Sketching and Ideation Activities for Situated Visualization Design

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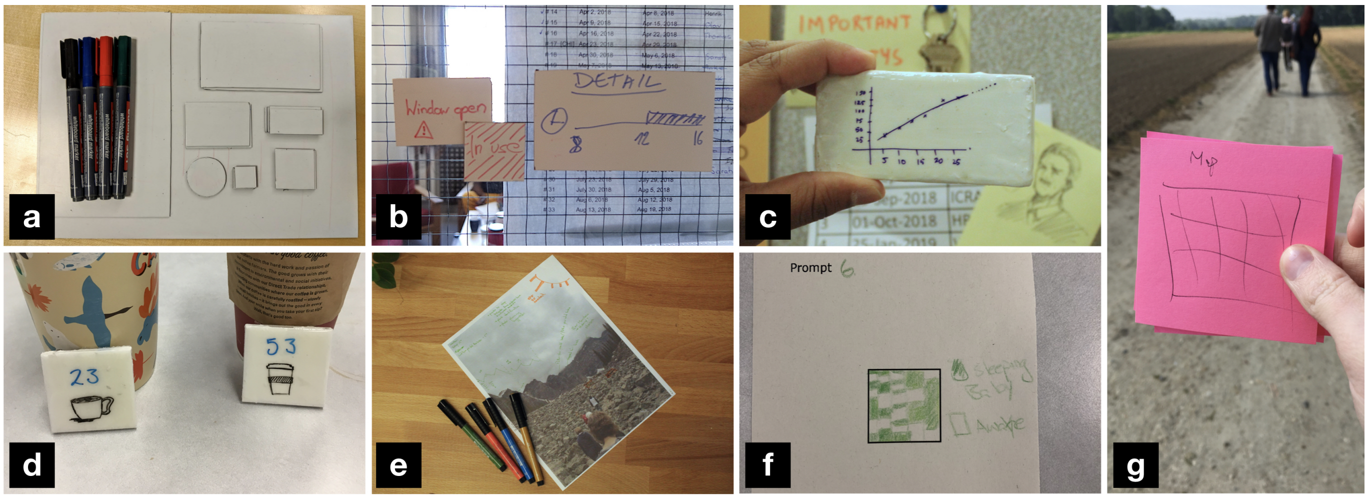

Figure 1. Sketching materials from our seven design workshops. (a) Whiteboard sheets in different form factors from W1 (Food Bank), (b) sketches on whiteboard sheets from W2 (Office Climate), (c) whiteboard tile from W3 (Tiles at Office), (d) whiteboard tiles from W4 (Tiles at Home), (e) photo with annotation from W6 (Photo Annotation), (f) paper cutouts from W7 (Self-Tracker), (g) sticky note sketch from W5 (Agriculture).

ABSTRACT

We report on findings from seven design workshops that used ideation and sketching activities to prototype new *situated visualizations*—representations of data that are displayed in proximity to the physical referents (such as people, objects, and locations) to which the data is related. Designing situated visualizations requires a fine-grained understanding of the context in which the visualizations are placed, as well as an exploration of different options for placement and form factors, which existing methods for visualization design do not account for. Focusing on small displays as a target platform, we reflect on our experiences of using a diverse range of sketching activities, materials, and prompts. Based on these observations, we identify challenges and opportunities for sketching and ideating situated visualizations. We also outline the space of design activities for situated visualization and highlight promising methods for both designers and researchers.

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Situated Visualization; Information Visualization; Design Workshops; Small Displays; Ideation; Sketching

CCS Concepts

•Human-centered computing → Interface design prototyping; Visualization design and evaluation methods;

INTRODUCTION

Situated visualization [43, 44] is an emerging research area in information visualization that focuses on placing data visualizations in physical spaces to support in-situ data analysis. To this end, data visualizations are displayed in proximity to physical referents that the data is related and relevant to, such as people, locations, or objects. This promising approach has the potential to support data-driven interaction and reflection in a variety of settings beyond those traditionally served by visualization systems. Research has identified application areas such as public visualization [5, 40], wearable visualization [35, 31], and task support in workplaces [18, 21, 41]. Advances in low-cost, embedded systems such as small wireless screens and head-mounted or handheld augmented reality displays are also creating opportunities for situated visualizations in new environments. In retail in stores and warehouses, in particular, small displays are becoming increasingly common. These kinds of displays can make it easy to deploy situated visualizations without substantial new infrastructure, encouraging collective awareness of site- and task-specific data. All of this makes situated visualizations extremely relevant both in civic [4] and workplace [21, 41] contexts.

