# *From Data to Physical Artifact*

## *Challenges and Opportunities for Designing Physical Data Artifacts for Everyday Life*

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## Key Insights

- We introduce the concept of physical data artifacts used to visualize data.
- We outline key elements to consider when translating data to everyday design.
- We synthesize insights about the use of physical data artifacts to inform future design.

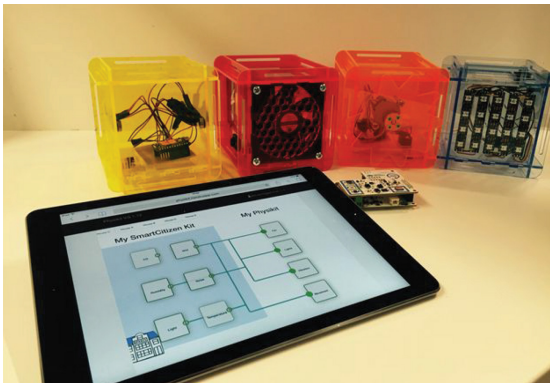
## *1. From Data to Design*

**The Role of Data in Design for Everyday life**

We are in the middle of a data revolution. Large amounts of data can be collected about ourselves and our environment. Modern technologies, such as wearables, sensors, and crowd-sourced tools are revolutionizing the way datasets can be accessed and used by bigger audiences than ever. This availability has the potential to empower individuals, groups, and communities, and lead to personal, communal, environmental, or even political change as they become a leveraging tool for reflection, discussion, and decision making.

However, the way in which such widespread data availability can be leveraged or embedded into everyday life is an open and difficult challenge. In recent years perspectives such as **Human-Data Interaction** (HDI) [5], '**data commons**' or '**data humanism**' [4] proposed to shift the ownership, actionability, and interaction with data towards people themselves. But democratizing the access and presentation of data in a meaningful context to non-experts remains a difficult problem, as there is a systemic lack of tools, visualization approaches, and conceptual and interaction models targeted at non-expert groups.

We propose that meaningfully embedding data into everyday experiences through artifacts is a way of bridging this gap between people and datasets. Literature and our own experiences with constructing '**physical data artifacts**' show that, for data to become meaningful to people, there needs to be a strong and direct connection to their own experiences, activities, or situations. Bringing data close to those personal experiences leads to interactions or understandings that leverage the data to create more informed and actionable outcomes (i.e. enjoyment, reflection, or behavior change). As this translation from data to designing everyday experiences is a fast-emerging research topic, we reflect on challenges and opportunities learned through our own experience of creating and deploying physical data artifacts in the wild [2, 3, 6, 7].



*A. Ambient Data Visualization - LOOP [7] & Physikit [3]*


*B. Data Sculpture - Econundrum [6]* *C. Data Installation - Roam-io [2]*

**Figure 1. Different forms of Physical Data Artifacts**

**What are Physical Data Artifacts?**

**Physical data artifacts** are *interactive physical artifacts that: (i) represent data through physical and material properties, and (ii) allow for meaningful interaction, configuration, or interrogation of that data.* In this context, *data* includes a wide spectrum of types and fidelity of datasets ranging from direct 'raw' data (e.g. *a sensor-reading*) to aggregated datasets (i.e. *a snapshot of air pollution in London*), experience sampling (e.g. *bullet journaling*), or even derived data (i.e. *quality of sleep through a motion sensor*). Broadly speaking, physical data artifacts are any form of physically designed objects that present one or more datasets to a person, group, or community within a specific context. In our views, this embeddedness or situatedness is fundamental to co-constructing meaning or actionable outcomes from data.

Physical data artifacts come in many different shapes and forms, and have been around for and evolved over centuries [1]. While other work provides a complete overview [1], we highlight some forms of physical data artifacts as observed within our own work. The first type is *ambient data visualizations*, which are abstract event-based communicators of changes in data that are important, but not essential to the viewer (Fig.1A LOOP [7] & Physikit [3]). The second type, *data*

*sculptures*, are artistic representations of socially relevant issues (Fig.1B Econdrum [6]). Finally, public *data installations* are often larger interactive systems that are designed as kiosks for data inspection and exploration on a larger scale (Fig.1C Roam-io [2]). These broad categories are not mutually exclusive or exhaustive, but are demonstrative of a spectrum of different form factors and different ways of interacting with data.

