, our visual language supports the 10 most common food types.

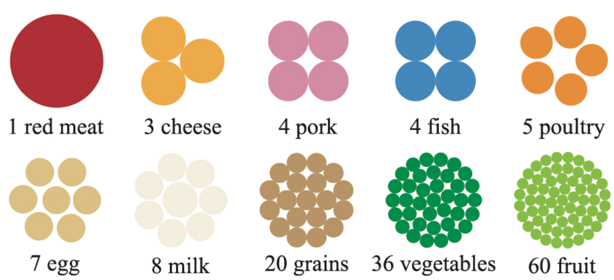

Figure 4. The relative carbon emissions of different food types. For example, the amount of carbon emissions resulting from 1 serving of red meat is the same as that of 60 servings of fruit.

These 10 food types are shown as transparent circles on the individual disks of *Econundrum* (Figure 2). The surface areas of the circles represent the relative carbon emissions of the represented food types, e.g. the circle representing red meat has a surface area that is three times larger than the one representing cheese. Icons are engraved on the transparent circles to indicate the food-types. Four LEDs are mounted against the rim of each circle representing the four meal types (breakfast, lunch, dinner and snacks). They are lit real-time when the food type is consumed in the corresponding meal that is entered in the app. We visualize the dinner of the previous day, as otherwise it would have been missed after leaving work. We selected one specific color for each food type (red for red meat, pink for pork, green for vegetables – Figure 2), so that each engraved icon would always light up in the same recognizable color *(D2: providing simple physical representations to pique interest)*. The disks have a diameter of 19.5 cm and are laser cut out of white acrylic and MDF.

Making sustainable food choices is often hard because many people are unaware of which products have a relatively high or low climate impact [7]. De Boer et al. [7] showed that knowledge on the effectiveness of reducing meat consumption relates directly to people's willingness to reconsider consumption. We therefore decided to show 10 food types clearly on the installation. In order to enable reflection, we depict the impact a user's food choice has but also how this impact is constructed. The easy-to-understand visual offered by *Econundrum* aims to directly inform users how they can lower their climate impact, and that lowering one's impact does not imply obtaining a vegan diet but can already to some extend be achieved by, e.g. choosing chicken over beef [13].

Layer 3 – Frame of Reference: *Econundrum* Installation

To allow people to compare their impact visualized on the personal visualization disk with others, *Econundrum* is located in a central workspace of the community so it is visible at all times (*D1&D3: placing the system in close proximity and unobtrusively in the environment)*. The installation consists of nine individual disks, which are suspended from the ceiling to allow for observation from multiple angles and distances. Eight disks represent data from the participants and an extra disk in the center of the installation shows the average carbon footprint of the community of the first week. Our design is inspired by design guidelines of shape-changing interfaces [50] on types of shape-change, transformation vocabulary, and ways of interaction. To support social comparison of individual climate impact we (i) visualized the members of the community by individual data points (disks) and (ii) showed the climate impact of each individual by vertical positioning, thus using a metaphorical 'light' or 'heavy' impact on the climate by a higher or lower position (*D4: using individual datapoints to support both individual and collective connection*). In case no data is submitted the lights of the disk are off and it is positioned close to the ceiling. Eight of the disks each are assigned to a member of the community. Each individual can identify their own disk by a unique geometric symbol (Figure 2) to allow easy recognition of their own disk while keeping the option of remaining anonymous to other members of the community (*D5: foster privacy in public setting*). *Econundrum* scales itself according to the largest and smallest carbon footprints.

<u>Technical setup:</u> *Econundrum* uses a Wi-Fi-enabled microcontroller that powers nine servo motors and 360 RGB LEDs. Each motor drives a vertical pulley that controls the elevation of the disks. Telephone wires were used to power the disks. All components are mounted in a frame attached

to the ceiling. Participants input data via a personal application with an embedded Google Form [27] which was added to the home screen of their smartphone. The data is saved in a Google Spreadsheet [28] that performs calculations to convert the data to rotation values for the servo motors and color values for the LEDs. The system fetches the data when new, resulting in the installation updating the colors and heights.