Designing new situated visualizations is complicated by their nuanced relationship with their surroundings. Beyond understanding the environment and the context where the visualizations will be deployed, designers must identify other practical requirements including appropriate form factors, placements, representations, and levels of detail. Contemporary visualization design exercises, including Roberts et al.'s Five Design-Sheet Method [36] and McKenna et al.'s visualization worksheets [32] still focus on supporting the creation of more traditional desktop and mobile applications. However, these techniques do not address the unique challenges inherent in designing situated visualizations. In particular, they do not consider the opportunities and constraints posed by the visualization's physical referents [44] or how to integrate visualizations into existing physical environments and tasks.

In this paper, we report findings from seven workshops examining situated visualization design: six workshops with researchers and one with end users. Across the workshops, we examined different sketching materials and ideation activities. Our workshops focused primarily on designing situated visualizations that use small physical displays, both because they represent an increasingly practical hardware platform for ubiquitous visualization and because the scenarios we considered were set in workplaces and social environments. We detail our workshop activities and categorize the workshops based on their focus (hardware, ideation, and task) to outline the space of design activities for situated visualizations. Finally, we reflect on the workshop findings and identify opportunities and challenges for researchers and designers.

RELATED WORK

Situated visualization is still an emerging topic with a small catalogue of examples (including [4, 25, 33, 43]). Most visualizations are still designed to support specialists performing data analysis on desktop computers or to enable public consumption on the web and mobile devices. Because of this, common visualization design exercises do not specifically account for the challenges and opportunities associated with integrating visualizations into existing physical environments, activities, and work practices. We provide an overview of prior ideation methods for designing and sketching visualizations, the role of sketching for design and Human-Computer Interaction (HCI), and existing examples of ideation and design activities for situated visualization.

Designing and Sketching with Data

We take inspiration from several works that discuss working with data as a "design material" to aid in visualization ideation for both designers and end users. A number of workshop formats specifically focus on novices and teaching data visualization design [12, 17, 19]. VizItCards [17] introduces a card game mechanic into a design workshop format. Goodwin et al. [11] examine the potential for introducing different creativity techniques as part of a workshop focusing on developing design concepts for energy analysts. Meanwhile, Dove & Jones [10] use information visualizations as creative stimuli in design workshops, focusing on how domain-relevant data and ambiguity in the information visualizations influence the quality of the generated concepts. They find that domain-specific data help participants generate appropriate concepts but that ambiguity can have a negative impact on their quality. Combining this insight from Dove & Jones with inspiration from VizitCards [17], we provided data cards in one of our workshops (Figure 3c) and a sample dataset in another one (Figure 3d). Notably, Kerzner et al. [23] provide a framework for creative visualization opportunities workshops, based on a meta-analysis of their collective experience and research outputs from conducting 17 such workshops in different contexts. For all of our workshops, we follow Kerzner et al.'s suggestion of having participants create physical and visual artifacts to externalize ideas and support later documentation and analysis of the generated ideas (see also [9]).

Our workshops are also inspired by prior work on the potential of sketching for visualization design. Walny et al. [42] examined different approaches to sketching data visualizations based on a specific dataset, suggesting that data sketching has the potential to foster deeper understandings of the particular data and produce less common representations. However, common visualization design sketching exercises such as Roberts et al.'s Five Design-Sheet Method [36] and McKenna et al.'s visualization worksheets [32] do not account for the unique challenges of designing situated visualizations. As a notable exception, Keefe et al.'s VR painting interfaces for designing scientific visualizations [22] highlight the potential for more expressive and spatialized approaches for visualization prototyping. However, outside of this work, mixed-reality (MR) and virtual-reality (VR) interfaces for visualization ideation and design remain largely unexplored. This is due in part to the fact that contemporary VR/MR systems lack the precise input and output necessary to explore small-scale embedded and situated visualizations, particularly those that rely on small displays integrated into physical environments.

Sketching in HCI

Sketching serves multiple roles in HCI design activities and is frequently used to support the design process [3, 13, 30, 29, 38]. Dix and Gongora [9] discuss sketching (and sketches) as informational, formational, transformational, and transcendental. Sketching can help designers capture and communicate ideas, shape and give form to vague or abstract concepts, aid thinking through externalization, and enable practitioners to see existing ideas from a new perspective. Tohidi et al. also report on the value of sketching for user feedback [39]. We follow Greenberg et al.'s [13] model of using hybrid sketches to focus attention on a given context. Like Greenberg et al., we also use sketching in and on physical device mock-ups to explore different visualization form factors (Figure 1).

