Physicalization from Theory to Practice: Exploring Contemporary Challenges for Physicalization Design

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ABSTRACT

CCS CONCEPTS

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

KEYWORDS

Data Physicalization, Grand Challenges

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1 INTRODUCTION

In proposing this workshop, we aim to address the evolving challenges in the field of physicalization, drawing from prior research [e.g. 9, 18, 25, 31] and workshops [12, 28]. While a prior workshop [28] focused on exemplar application domains, this workshop takes a distinct approach, exploring observed grand challenges within physicalization using their insights and existing literature.

Throughout history, people have been shaping (digital) data into tangible information and human-readable representations [8]. In 2015, Jansen et al. [18] formalized this practice within the realm of Human-Computer Interaction (HCI) and introduced the concept of *physicalization*: encoding data into physical artifacts leveraging their geometry or material properties [18]. Their work played a pivotal role in formalizing physicalization as a distinct research field and establishing a comprehensive research agenda, highlighting grand challenges within the field. These challenges included understanding the perceptual effectiveness of various representation approaches, incorporating non-visual senses, ensuring accessibility, effective evaluation, and identifying, exploring, and classifying physical and haptic variables to understand the expansive design space of physicalizations [18].

Nearly a decade later, significant strides have been made in addressing some of these initial challenges. Research has delved into the perception of tangible information [17, 19, 30], a design vocabulary for encoding variables [14], diverse ways in which physicalizations can be created [15] or rendered [6], methodologies for evaluation [25], and frameworks discussing the variety of data topics, design purposes, locations, and audiences that physicalizations can have [1, 10, 31]. These works highlight the multifaceted nature of physicalizations and stress the importance of considering them within a broader context of use and in relation to their audience.

Nevertheless, the dynamic nature of technology and human interaction has introduced new challenges [9, 25, 31], as evidenced by observations from a previous workshop [28]. Therefore, our workshop aims to foster a more in-depth discussion on these evolving challenges, focusing specifically on unresolved complexities surrounding privacy, collaborative sense making, temporality, and sustainability of physicalization practices. These four focal points, derived from insights gathered during a prior workshop [28], acknowledge the inherent susceptibility of physicalizations to privacy concerns, the collaborative nature of their interpretation in a shared space, the temporality and frequency of usage, and their sustainability in diverse contexts.

2 BACKGROUND & MOTIVATION

In the multifaceted landscape of designing physicalizations, progress has been made in understanding the overarching challenges [e.g. 1, 14, 25, 31]. In a previous workshop [28], we focused on domain-specific challenges, gaining insights into the distinct intricacies faced in exemplar application areas. However, we recognized the need for a broader exploration into the contextual factors influencing the real-world deployment and impact of physicalizations.

Our previous investigation demonstrated that challenges and opportunities in physicalization span a spectrum, from being highly domain-specific to having transferability between domains, are interconnected with one another (e.g., a physicalization's temporality influences its privacy), and extend to general physicalization concerns. Building on these lessons, we have identified four key

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grand challenges: (1) addressing privacy concerns [3], (2) understanding temporal dynamics in real-world settings [14, 31], (3) developing strategies for collaborative data sense-making in shared contexts [36], and (4) integrating sustainable principles across the lifecycle of physicalizations [12, 13, 26].

By adopting a challenge-centric approach, we aim to address questions that transcend individual domains and contribute to the ongoing exploration of grand challenges, both the initial and new ones. The four grand challenges we will explore encapsulate crucial aspects that draw from our own experiences [28] and related work [1, 10, 14, 18, 25, 31]. Below, we elaborate on each challenge:

2.1 Privacy

Physicalization has gained attention for its potential to engage broader audiences and enhance shared meaning-making [17, 18]. However, the deployment of physicalizations in (semi-)public spaces brings certain risks, including privacy implications, the use of personal data, and the potential for misinterpretation.

When presenting data publicly, it is crucial to consider privacy concerns [3, 31]. Haphazardly transforming raw data into accessible physicalizations for the public eye may inadvertently expose sensitive information. Striking a balance becomes crucial; the physicalization must be both informative and engaging, while upholding privacy. Previous work has illustrated strategies to navigate privacy concerns, such as decoupling input and output modalities to preserve privacy on personal devices while fostering community engagement on a shared system [26]. Another tactic involves allowing individuals to identify their data points through unique symbols, maintaining anonymity within the community [26].

Moreover, relying on prior knowledge of specific use cases can also safeguard privacy. For instance, LOOP [27] uses abstraction to protect privacy when seen by others. This approach allows individuals to decipher the representation, without compromising personal data. However, such actions require careful consideration, as oversimplification may lead to misunderstandings or misinterpretations [2]. Therefore, designers should carefully select appropriate techniques for presenting data, ensuring they match the data's intricacies and preserve its intended message without distortion [4].

Beyond these individual strategies lies the social dimension of privacy with physicalization. Users engage with these representations, sparking discussions about positive and negative impacts, such as social pressure (e.g., a physicalization in an office should always show that everyone is hard at work) [2, 3]. Because of these various privacy aspects in physicalization, our workshop will explore: *How can privacy considerations in physicalizations be effectively addressed, considering the contextual setting, hierarchical relationships, and the level of abstractness in the presentation?*

2.2 Temporality

Recent survey papers underscore the role of time in the design of physicalizations. As highlighted by Bae et al. [1], data used in physicalizations can range from ephemeral to permanent, shaping the design approach accordingly [14]. Moreover, Sauvé et al. [31] discuss the different temporal distances that can exist between the data and its use, which can range from a static dataset integrated into the physicalization, to dynamic data that is updated immediately or in set intervals (e.g., hourly, weekly, monthly). This necessitates physicalization creators to consider the temporality of both data and physicalization. For instance, as mentioned above in Privacy, sensitive data may need discretion, requiring an ephemeral representation (i.e., data is displayed for a brief period), while other data sources demand a permanent presence as a keepsake (i.e., data is a lasting part of the physicalization structure). Reflecting these temporalities in physicalization is crucial, whether tailored for specific durations (e.g., ephemeral or permanent) or designed to adapt dynamically. Furthermore, a physicalization's temporality can also be seen as something speculative, using data to make the physicalization reflect speculative future(s) based on data extrapolation.

