Physicalization from Theory to Practice: Exploring Physicalization Design across Domains

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ABSTRACT

Currently, physicalization research is dominated by technology-centric explorations with limited insights into the broader domain implications. The goal of this workshop is to bring together researchers and practitioners who share an interest in using data physicalizations to solve real-world problems. Hence, we aim to further explore the utility of physicalization for different domains that (already) apply data physicalization in their practices (e.g., sustainability, office vitality, education, and personal informatics). The objective of the workshop is to combine the expertise of researchers working in physicalization and/or exemplar domains to (i) develop an understanding of common challenges, (ii) map out overarching factors across domains, (ii) operationalize design strategies for common domains, and (iv) reflect on the implementation of data physicalizations for different domains. Upon completion of our workshop, we plan to create a BIT Special Issue addressing the challenges and potential directions of the domain application of data physicalizations.

CCS CONCEPTS

• **Human-centered computing → Visualization application domains**.

KEYWORDS

Data Physicalization, Domain application, Personal Informatics, Sustainability, Education, Office Vitality

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1 BACKGROUND

A physical data visualization or *data physicalization* is *"a physical artifact whose geometry or material properties encode data"* [22]. There is a breadth of work in this research field [11], ranging from static physical representations [21], to constructive visualizations [18], to fully interactive systems [40]. Physicalizations are beneficial as physical interaction with data can increase user engagement, facilitate learning and understanding, and make data more accessible [22]. Active touch also facilitates effective information retrieval from data physicalizations [21]. Finally, physicalizations allow for social interactions around them to facilitate collaboration and shared sense-making [22].

State-of-the-art physicalization research is often device-centric: focusing on the design of the apparatus, device, or mechanisms that facilitate the physical representation of data [1, 22]. However, recent efforts have been made to better understand the context surrounding physicalizations through literature reviews [12] and conceptual frameworks [3, 36]. Sauvé et al. [36] discussed how the different design elements of a physicalization – physical and digital – should be considered as part of a wider *physecology*, and can be united through six design dimensions (e.g., data type, audience, and method of information communication). Dumičić et al. [12] analyzed 163 publications on physicalization artifacts and illustrated the variety of data themes and topics they cover (e.g., personal data, medical sciences, and geoscience), the variety of design purposes (e.g., tool for tracking and communicating personal data, research/education tool, artwork, public display), and provide a list of researched impacts (e.g., assist with understanding data, user engagement, hedonic experience, impact on behavior/motivation). Finally, Bae et al. [3] analyzed 47 publications and discussed the variety of audiences, locations, and data sources that occur for existing physicalization work. They found that approximately a third of their corpus provided little to no information about the target location, and almost a fifth did not explicitly specify their audience.

In line with these prior efforts to better understand the surrounding context of physicalizations, we argue for a more active consideration of contextual factors and how these correlate to exemplar domains. Currently, there is little discussion on the implications of domain-specific physicalizations and very few generalizable insights, principles, or guidelines exist on how to design physicalizations for domain use. However, designing physicalizations for real-world problems is non-trivial and requires sophisticated translations and transformations for it to be used in context. A better understanding of the intended context can help to further tailor future physicalizations for their specific audience, location, and interactions among others. There are overarching challenges that concern any physicalization such as (i) which data is 'valuable' or 'suitable' to represent through physicalization? (ii) for which context and location do we design them? and (iii) how do we physically encode the data (as 2D visualization principles [28] are only partly informative for physical 3D space)? In contrast to prior work, we aim to cross-reference these contextual factors with specific domain applications, to further understand how different design elements are appropriate for specific domains. Herein, we reflect on prior work in four example domains to (i) illustrate the variety of implementations that exist and (ii) identify different challenges that occur when designing physicalizations for specific domains.