Ideation and Design Activities for Situated Visualization

Although a number of examples of situated visualizations have been deployed [1, 4, 6, 25, 33, 43], details of their ideation and design process are rarely documented or discussed in detail. Several works on urban community visualizations involve engaging with community members in local spaces [8, 24, 25, 37]. Work by Taylor et al. [37] and Coulson et al. [8] exemplify projects that invite citizens to engage with data as a mode of understanding communal aspects of data (data-in-place) and empower citizens to take action on matters of common concern. Both projects describe community meetings, workshops, data collection, and mapping exercises. These examples take a high-level view of situating design activities and predominantly do so via engagement with community members, rather than specifically focusing on visualization design. Exceptions include Koeman et al. [24] and Claes & Van de Moere [6]. Koeman et al. created initial sketches of visualizations and discussed them with local community groups to ensure easy interpretability. With Street Infographics, Claes & Van de Moere [6] discuss first testing their public visualization street signs in an outdoor context to assess robustness against harsh weather conditions.

A few cases provide more detailed insights in terms of ideation and design activities for situated visualization. Claes et al. [4] designed spatially distributed displays and placed them over several residential home facades with the goal of conveying civic issues. They discuss organizing several co-design sessions on the street where they showed participants mock-ups of the small displays. Participants were asked how they would present a particular local civic cause on the mocked-up public visualization displays, with ideas recorded on sticky notes and attached next to the mock-up displays. Similarly, Vermeulen et al. [41] organized a one-day workshop with caregivers at a psychogeriatrics ward to investigate design considerations for situated glyphs [21], small displays presenting visualizations of task-related information for healthcare professionals. The workshop consisted of demonstrating prototypes of the small displays as a technology probe [20] and inquiring about caregivers' information needs in their daily work activities. Afterwards, the authors ran a sketching activity where participants sketched how they would represent and visualize this information on the small displays.

In domains like health care, where it can be difficult to gain access to the sites where visualizations will ultimately be deployed, several researchers have suggested design strategies for designing at a distance. These include using cultural probes to collect rich descriptions and map the homes of elderly citizens [28] or using blueprints and small-scale card-board personas to develop scenarios for buildings under construction [16]. In developing design proposals for a media facade for a metro station still under construction, Korsgaard et al. [26] propose several strategies for situating design activities when an actual site is unavailable. These include identifying and visiting existing spaces with similar properties, exploring 3D models of buildings in a 3D cinema, and sketching design proposals by superimposing 3D models on top of a whiteboard. This relates to the notion of employing *facsimiles* as stand-ins for the original physical referent(s) [44], which may be a valuable approach for facilitating situated visualization design.

While this prior work suggests some potential activities for situated visualization design, our reflections on seven workshops employing a variety of sketching activities, materials, and prompts help outline a richer overall design space and highlight new opportunities and challenges for practitioners.

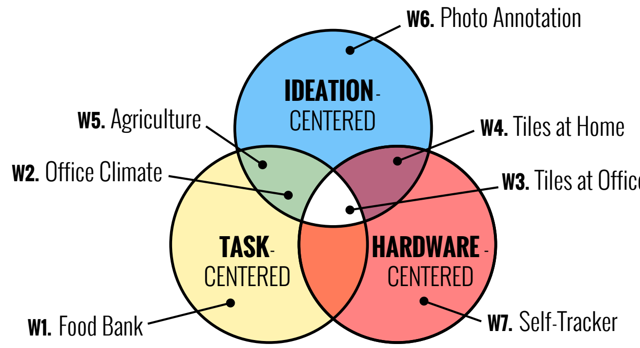

Figure 2. Our design activities organized based on their ideation-, task-, or hardware-centeredness.

DESIGN ACTIVITIES FOR SITUATED VISUALIZATION

As part of our effort to explore new situated visualization designs, we conducted seven workshops (W1–W7) in which we tested a diverse range of sketching activities, materials, and prompts (Table 1). We focused each of the seven workshops around a set of sketching exercises intended to elicit design ideas and requirements for site-specific situated visualizations. The workshops used a variety of different sketching media, including sticky notes and printed images, as well as several types of magnetic whiteboard materials. These workshops also gave us the chance to examine situated visualization design across a variety of settings, datasets, and application domains.