Beyond survey works, temporality remains an underexplored aspect of physicalization. Insights from multisensory data representations and visualizations stress the importance of aligning data duration (*display duration*), similar to tempo in music, as it provides the temporal reference for how people perceive the data [23]. Thus, the data duration affects the entire *"rendering process"* of the physicalization [16]. Recognizing the impact of temporality on data physicalization and user experience, our workshop aims to delve deeper into its role and implications. Specifically, we ask: *What guidelines can be formulated to actively account for the temporal aspects of physicalizations in real-world settings, including their lifespan, frequency of use, and opportunities for reappropriation?* For this, we will be looking at insights from ephemeral interfaces [7] and autographic visualizations [24].

2.3 Collaborative sense-making

Physicalizations can support the sense-making of complex and abstract concepts, and the relationships between them [18]. A sense-making process can be understood as the active effort to build meaning out of ambiguous data [20], both at the individual and group levels. While most physicalizations in the literature focus on data interpretation by individuals [25], the potential benefits of a physicalization's tangible nature extends to creating collaborative spaces in which multiple individuals can divert their shared attention. Its physical, and potentially multisensory, form also enhances accessibility as a means of facilitating conversation between individuals with differing abilities and needs [37].

Prior work has utilized physicalization to support collaborative narrative creation about difficult social topics [21, 22], reflection on behavior [29], decision-making [36], and data literacy learning [5]. Based on these works, we imagine the potential for physicalizations to: (1) support sense-making of data around complex topics and between groups of different world views, or (2) lower the threshold for laypeople to engage in discussion on complex topics.

However, despite these potentials, there has not yet been substantial research on methods to support collaborative sense-making through physicalizations. Requirements for fostering collaborative sense-making have been outlined in visualization research [35], but their applicability to three-dimensional data representations remains unclear. Thus, on one hand, we need to design and investigate interaction modalities that can support *collaboration* for various forms of data physicalizations (e.g., interactive bar charts [34]). On the other hand, we need to study how these interactions contribute to collaborative *sense-making* in the forms of: (a) creating collaborative mental models of the data artifacts, (b) collaborative narrative construction of their contextualized meanings, and (c) collaborative decision-making based on these newfound understandings. Therefore, in our workshop we ask and explore: *What strategies can be implemented to enhance collaborative data sense-making through physicalizations in shared contexts?*

2.4 Sustainability

Sustainability is a complex concept in the realm of physicalization [15], encompassing design principles, creation processes, lifespan considerations, and broader environmental impacts. Physicalizations play a dual role, serving to make complex climate impact information more accessible, while also necessitating exploration of sustainable practices in their creation and maintenance. Recent critiques in HCI underscore the inefficiency of 'physical pixels' compared to digital ones [13], prompting reflection on the value of physicalizations and the exploration of multipurpose or dynamic designs. By integrating sustainable design principles from fields like biomimicry and circular economy, we can better assess the worth of physicalizations while minimizing their ecological footprint.

Real-world examples, such as systems for communicating the environmental impact of personal consumption behaviors [26, 33] and workshops exploring sustainable brainstorming for physicalization creation [11, 12], offer insights into potential applications. However, these examples often hint at future challenges without actively addressing the grand challenge of sustainable physicalization design. Nevertheless, initiatives like the ZeroWaste Physkit [12] and decomposable interactive systems [32] show promising steps towards more sustainable practices.

Lastly, navigating conflicts of interest between collective and individual goals in sustainable physicalization design requires careful consideration. Insights from exemplar real-world projects provide some guidance [26, 29] but there is a lack of structured approaches. Therefore, our workshop explores: *What approaches can be adopted to integrate sustainable principles throughout the entire lifecycle of physicalizations, promoting awareness of environmental issues from design to end-of-life?* By addressing these aspects, we can advance sustainable physicalization design and promote environmentally responsible approaches in HCI.

3 ANTICIPATED OUTCOMES

In this one-day workshop, our primary aim is to establish an inclusive platform for physicalization researchers and practitioners to engage in in-depth discussions on the design of physicalizations tailored for real-world settings, emphasizing active considerations of the challenges involved. Each workshop group will be provided with the same dataset and assigned one of the four challenges, encouraging participants to design a physicalization through the lens of their designated grand challenge. In the subsequent phase, they will engage in collaborative discussions, exchanging experiences, and refining their designs by incorporating a second grand challenge. Our deliberate emphasis on addressing these four grand challenges serves as a strategy to provide a focused and impactful contribution. This approach offers an accessible pathway for contributing to the evolving field of physicalization, aiming to meaningfully contribute to its maturation while considering the contemporary challenges faced in our dynamic world. Practically speaking, we intend to share the workshop submissions, with the authors' consent, on our public website. Additionally, we will invite all interested participants to contribute to a publication, either as an ACM Interactions article or as a paper submission to Computing (X) Crisis 2025.

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