1.1 Personal Informatics

A popular area for data physicalization is that of Personal Informatics (PI) [13]. Here, personal data is used as the foundation for the physicalization. Examples of this domain often focus on (i) monitoring well-being, such as physical activity and health-related data [17, 35]; (ii) facilitating self-reflection [24, 41]; and (iii) improving self-knowledge [10, 33]. These physicalizations become a reflection of the user [25], as they express (some of) the user's qualities and characteristics. Moreover, physicalizations highlight different perspectives of data – on one hand, the focus can be on storytelling and showcasing a multitude of interpretations, on the other hand on efficient and accurate data representations [25, 29, 42]. Therefore, physicalizations of personal data pave the way to changing our understanding of what data is [29, 42]. This change in perspective is needed since most PI tools and representations focus on quantitative data, where the data is seen as objective, all-knowing, and neutral [9, 31]. These do not explore or create room for what the data means to or does for the user [25]. Yet these aspects are often what matters most; being more relatable and less distant than numbers [31] and facilitating meaningful comparisons [35]. It is important to realize that (personal) data is not binary and can be viewed from multiple perspectives that are of equal importance and validity – something which is embraced by physicalizations [29].

Although PI data physicalizations offer a lot of potential for (re-)exploring what personal data is, there are open challenges. Considering PI is a sensitive topic, how do we ensure the user's privacy when physicalizing the data? And how do we maintain data ownership when a physicalization is used in a shared space or is shared amongst members of a household?

1.2 Sustainability

Looking at physicalizations designed for sustainability topics, we observed that they are often created through either (i) a metaphorical or abstract representation of environmental factors to illustrate the problems at hand, or (ii) a reflection of people's behavior or opinions to inform future decision making. Example works of metaphorical or abstract representations are Yellow Dust [11] – a public installation visualizing local air pollution through variable yellow mist – and Garden of Eden [11] – a set of eight lettuces in transparent acrylic boxes that receive a different concentration of ozone based on the pollution levels in major cities. Examples of representations based on people's behavior are Tidy Street [4] – visualizing the electricity usage of a neighborhood street – and Econundrum [34] – showing the climate impact of personal dietary choices. Finally, Squeezy Green Balls [23] provides exemplar statements on sustainable behaviors to which people can indicate their agreement by squeezing balls of different colors.

When designing physicalizations for sustainability, we observed the following challenges. The first challenge can be explained by the concept of *social dilemmas* [8], as environmental issues often represent a situation in which individual and collective interests are conflicted. Hence, the challenge is how to convey the data in a way that unites these perspectives or at least allows for some form of social comparison between them. Second, the intangibility of the implications of climate change and possible results when performing behavior change in favor of it. This is not necessarily unique to environmental issues, but it remains a challenge how to translate an otherwise intangible and complex topic towards a visualization that creates awareness or actionable pointers. Finally, sustainable behavior often starts with creating awareness, hence we see many prior examples focus on creating environmental awareness (e.g. [34]). However, it remains unclear how a physicalization could be informative for promoting behaviors and/or is there an optimum for how far a physicalization can go? Hence, are physicalizations only suitable for initial phases of behavior change or can they also facilitate actions and maintenance?

1.3 Education

As part of their seminal work, Jansen et al. [22] discussed the potential for data physicalization within education as manipulable physical representations can aid cognition [21]. Students may benefit from physicalizations when learning about the different topics that data can encode or how data is represented. For example, students can learn about the topic of geography through experimentation with the Augmented Reality Sandbox [44] or about basic statistical functions through interaction with the interactive scatter plot CoDa [43]. While there seems to be a wide variety of possible learning objectives, learning outcomes of physicalization interventions are rarely investigated.

In previous work, a one-day workshop protocol has been developed for teaching physicalization through the creation of data sculptures [19]. Data sculpture creation has seen wide implementation as an educational activity within higher education [27, 30].

However, data sculptures are often static and thus lack the educational benefits that interactivity and feedback can provide. When creating constructive data physicalizations [20, 37] learners might be preoccupied with memorizing self-set rules regarding data-object mapping. This cognitive load [39] can interfere with the students' ability to interpret the relationship between the physical data and the information they encode. In the CoDa [43] system the data-object mapping is already present and it's interactivity affords digital exploration [26]. However, this system is too expensive to be realistically implemented in an educational context.

Paper has been explored as a low-cost material for data physicalization in STEM education [15]. While static in nature, paper can be embedded with markers for computer vision [2] or Augmented Reality (AR) [16] augmentation. While this would create a manipulable, low-cost, and interactive physicalization material, these augmentations might not be appropriate for all learning objectives or age ranges [14].