We explored different strategies in each of the workshops, including conducting the activities in the target environment (W1–W5) and asking participants to sketch using templates that replicated the size (W1, W2, W7) and tactility (W3, W4) of possible situated displays. We also used sketching activities to explore the design of augmented reality visualizations, both on-location (W5) and remotely using a photo-sketching approach (W6).

Inspired by Coenen et al.'s [7] step-by-step methodology for their Citizen Dialogue Kit (a set of tools for information and polling displays), we provide details on the materials and procedures we used for each workshop in our supplementary material and on Github[1].

Activities and Objectives

The set of workshops that we conducted spanned several phases of early-stage design, including open-ended ideation as well as more targeted task-centered and hardware-centered activities (see Figure 2).

Ideation-Centered

Our ideation-centered design workshops were characterized by open-ended idea generation, and focused on facilitating the rapid and iterative production of new potential designs and applications for situated visualizations. In these activities, we encouraged open-ended design sketching in the context of a specific physical environment with less emphasis on datasets, tasks, or hardware configurations.

[1] https://github.com/hci-au-dk/situated-vis-sketching

	Workshop	Participants	Backgrounds	Data	Activity Location	Duration	Sketching Medium	Target medium
W1	Food Bank	4	Food bank employees + volunteers	Logistics + management data	Warehouse	2 hrs	Whiteboard sheets (A4 to 2 cm×2 cm)	Small displays
W2	Office Climate	3	Vis and HCI researchers	Environmental data	Office setting	1.5 hrs	Whiteboard sheets (A4 to 2 cm×2 cm)	Small displays
W3	Tiles at Office	15	Vis and HCI researchers	Participant-generated	Office setting + Fablab	1 hr	Whiteboard tiles (5 cm×5 cm, 5 cm×10 cm)	Small displays
W4	Tiles at Home	5	Vis and HCI researchers	Participant-generated	Participant's homes	1 week	Whiteboard tiles (5 cm×5 cm, 5 cm×10 cm)	Small displays
W5	Agriculture	15	Vis and HCI researchers	Unspecified	Farm	2 hrs	Sticky notes	Small/large displays + AR
W6	Photo Annotation	15	Vis and HCI researchers	Unspecified	Meeting room	1 hr	Photos of physical environments (A4)	Small/large displays + AR
W7	Self-Tracker	12	Vis students + researchers	Participant-generated	Meeting room	1.5 hrs	Paper display cutouts (4 cm×4 cm)	Small e-paper displays

Table 1. Details of the seven design workshops we conducted.

Task-Centered

Meanwhile, our task-centered design workshops focused on examining the design of situated visualizations to support specific tasks. In these cases, we emphasized design activities as a mechanism for requirements elicitation, and asked participants to actively consider the relationship between potential situated visualizations and real-world tasks, routines, environments, and datasets.

Hardware-Centered

Finally, our more hardware-centered activities examined the design of situated visualizations based on the physical constraints of a more specific hardware platform. Here, we encouraged participants to generate concepts that were compatible with the form factor, display technology, and interaction capabilities of particular kinds of systems. We focused in particular on designing situated visualizations for small, low-power e-paper and LED displays with limited input capabilities which could be integrated into a variety of different domestic and workplace settings.

As Figure 2 highlights, many of our workshops combined these approaches. Several (W2, W5) encouraged open-ended ideation in the context of a specific application domain. Meanwhile, others (W4) encouraged free-form ideation with more concrete hardware constraints or combined elements of all three approaches (W3).

Sketching Media

To help participants more easily prototype situated visualizations for small displays, we tested several different types of sketching media across the workshops. In particular, we explored a variety of different kinds of magnetic whiteboard sheets and tiles (Figure 1), which served as alternatives to more traditional paper and sticky notes.

Using whiteboard material provides several advantages over paper, permitting participants to erase, update, reuse, and reposition sketches throughout an exercise. These sheets and tiles can more accurately simulate the size, weight, and form factor of small lightweight displays—one of the most promising platforms for situated visualizations [4, 14, 41]. Participants can also use integrated magnets or adhesive putty to attach these sheets and tiles to physical objects as well as architectural features like walls, windows, and doors. This flexibility makes it possible to move and reconfigure sketches over the course of an activity, exploring what new visualizations might look like at different locations in the environment.