## *2. Lessons Learned from Designing Physical Data Artifacts*

**How to select data?**

The goal of **physical data artifacts** is to translate complex problems or situations into a representation that leads to an awareness, understanding, or reflection, which in turn enables meaningful outcomes or change. For example: '*how to understand the climate impact of dietary choices?*' or '*what is the impact of pollution in cities on everyday life*?'

The main consideration when designing a physical data artifact for a particular context is *what* is the actual information people need and in what form to tackle the topic at hand? We often see data communicated through classic UIs with numbers and graphs. However, people are generally more interested in relative changes, and not in absolute values. Secondly, we have to consider *how* to communicate the information. There is a difference between communicating 'if something is happening' versus visualizing 'what is happening'. We want to utilize physical space and the design to communicate data changes and relations, not only states. Moreover, the target audience can have different goals and information needs that can change over time. Important data elements that need to be defined are *granularity* (what level of detail does the audience need?), *actionability* (how can they use it in daily life?), and *temporality* (in what frequency over what timespan?).

In our work, we observe different strategies when it comes to dataset selection. One can either take a user-centric or domain-centric approach, by directly inquiring the target audience (i.e. interviews with users of activity trackers for LOOP) or obtaining knowledge from related fields (i.e. looking at eco-visualization literature for Econundrum). These activities can happen in a more or less participatory way, and with different stakeholders in relation to the topic (i.e. target audience or experts).

**How to translate Data to Design?**

The next challenge is to translate the selected data into a meaningful design. This *translation process* (or representation mapping) is not straightforward, and 2D visualization methods are only partially informative for communicating information in 3D space. As there are currently no established communication tools, we need to develop a specific *visualization vocabulary* - a visual

language that can be understood and interpreted by the audience. From our experience, we extract 3 important things to consider when constructing this language:

1. **Aesthetics**: If something is not aesthetically pleasing people do not want it in their home (LOOP, Physikit), or in the case of (semi-)public environments, they would not be inclined to look at it when it is not aesthetically interesting or stands out (Econundrum). Therefore, a physical data artifact should balance informative and aesthetic properties, so it's meaningful for the audience, but also pretty to look at for other people.
2. **Abstraction**: It is important to keep in mind the difference between a metaphor and abstraction, as they can be more or less effective in communicating information. An abstraction is general enough to make the physical data artifact blend in the physical environment (in people's periphery) so it can be ignored when not needed, but also allows for its own interpretations and metaphors when chosen to look at. Using abstraction creates information that is easier to comprehend by people. For example, LOOP visualizes the increase of steps (progress) by abstract upward movement, whereas Econundrum metaphorically visualizes food types through graphical icons.
3. **Comparison**: 'Raw' values or data points (e.g, from an air pollution sensor) are often difficult to interpret. If we can compare data over time (historical data), or across different categories (any type of reference data) it can become more informative. Hence, creating meaningful comparisons, either absolute or relative, between elements of a dataset allows for the audience to make sense of the data. For example, knowing the number of steps you walked is not interesting in itself, but knowing if you did better than yesterday, or better than your friend allows for meaningful comparison.

**How to develop and construct Physical Data Artifacts?**

The next challenge is to develop the concept and build the artifact. There is no fixed infrastructure when it comes to the tools and methods for designing and constructing physical data artifacts, and it is often an intersection of many digital and physical elements, such as online data systems, sensors, and actuation mechanisms, that together form the physical representation of data.

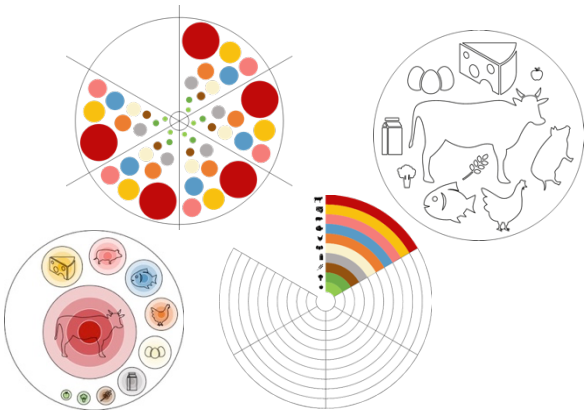
**Where do you start?** It can be helpful to get inspiration from related fields as the design of physical data artifacts is really at the intersection of different disciplines. We can build on knowledge from related fields (i.e. shape-changing interfaces and InfoVis) and they can support the translation process of figuring out how to visualize the information most effectively, from a mechanical, constructive, and conceptual perspective.