1.4 Office Vitality

Finally, physicalizations have been used as a means to communicate data to improve the well-being of office workers [7]. The communication of data focuses on several types of data including personal data (e.g., posture, physical activity level, sedentary behavior), work-related data (e.g., productivity), and environmental data (light level, sound level, temperature, air quality). Prior work has used several modalities to communicate these different data types such as light [38], ambient displays [6], sound [38], or movement [32]. These data physicalizations are presented in several (social) settings and environments (e.g., meeting rooms, outdoors, office desks, on-body) triggering different social dynamics including cooperation, competition, and social support.

While data physicalization has been indicated as a promising area to represent office data [5], there are remaining challenges when introducing physicalizations in the office environment including the role of demographics, personalities, and social relationships when presenting a data physicalization, the role of physicalization in hybrid ways of working and how to utilize the situatedness of the data physicalization, the possible benefit of tangible data physicalization over digital interfaces, and what the effect will be of the data representation on the office environment. These challenges are work for future implementations and the development of data physicalization artifacts in the research field of office vitality.

1.5 Challenges

To summarize, there is a wide variety and breadth in the problem space of designing physicalizations for specific domains. For the above exemplar domains, we observed challenges ranging from general topics that are transferable across domains (such as physical encoding) to more domain-specific challenges. We provide an overview of key questions raised by prior work which include (but are not limited to):

1.5.1 Physical Encoding and Situatedness (generalizable challenges across domains).

1. As physicalizations have the ability to highlight different perspectives on (personal) data, what data are 'valuable' or 'suitable' to represent through physicalization?
2. As physicalizations are situated and/or embedded in a physical location, for which contexts do we design them?
3. As the principles of data visualization only partially inform physicalization design, how do we encode the data to physical form?
4. What are the implications of introducing a physicalization in a specific context (e.g., office space)?

1.5.2 Privacy and Ownership (strongly related to Personal Informatics but transferable across domains).

5. How do we ensure the user's privacy when physicalizing (PI) data?
6. How do we maintain data ownership of (PI) data when a physicalization is used in a shared space or is shared amongst members of a community (e.g., household, office space)?

1.5.3 Communication and Actionability (strongly related to Sustainability but transferable across domains).

7. As sustainability topics often represent a situation in which individual and collective interests are conflicted, how can the data be conveyed in a way that unites and/or allows for a comparison of these perspectives?
8. How can we translate an otherwise intangible and complex topic towards a visualization that creates awareness or actionable pointers?
9. How can physicalizations be informative for promoting behaviors, or even be designed for different phases of behavior change?

1.5.4 Evaluation and Pragmatism (strongly related to Education but transferable across domains).

10. How can we design physicalizations for a variety of different learning objectives?
11. How can we evaluate the learning outcomes of physicalization interventions in education?
12. How can we design physicalizations that facilitate interactivity and feedback without creating too much cognitive load for students?
13. How can we create realistic physicalization implementations for an educational context (e.g., costs, safety, ethics)?

1.5.5 Adaptability and Customization (strongly related to Office Vitality but transferable across domains).

14. How should we balance out different aspects of office vitality (well-being and productivity) when introducing physicalizations in the work environment?
15. What is the role of demographics, personalities, and social relationships when introducing a physicalization in the work environment?
16. What is the role of physicalization in hybrid ways of working and what are the potential benefits of physical representations over digital interfaces?

2 ORGANIZERS

Kim Sauvé (primary contact for the workshop) is a Ph.D. candidate in the Interactive Systems group at Lancaster University, United Kingdom. Her research focuses on exploring the underlying principles of physicalization design. She has conducted empirical work on the perception of and interaction with physicalizations, but also explorative work such as designing physical representations of personal activity data and the climate impact of dietary choices.

Hans Brombacher is a Ph.D. candidate at the Eindhoven University of Technology, The Netherlands. His Ph.D. focuses on Office Vitality, which aims to increase the well-being of office workers. The topic specifically focuses on taking a user-centered approach in the collection of office-related data, and translating this data to users in an understandable way (e.g., via data physicalization).

Rosa van Koningsbruggen is a Ph.D. candidate at the Art and Design faculty of the Bauhaus-Universität Weimar in Germany and works as a research assistant in the Human-Computer Interaction group. Her research focuses on data physicalizations of personal data in the everyday life. Here she explores the role of physicalizations in our understanding of data, and the aesthetics and interactions of this type of physicalization.