FIELD STUDY

We conducted a three-week field study with eight participants to evaluate the extent to which a data sculpture in a communal setting mediates social interactions and facilitates collective reflection on the relation between food consumption and climate change. The study was run under the ethical code of conduct for scientific integrity of the Eindhoven University of Technology. The goals of the study were to demonstrate people (i) are willing to submit data, (ii) can read both personal and shared data using *Econumdrum*, and (iii) reflect and discuss the effect of their food choices on the climate.

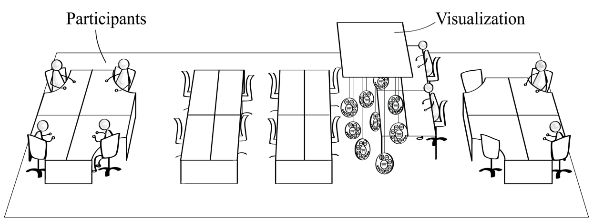

Figure 5. The layout of the workspace of our participants.

Participants

To evaluate the shared aspect of the data sculpture in situ, we selected a community as an existing social circle, a suggested practice in qualitative research on groups [40]. We recruited a pre-existing community of eight adult knowledge workers (18+) in the field of Industrial Design, who were co-located in a university shared workspace (Figure 5). Most participants were present full-time in this workspace, with exception of P5 and P8 who were present part time and P7, who was only present one to two days a week. All participants followed an *omnivorous* diet, however P6 indicated that they consumed little to no meat for religious reasons, and P7 did a 'meatless Monday'. All the participants indicated that they prepared food at home most days of the week. Further, for decades P3 kept his own vegetable garden. For more background information of each participant see Table 1.

P#	AGE	GENDER	OCCUPATION	LIVING
1	58	Male	University teacher	Alone
2	61	Male	Technical assistant	Partner
3	57	Male	Education & research assistant	Family
4	28	Male	Research assistant	LAT
5	26	Female	Master student	Partner
6	45	Male	Research assistant	Family
7	27	Male	Design engineer	Partner
8	24	Female	Master student	Alone

Table 1. Demographics of the participants.

Procedure

The study started with an individual meeting between researcher and participant, in which we introduced the study, collected demographics, asked the participant to sign a consent form and conducted a short individual qualitative interview on their current diet and its relation to climate change. We asked participants to fill in a questionnaire (Q1) to gather (i) their current motives for the selection of food by an adaptation of the Food Choice Questionnaire [57] and (ii) their attitude towards climate change by an adaptation of the Climate Change Attitude Survey [15]. We installed the smartphone application on the participants' phones so that they were able to submit data entries. Each participant did so for a period of eight to 13 days before *Econundrum* was installed during three weeks in their shared office space. The data collected in this eight to 13-day period was used for the 'average disk' in the center of the installation. For an overview of the procedure per week see Figure 6.

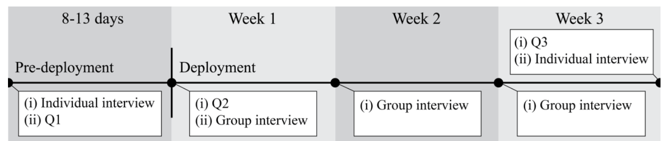

Figure 6. Procedure timeline.

At the start of deployment, each participant filled in the mentioned questionnaire again (Q2) and we conducted a qualitative group-interview on the overall experience with the application. At the end of the interview we explained the working of *Econundrum* and visualized three example days of the past week to familiarize them with the system. During the following weeks the participants kept using the app and their data was used to update *Econundrum*. We conducted weekly group interviews to capture the participants' experiences. After the end of the three-week deployment, all participants completed the initial questionnaire again (Q3) and we conducted individual interviews on their overall experience.