**Who do you involve?** It can be challenging to identify stakeholders and their interests, moreover, different stakeholders can have conflicting interests, which will most likely influence the creation

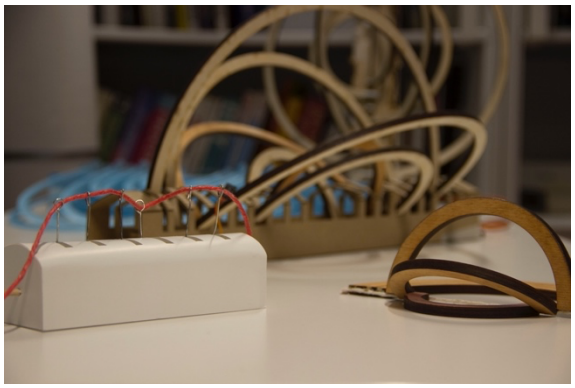
of your physical data artifact. Hence, it is important to identify the stakeholders and users relevant to your topic and involve them in the translation process early on.

**What design activities can you do?** Explore a variety of creative methods, either with or without users/stakeholders, as these can help you to draw inspiration and insights in unique ways. Example activities are, but not limited to: analog/digital sketching (Fig. 2A), rapid prototyping (Fig. 2B), creative sessions with users (Fig. 2C), and pilot studies (Fig. 2D).

**How do you realize it?** After the concept development of the physical data artifact, a varied skill set is needed to create the final system (Fig. 3), which also needs exploration in itself. Think of activities such as developing the UX design of the interface, mechanics for actuation, electronics for artifact behavior, but also to develop the 'online' part of the system: to connect the physical changes to digital data, and to bridge the physical artifact and the digital data stream.



*A. Digital sketching*

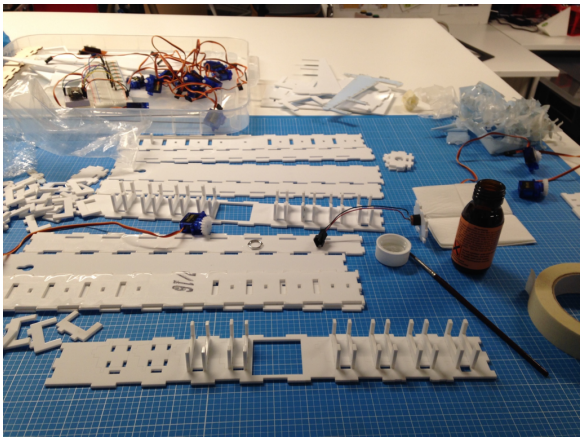


*B. Rapid prototyping*

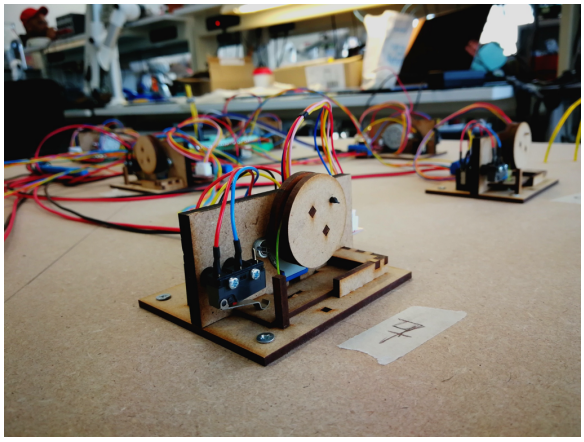
*C. Creative user sessions*

*D. Pilot studies*

**Figure 2. Exemplar design and translation activities.**



*A. Design & Construction*



*B. Electronics & Mechanics*

**Figure 3. Exemplar realization and implementation activities.**

**How are Physical Data Artifacts Used?**

The role of physical data artifacts is to explore how people can leverage different situated representations of data in everyday situations. From our experiences with deploying physical data artifacts in field studies, we observed three main important usage patterns that are central to designing new physical data artifacts:

1. **Exploratory awareness**: As people often start with little to no insights about the data, there is an initial phase of highly explorative behavior and interactions with the physical data artifact in which people explore the changes, meaning, and understanding of the data through various mappings and actions. The more physical data artifacts enable such exploratory interactions (e.g., through reconfigurations or mapping tools) the faster people will construct a basic understanding of the scope of the data that will lead to more sustained and meaningful interactions. Physical data artifacts are a portal into an intangible data space and often become a central hub or meeting place for the discussion of the topics related to the data. While an initial understanding or awareness about the data can be valuable for people, concrete actionable outcomes, activities, or steps will help people internalize the importance of the data and its consequences.
2. **Appropriation as utility**: One of the central observations across our different field studies is that once people build a basic understanding of the scope of the data, the presentation of that data becomes a platform for more refined exploratory appropriations to bind the meaning of the data to situated activities, events or context. To facilitate these explorations, physical data artifacts could explicitly support ways of appropriation through a range of basic flexible design patterns. For example, being able to: move the physical data artifacts, turn them on/off, change the basic data mapping, use it by multiple people, or remote control it.

3. **Social frame of reference:** A third central observation about the way physical data artifacts are used in the wild, is the importance of a social frame of reference. In all our studies, we observed how people compared their own interpretation of the data to other mappings or data representations to create a direct comparison that allows them to understand the data in relation to an external point of reference. Examples are: rather than trying to understand the air pollution level in their street, people would compare the change to a location which they knew was heavily polluted. Furthermore, we consistently observed that physical data artifacts are used by groups of people (i.e. colleagues, families, passers-by) and *not* individuals alone. Data exploration through physical data artifacts is a collective sensemaking activity, and the basic design of these artifacts should directly support this.

**What are the implications and consequences of data in the real world**?

Making data visible in everyday life brings it close to the context, activities, or situations it impacts. This can lead to direct and important consequences at a personal (e.g., *behavior change*), social (e.g., *community impact*), environmental (e.g., *climate change*), or even political (e.g., *policy changes*) level. However, because physical data artifacts are embedded into everyday life and experiences, there is also a danger for negative consequences:

1. **Lack of actionability**: While increased awareness of situations through data can be empowering, the lack of actionable outcomes or steps can lead to a situation of helplessness or confrontation. For example, continuously exposing people to COVID dashboards can be anxiety-inducing, or what happens if people understand that the air pollution in their street is consistently at a high level, but they have no means to affect change to it?
2. **Privacy and sharing:** We observe in our studies that physical data artifacts are almost consistently used or appropriated by groups of people, which poses interesting challenges about how data - that might be personal or identifiable - should be treated. For example, people might differ in what they feel comfortable sharing about themselves or have different reactions to the shared data of others. Particularly for (semi-)public physical data artifacts, there are open challenges about data ownership, accountability, and representations.
3. **Temporality**: Physical data artifacts are often introduced in everyday life through temporarily in the wild evaluations (1 week up to several months). Hence, we still do not fully understand how they would coexist with people over a longer term, and passed the novelty effect. One can imagine there is a saturation point of the usefulness of making information accessible to the public. Are physical data artifacts here to stay for the long term in a particular context? Or will they have a saturation point of engagement and are meant to travel around different contexts to inform multiple communities? Do we expect

people to engage with them more frequently over the short term to plant a seed (multiple times a day for a week), or do they benefit from long-term exposure to possibly elicit behavioral change (daily for a couple of months)?

4. **Physicality**: Due to the tangible nature of physical data artifacts, the availability of data gets bound to (and associated with) a physical location, which is something that has to be carefully considered when designing. Moreover, one has to anticipate the sustainability and maintenance of the physical system over time. Lastly, how is the 'ownership' or responsibility over the system arranged over time?

## *3. What's Next?*

The central goal of physical data artifacts is to provide people with tools and designs that are integrated into everyday life, which support people in building a shared understanding of data and its impact or consequences. We increasingly see physical data artifacts emerge for topics on sustainability and climate change, personal health and vitality, city and environmental data, and even artificial intelligence. While all these domains have specific challenges for how to translate data into actionable explorations and outcomes, we summarise our findings from our own experiences of designing multiple physical data artifacts and hope they can be inspiring for future designs and conversations around the role of data in every life. As we are still in the early phases of physical data artifacts, we see future research challenges at a (i) conceptual level - how to talk about and discuss the concepts of physical data artifacts, (ii) technical level - how to construct new physical data artifacts that can be used in the wild, and (iii) empirical level - how to further our understanding of the impact of data awareness for people lives.

## Endnotes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## Bio

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