Annemiek Veldhuis is a Ph.D. candidate at the School of Interactive Arts & Technology of Simon Fraser University, Canada. As part of the Tangible, Embodied, Child-Computer Interaction Lab, her research focuses on the design of tangibles that support agency, collaboration, and learning during design-based activities in elementary and middle school. Her earlier work explored physicalization interpretation in educational contexts.

Steven Houben is an assistant professor in human-computer interaction at the Eindhoven University of Technology, The Netherlands. His research focuses on physical and ubiquitous computing systems. His work explores physicalizing human-data interaction to support "from sensor to physicalization" and study new co-creation processes, concepts, interaction paradigms, and data embodiments for non-expert human-data/AI interaction.

Jason Alexander is a Professor of Human-Computer Interaction at the University of Bath, United Kingdom. His research develops novel interactive systems that straddle the physical-digital interface. His recent work focuses on the development of shape-changing interfaces – surfaces that can dynamically change their geometry based on digital content or user input – and their application to data physicalization.

3 WEBSITE

We developed a website (dataphys.org/workshops/chi23) that will provide the participants with the needed information for the workshop, including the homework assignment(s) which need to be completed before the start of the workshop. Additionally, it will briefly introduce the workshop topic, its objectives, and its organizers. We will share the workshop schedule and provide details for submission and acceptance. Finally, after the workshop we will (if agreed upon by the participants) share the outcomes of the workshop (e.g., the created artifacts and cross-domain analyses) for everyone interested in the domain application of data physicalization.

4 PRE-WORKSHOP PLANS

We will launch an open call for participation but will also personally invite key researchers who are currently active in the specific domains. We are particularly looking for people working in the four exemplar domains, but are also open to applications from other domains. Before the start of the workshop, participants are asked to submit a 2-page position paper (excluding references) or another medium which fits their work (e.g. video or poster) that discusses at least one of the following: (i) one or more of the listed domain areas of physicalization; (ii) the challenges you see for the domain area(s); (iii) your experience or vision on how context influences the design of a physicalization. The organizers will collectively review and select the submissions, and aim for a balance of complementary domain and physicalization expertise among the participants.

5 IN-PERSON, HYBRID OR VIRTUAL-ONLY

We aim to organize the workshop completely in person due to the physical nature of the research topic. Participants will most benefit from collective hands-on activities as physicality and embodied cognition is important when designing for and learning about physicalization. To have an engaging workshop, we aim for a minimum of 10 and a maximum of 30 participants, of which the majority is preferably in-person (75%). As mentioned, we prefer to organize a fully in-person workshop, with hybrid (online) options for a small group if necessary. Therefore, participants are encouraged to join in person to get the best experience when participating in the workshop. The workshop will be synchronous, but all the materials (such as developed artifacts, findings of the workshop, and evaluations) will be made available on the website after the workshop for asynchronous viewing.

In case the pandemic limits travel opportunities, we will consider a fully virtual workshop as an alternative to ensure the safety for organizers and participants. However, online participation has the disadvantage that people are not able to physically build and interact with the data physicalization on location. Instead, we will share a list of materials prior to the conference that we strongly advise them to collect to engage in prototyping remotely.

6 WORKSHOP FORMAT AND ACTIVITIES

The workshop aims to address four main objectives: (i) understanding common physicalization challenges across exemplar domains, (ii) mapping out overarching factors, (iii) operationalizing design strategies, and (iv) reflecting on the implementation of physicalizations for different domains. Taking into account these objectives, we propose a workshop that will last six hours and consists of three parts: 1) design domain orientation, 2) hands-on artifact creation, and 3) cross-domain analysis (see overview Table 1). We intend to involve a minimum of ten and a maximum of 30 participants.

6.1 Design domain orientation [2h]

As part of the first phase, we aim to identify the common challenges associated with data physicalization across and within the four domains and formulate design implications. This phase consists of three activities: 1) a poster creation session, 2) a selection of challenges within their domain, and 3) a contextual framework creation session (see Table 1).

Poster. After a brief introduction by the workshop facilitators, participants will work in small groups to create a poster showcasing their work and challenges pertaining to data physicalization. Upon completion, they will present this poster to the other groups. In this activity and the accompanying discussion, we hope to foster a better understanding of each other's fields and stimulate cross-disciplinary conversations.