Data collection & analysis

During the study, qualitative data was collected via individual pre- and post-interviews and intermediate group-interviews. All interviews were audio-recorded with participants' consent. Recordings were transcribed and the subtracted 465 quotes were categorized by the researcher with a deductive approach along the three research themes: (i) personal reflection on the topic, (ii) encoding and understanding of the data sculpture and (iii) social interactions due to the system. Per theme, the quotes were analyzed using inductive thematic analysis [8]. To increase reliability, the first author conducted the analysis together with two external researchers with no involvement in this research to identify emerging common themes in the qualitative data. For each theme, each researcher first individually clustered one third of the quotes, after which the emerged clusters were discussed until agreement among the three researchers on the final clusters was established. Complementary to the qualitative data, quantitative data was gathered from system logs, providing information on the food consumed per meal per participant. Further, data was gathered from the questionnaire. The interviews were performed in Dutch; the quotes presented in the next section have been translated to English.

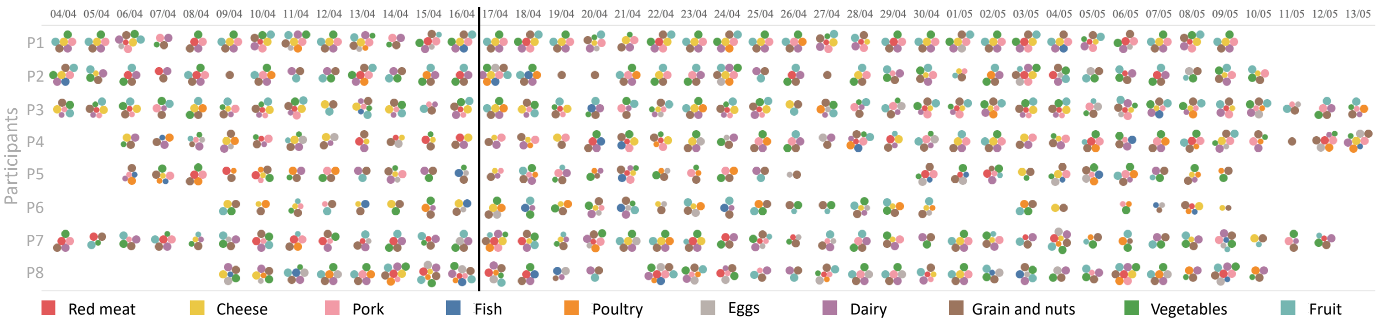

Figure 7. App submissions throughout the deployment, the line shows from which date the data sculpture was introduced.

RESULTS

The findings suggest that the physicality of *Econundrum* provided the participants with continuous access to peripheral information. *Econundrum* facilitated social interactions and its location functioned as a meeting place. The clearly visible physical features, such as difference in colors, surface areas and height were simple to remember. The study indicates that different layers of information helped people build understanding of the topic. In this section, we summarize the raw data from the application logs, and present qualitative findings from the group and individual interviews according to the three layers of information: (i) personal reflection, (ii) visualization vocabulary and (iii) social interactions.

Application Logs and Data

All eight participants contributed personal data to the app. Together they submitted 821 entries ($\bar{x}$: 102.9, min: 67, max: 136, $\sigma = 21.23$), with on average 2.9 submissions per person per day. Figure 7 visualizes the full breakdown in food types for all data used by the *Econundrum* to configure the installation. As indicated by the standard deviation, some participants did not submit many lunch or snack entries (Figure 8). Aggregated questionnaire data regarding food choice showed that ethical concern with climate change ranked low ($\bar{x}$: 2.3, $\sigma = 0.19$). However, aggregated questionnaire data regarding the climate attitude showed a high average score for its two constructs *believe* and *intention* (5-Likert scale, $\bar{x}$: 4.1, $\sigma = 0.10$), meaning the attitude towards climate change is positive: the participants *believe* it exists and show *intention* to act upon it. Therefore, participants were willing and quite consistent in contributing their personal data to the system. Figure 8 shows a breakdown of entries per participant.

Participants were instructed to submit meals at their own discretion. All reported that they attempted to estimate their food consumption honestly and correctly. Some expressed challenges when submitting products that did not clearly fit one of the food types, e.g. pizza or other processed foods. In these cases, participants would estimate the quantity per food type. Overall, the input was considered easy and useful.