Domain challenge selection. Afterward, participants will be divided into pre-established groups according to their affinity with one of the four domains. We will prepare handouts listing five challenges within each domain (see section 1.5). Each group is asked to come up with additional challenges within their domain and to select at least one challenge to address during this workshop. During this activity, participants gain a deeper understanding of data

Table 1: Overview of the proposed activities in our workshop.

Time	Phase	Activity	Grouping	Prospected Outcome
10:00 - 11:00 (1h)	1	Poster creation	Discussion groups (#5 - 6)	Overview of common challenges (overarching)
11:00 - 11:10 (10 min)		*Coffee break*		
11:10 - 11:25 (15 min)	1	Domain challenge	Domain groups (#3 - 5)	Overview of common challenges (domain)
11:25 - 11:45 (20 min)	1	Contextual framework	Domain groups (#3 - 5)	Design implications for each domain
11:45 - 12:30 (45 min)		*Lunch break*		
12:30 - 13:00 (30 min)	2	Brainstorm	Domain groups (#3 - 5)	Implementations of data physicalizations
13:00 - 13:45 (45 min)	2	Prototyping	Domain groups (#3 - 5)	Implementations of data physicalizations
13:45 - 14:00 (15 min)		*Coffee break*		
14:00 - 15:00 (1h)	3	Handover	Domain groups (#3 - 5)	Implementations of data physicalizations Overarching factors across domains
15:00 - 16:00 (1h)	3	Post-discussion	Collective	Overarching factors across domains

physicalization within their domain, and come to a collaborative goal through discourse and discussion.

Contextual framework. To capture design implications for each domain, we will provide participants with a contextual framework handout (based on/inspired by [3, 12, 36]). This allows them to reflect on the requirements and constraints within each domain (e.g., cost in the educational domain).

6.2 Hands-on artifact creation [2h]

The participants will engage in two activities in the second phase: 1) a brainstorming session and 2) a prototyping session to explore implementations of data physicalizations that address or embody the challenges within each domain.

Brainstorming. Participants are asked to document their design process and design considerations. To support their process, handouts on critical considerations when designing a physicalization (e.g., data semantics and encoding) will be made available. *Prototyping.* Participants are also required to create a prototype demonstrating their final design. A variety of rapid prototyping materials will be available. Through prototyping, the groups will be able to test their assumptions and communicate their ideas more effectively.

6.3 Cross-analysis [2h]

During the final phase, we aim to gain insights on overarching factors across domains through two activities: 1) a design handover session, and 2) post-discussion.

Handover. Each group will hand over its design to a group working on a different domain. This group will modify or iterate the physicalization. Groups will be asked to reflect on the knowledge they gained from designing a physicalization for their domain and consider how this might inform design decisions in another domain.

Post-discussion. Through a final collective discussion, we will examine the benefits, overarching factors, and challenges associated with data physicalization implementations in the four domains.

7 POST-WORKSHOP PLANS

The workshop aims to bring together researchers and practitioners and provide them with a networking opportunity to discuss physicalization as a broader concept across different domains. We plan to synthesize the workshop findings for a Special Issue of the Behaviour & Information Technology (BIT) Journal and will encourage interested participants to contribute.

8 CALL FOR PARTICIPATION

Although data physicalizations have been around for centuries (e.g. Quipus [1]), little is known about how their context influences the design and interaction needs. For example, what does it mean for a physicalization to be designed for sustainability, and how does this differ from a physicalization placed in an office environment?

In this workshop, we will explore four domain areas of data physicalization: personal informatics, sustainability, education, and office vitality. We are particularly looking for people working in these exemplary domains, but are also open to applications from other domains. Through discussions and the creation of physicalizations, we will explore the needs and challenges of these domains. We invite experts in physicalization and the relevant domains to join us for this one-day workshop.

If you are interested in participating, please submit a 2-page position paper (excluding references) or another medium that fits your work (e.g. video) that discusses at least one of the following:

[1] http://dataphys.org/list/peruvian-quipus/

(i) one or more of the listed domain areas of physicalization; (ii) the challenges you see for the domain areas; (iii) your experience or vision on how context influences the design of a physicalization. Submissions should be submitted via the provided form.

Successful submissions will be selected based on their ability to trigger discussion and will be published on the workshop's website. For each accepted submission, at least one author must attend the workshop. All participants must register for the workshop and at least one conference day.

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