The application data does not reveal any significant changes in the diets of participants (Figure 7). However, after the introduction of *Econundrum*, there were small indications of change in individual's food choices. For example, P6 reduced cheese consumption during breakfast and P6 and P4 increased vegetable consumption during lunch and dinners. Furthermore, the explicit connection to the physical installation became more apparent as people noticed the direct impact of their food entry. Finally, some participants mentioned additional portion sizes and information about the wider sustainability of individual food items could be added to the app.

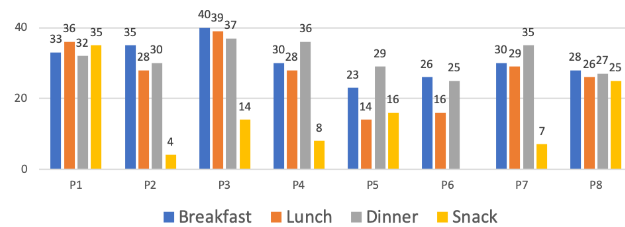

Figure 8. Data entries per meal type per participant.

Personal reflection (Layer 1)

We observed that *Econundrum* helped to facilitate personal reflection and building of understanding through interaction with both the application and the shared data sculpture.

Understanding the relation between food and climate

During the group interviews participants described their understanding of the relation between (their) food consumption and climate change differently. Four participants solely acknowledged the existence of a relation, two related the connection in the context of physical elements of the system, e.g. *"the larger the icons are, the more damaging it is"* (P6), and two expressed a deeper curiosity of the relation, e.g. "*what is actually a sustainable diet? […] there are so many aspects, what should you pay attention to?"* (P3). When asked about their key takeaway from the study, seven participants recalled the visualized impact proportions of the food types on the disks (Figure 2). As a result of the study, all participants had formed *new questions and concerns*, amongst others related to: (i) the knowledge behind impact of food types, (ii) the calculations behind the system, (iii) the relation and possible conflict between eating healthy or varied, and eating sustainably and (iv) which concrete products and dishes could be consumed to be more sustainable.

Awareness leading, small actions and alternatives

Five participants reported on different emotional responses triggered by the system, ranging from indifference, *"It is a visualization of what I do, nothing more"* (P1), to feelings of guilt or hypocrisy, e.g. *Econundrum* made P7 realize that his 'meatless Monday' may not be effective when he substitutes chicken or pork for cheese. Contrarily, P4 and P6 were happy with their diet in terms of sustainability: *"I do not eat much meat, so I do not have to change that pattern"* (P6).

Econundrum led to increased awareness on, and attention for, the topic of climate impact caused by food consumption. Six participants reported thinking about it and discussing it with others more than usual. The visualization stimulated feelings of self-consciousness: *"I only think, 'damn, now I have to fill in that cow again', but it does not necessarily mean I will not eat it"* (P4), *"What starts now as a feeling of guilt might later be the reason to change behavior"* (P6).

Two of the participants discussed challenges to change their diet because of a lack of alternatives. P3 felt he had to choose between two evils regarding sandwich fillings: cheese which is a high-impact product, or chocolate spread, which he believed to often be produced by child labor. Others showed small actions in favor of sustainability because of *Econundrum*, e.g. choosing poultry over red meat on their sandwich (P2), being open to vegetarian meals (P5), trying to reduce cheese consumption during breakfast (P6) and committing to plan meals and have healthier breakfasts without meat (P8).

Other priorities and values

Eating sustainably was perceived as not easy to combine with other priorities or values the participants have, such as healthy food, variation, availability, convenience, costs, beliefs, taste and - often mentioned - habit. This is in line with the findings from the questionnaire, which showed that the ethical concern came after sensory appeal, health, price, convenience, natural content and mood. Only one participant saw eating more sustainably as a direct win-win situation: *"I have to eat more vegetables anyway, because otherwise it is a waste of myself, and it is also not so bad for the environment, so in that respect you have a win-win situation"* (P5).

Visualization Vocabulary (Layer 2)

Our study illustrates how a complex topic can be visualized in a peripheral and physical form factor such as *Econundrum*. All participants understood the visualization and reported that the bright colors, shapes and changing heights were easy to remember and could be perceived at a glance.

Peripheral information

All participants reported that they observed *Econundrum* multiple times a day both from their workstation as well as when they passed by: *"When I entered the workspace I only had to look at [Econundrum] for a moment and then I immediately had an idea of: I'm not doing very badly or others have not filled in anything yet ..."* (P7). *Econundrum* functioned as a reminder to submit new data, but also provided immediate feedback on submitted data. Five participants reported that after seeing the data sculpture, they frequently added new data and would consciously monitor *Econundrum* to check the immediate change to the system, e.g. when entering the workspace after having lunch together. Moreover, P8 mentioned she regularly thought about the data sculpture before entering the building and P7, when submitting data remotely, felt motivated by the thought that others could obtain his information while him not being present.

Physicality and aesthetics

Seven participants indicated that the pleasing aesthetics of *Econundrum* enticed them to look at it. Six participants commented on the physical presentation of information, which made it stand out (novel) in comparison to traditional displays: *"The use of light, colors, icons and movement [...] If you would take that away you end up with 'just another system'. We already have so many of those"* (P2). Five participants reported that the level of abstraction of the data sculpture was appropriate in the environment and the relative surface areas of the food types provided sufficient information. Four participants reported that the icons used in *Econundrum* clarified the connection with food immediately. However, grasping the full implications of their actions on the climate was less intuitive and instead the association between good and bad was made: "*It is nice that, for example if you have eaten badly for the environment, you literally drop to the ground … Rising is kind of a good thing in our eyes"* (P5).

Interpretation strategies and challenges

All participants associated the individual disks with themselves, which showed in their explanations: *"Sunday I had a barbeque, so I thought: tomorrow I [disk] will probably hang low"* (P4). Seven participants reported that when viewing *Econundrum*, they first looked at the height and colors of their individual disk, before comparing to disks of the others or the average disk. They indicated that, in later weeks, they could interpret the data sculpture at a single glance: *"In the course of time [interpretation of the data] goes much faster. You walk past it and you quickly scan the colors […] which also means that you can read, interpret and easily discuss those [disks] of others"* (P3). Six participants indicated that they could predict how the submitted food types would roughly show in the colors and height of their disks. Three participants indicated an inadvertent negative connotation between the perceived variety of someone's diet and its climate impact. The amount of colors in the individual disk was associated with the variety of someone's diet, whereas for a minimal impact people ideally would consume only the smallest food types, resulting in a lack of colors.

Data mapping ambiguity

During the weekly group sessions, we observed ambiguity in participants' perception of the data due to the following two reasons. The first problem was that when entering data, participants had to indicate which one of four meals was consumed, which reflected in one of the four LEDs against the rim of each food type circle. However, six participants reported they were not always able to see which and how many LEDs were lit up and therefore miss information about submitted meals. The second problem was reported by four participants, regarding the selection of portion sizes for each food type consumed. The weight of portion size only reflected in the height of the disk and not in the LEDs as these only indicated if a food type was eaten at all (regardless of portion size). Entering for example a lot of red meat or a little of red meat would result in the same red light, but in a different height. Therefore, difference in height could not always be explained by observing the food types solely and required for inquiry: *"Sometimes we would argue, for example, why someone who has eaten beef once would hang lower than someone who has eaten cheese and pork twice. Then it is not entirely logical why that person with only beef is still hanging lower"* (P5). These two problems were not mutually exclusive, which led to further confusion among participants.

Social Interactions and Group Dynamics (Layer 3)

Our study revealed the social dynamics that occurred around a data sculpture such as *Econundrum* in a shared office space.

Social role: discussions about data

As reported by six participants, *Econundrum* provided a meeting place in the group's shared office: *"[Econundrum] is a bit like a coffee machine [...] you walk there to talk about it. You come into contact with people"* (P3). The location of *Econundrum* often served as a conversation starter. In case an individual was standing close to the data sculpture to observe it, this was often interpreted by colleagues as willingness to chat about the data shown. Five participants explained that *Econundrum* was perceived as a group activity and connected them because it triggered to exchange perspectives and share experiences. The data sculpture was experienced as being meaningful because it visualized everyone both individually and together: *"It was about all of us together and that you start talking to each other [...] Collectively giving feedback on how someone eats"* (P5).

Social comparison and approaching others

All participants used *Econundrum* to make comparisons, mostly regarding relative position, between each other. Most attention was paid to the highest and lowest disks, however P2 preferred to compare himself with the average instead of the others. These comparisons allowed the participants to assess their diet in relation to others, leading to self-reflection.

Five participants reported that several situations, such as the height of an individual disk, the lack of submissions of an individual or the amount of colors on an individual disk, gave them reason to approach others and start a conversation: *"If everyone hangs quite high and only one person hangs low I would go and get an explanation from that person"* (P5). Often these approaches were done in a humorous way: *"I once said to P2: did you have a barbeque? ... Because his disk had many colors and was hanging low"* (P4). Lastly, the data sculpture initiated conversation by coincidence: *"I never knew which [symbol] belonged to whom, so I just made a general comment such as: 'Circle has ...' and then there is sometimes a reaction from Circle [other participant]"* (P8).

Conversation within and outside the community

Econundrum initiated various conversation topics among the participants during the group sessions. These included consumed food, sustainability, health, variety of food, the technology behind the system, and the effect of consuming certain food types on the data sculpture. In the individual post-interviews, no one reported that they felt negatively influenced by others – which was also observed during the group interviews. Lastly, P7 used humor as a mechanism to cope with the low position of his disk compared to others: *"On the one hand it was fun to joke around, but it also gave me some sort of balance, because I felt that the rest [of the group] was on a different scale [and doing much better]"*.

Six participants indicated that conversations about *Econundrum* were not limited to within the group of participants and they would also discuss *Econundrum* with family and friends outside work. In such conversations, they regularly showed pictures and sometimes these chats were about sustainability as well. Further, during the deployment of *Econundrum*, a lot of visitors who did not participate in the study were present in the shared workspace. Therefore, five participants reported that the installation regularly triggered conversations between them and the visitors, mostly about the functioning of *Econundrum*. This could have been due to novelty of the system but also led to conversations about sustainability. Lastly, conversations with peers would occasionally demonstrate to participants the effect of *Econundrum* on their environmental awareness: *"I told my friends, but they did not respond ... Before I was just like them, we did not really care about sustainability, food and what it does to the environment. Now that I think more about it, I wanted to share that with them, but they did not go through that process"* (P5).

DISCUSSION

To achieve a global systematic adoption of sustainable behavior, better applications, systems and tools are needed that allow people to appropriate sustainability to their personal lives and build environmental awareness. While strategies to motivate sustainable behavior – e.g. supporting reflection and targeting beyond the individual [10] – exist, there are no clear mechanisms or approaches to translate the concepts and problems around sustainability into design. We operationalize these concepts into design principles, and designed *Econundrum* as an exemplar, implementing these principles.

Designing for a social context requires a careful balance between personal reflection, and social sharing and visualization. Personal tools enable people to collect individual data in a private context, while social tools allow them to contribute those data to a shared frame of reference, which helps comparison and wider reflection. *Econundrum* leveraged personal tracking to collect and reflect on personal data, while the shared physicalization functioned as an in situ ad hoc shared visualization that helped people assess and understand their own impact within their social circle and context. Combined, these tools allowed people to explore personal as well as societal impact of dietary choice on climate change.

Personal Reflection (Layer 1)

Econundrum facilitated personal reflection and building of environmental awareness through interaction with both the application and the shared data sculpture. The application functioned as an initial in situ reflection tool that enabled participants to reflect on and contribute their personal data [14]. Together their submissions co-constructed a shared frame of reference for social comparison. This shared representation helped in building an understanding of the relation between (personal) food consumption and the impact on climate change. The physical presence of the data sculpture prompted participants to submit data and provided them with a readily available representation of their personal impact.

Although the focus in this study was not on behavior change, we observed a change in participants' attitudes and discussions during the weekly group sessions, suggesting an increased environmental awareness. Particularly, the addition of personal data over time proved to be beneficial in establishing a personal connection to the system. It elicited different emotional responses and reflections on what it means to be sustainable, also in the light of other personal goals [51].

A secondary topic that emerged in multiple ways during our study was the *importance of health*. Participants highlighted it as an important value across the three information layers. By leveraging instances where health and climate impact intersect, e.g. reducing red meat consumption, one can appeal to the person's self-interest, i.e. personal health, whilst encouraging sustainable behavior. Future work could focus on raising awareness while getting the climate impact of food choice higher on the priority list when selecting what to eat.

Visualization Vocabulary (Layer 2)

Physical visualizations are always "on" and enable spontaneous interactions with data [36]. The materiality and decomposition into smaller personal objects give people individual ownership over their 'data disk' and can be perceived from multiple angles and distances, which is not always the case with displays [4]. Public displays can suffer from interaction or display blindness [34] which makes them notoriously hard to use. While physicalizations can be prone to perception problems as well [53], the design of *Econundrum* was directional, as the disks could be read from both sides. The 3D shape and position of *Econundrum* allowed it to act as a centerpiece in a shared office that was easily accessible and afforded people (both participants and visitors) to come together and (informally) discuss the data. Our design illustrates how a complex topic can be visualized in a peripheral and physical form factor. Difference in colors, surface areas and height were easy to recognize, simple to remember and over time could be perceived at a glance. Therefore, observing it did not require extra time or effort, but could be done casually and on-the-go, e.g., when walking by. Moreover, these features leveraged the novelty effect [43] making the physicalization stand out in its environment.

Designing a physical system requires some trade-off between providing precision and fidelity, and a visualization that can be read and understood at a glance [45]. As there is little room for detailed information, this can lead to ambiguity in the interpretation of different physical aspects; e.g. the disconnect between the granularity of input and output of data, which created confusion among the participants when attempting in-depth interpretations of *Econundrum*. Further, differences in disk-height provided a natural mapping to good' and 'bad', however the connection between *Econundrum* and carbon emissions was not experienced as intuitive. This can be understood by the *metaphorical distance* [65] between the dataset and the physicalization, which needs to become smaller to create a direct association with climate change. The relative changes in *Econundrum* helped to understand the changes in data. Everything happened within a frame of reference of the social circle, making it easier for people to understand changes, even though the absolute positions of the disks was not always understood in depth. Through a data sculpture such as *Econundrum*, a community is regularly exposed to data in an unobtrusive way, which could help in getting a sense for how their dietary choices and those of others are of influence on the climate over time.

Social Interactions and Group Dynamics (Layer 3)

In contrast to prior data sculptures for sustainability [5,37], *Econundrum* provided real-time data, both in aggregation and individual datapoints, further stimulating reflections and comparison among the participants. *Econundrum* had a *"water-cooler effect"* [25] as people could gather around and talk. It allowed an existing social circle to share their visions on a topic that would normally not be part of daily grind.

Shared systems create a '*social buzz'* [37] that engages a community with a certain topic. Because *Econundrum* was specifically designed for a small group of people within a social circle, it provides a dynamic frame of reference to contextualize data. People could choose to compare themselves to others in the group or the average. Further, this deployment site included a wider more 'public' community, as it was often entered by students and visitors, which allowed for the exploration of any additional social dynamics. The data sculpture drew in non-participants to look at the data, in which case the participants acted as '*champions*' [2] delivering the message to the general public. Although the spectators had no personal connection to the system, they could receive a takeaway from observing the visualized impact proportions of the food types and/or the conversations with the participants. Whilst in our study there was variability in age and occupation of participants, they exchanged their visions on the topic, engaging in a social influence process [21].

CONCLUSION

There is a need for novel ways of engaging and activating individuals, social groups and the public at large to address a complex topic as climate change. We contribute new design principles, empirical findings and insights into how social shared reflection occurs within small co-located groups. We introduce *Econundrum*, a shared data sculpture on dietary choice and climate impact. Our field study showed that *Econundrum* created understanding of the topic, by physically representing layered information in the periphery and providing continual association and immediate feedback. It illustrated how people can be involved collectively by facilitating social interactions within a community. As a result, *Econundrum* increased environmental awareness and provides insights for further change towards sustainability.

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