We also explored sketching activities that used printed photographs as a medium for sketching. This approach allows participants to quickly imagine how visualizations could be situated across a diverse range of environments. Moreover, it provides opportunities for sketching augmented and mixed reality visualizations which can be difficult to prototype using other kinds of sketching media.

Prompts

In a number of workshops we provided additional material to prompt ideation during the activities. In W1 and W7, we used technology probes [20] to help participants better understand the target display technology for their designs. In W1, we provided three e-paper displays in different sizes—2.7" (3.8 cm×5.7 cm), 2" (2.2 cm×4.6 cm), 1.44" (2.2 cm×2.9 cm)—that displayed simple visualizations to demonstrate the capabilities of the small displays (Figure 3b). In W7, we showed participants a low-fidelity prototype of the target device (Figure 3a) which included an e-ink screen and working inputs in a cardboard housing.

We also explored using sample data to encourage ideation. In W1, we used two-sided data cards with a database class on

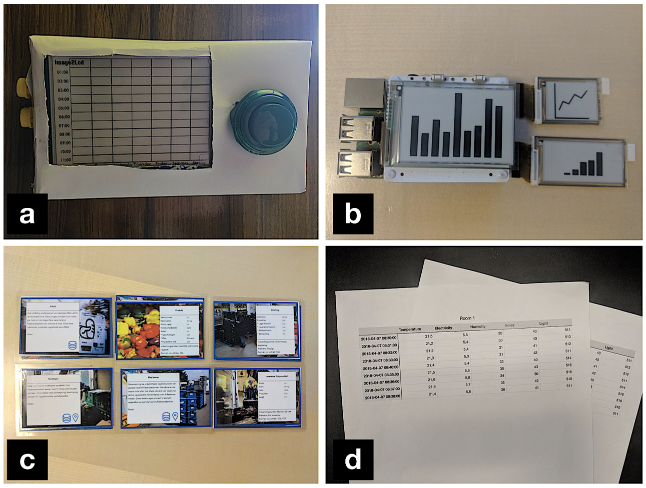

Figure 3. Prompts. (a) Low-fidelity prototype from W7 (Self-Tracker), (b) e-paper displays from W1 (Food Bank), (c) data cards from W1 (Food Bank), (d) sample data sheet from W2 (Office Climate).

one side and a list of data attributes on the other (Figure 3c). In W2, we provided a sample data sheet to help prime participants (Figure 3d). Similarly, in W7, we prompted participants to design using various kinds of personal data.

SITUATED VISUALIZATION WORKSHOPS

The seven workshops (Figure 4) were conducted by two teams of researchers who independently explored design activities for situated visualization. The connection between the two initiatives occurred mid-stream as part of conversations about how to involve people in the ideation and design of situated visualizations. The design of the interventions was not initially coordinated across the two teams. However, during the analysis process, all authors collaborated closely, sharing materials and considerations from each of the workshops. We elaborate on this analysis when we discuss our observations and findings in the Reflection and Recommendations section.

W1. Food Bank

We conducted this workshop at a local non-profit food bank in Aarhus, Denmark which distributes surplus food to social organizations. The aim of the workshop was to explore how situated visualizations can be used to make logistics and internal management data available in the food bank's warehouse to support the volunteers' and employees' work activities. The Food Bank workshop was *task-centered*, focused on sketching visualizations that support specific work-related tasks. We provided whiteboard sheets for sketching in sizes representing a variety of small displays, but did not focus on a specific hardware platform. The workshop was also driven by real-world considerations of the workers rather than open-ended ideation.

The workshop took place in the warehouse at the food bank where goods are stored, received, and packed for distribution routes. Four participants including two volunteers and two full-time employees from the food bank took part. Before the workshop, we conducted a site survey at the warehouse to gain an overview of the workplace and observed the participants both on one of the food distribution routes and in the warehouse where they scanned and sorted goods. We provided data cards (Figure 3c) of management data of the food bank based on a prior workshop and a survey of their database.

During the workshop, we asked participants to sketch with colored markers on magnetic whiteboard sheets in eight different form factors that were based on common display sizes (Figure 1a) including: an A4 sheet (21 cm×29.7 cm), 8.9" tablet (12 cm×19.2 cm), 5" smartphone (6.2 cm×11.1 cm), 2.7" (3.8 cm×5.7 cm) e-paper display, 2" (2.2 cm×4.6 cm) e-paper display, 3.5 cm×3.5 cm square smartwatch, ⌀ 3.5 cm round smartwatch, and 2 cm×2 cm square tile. The participants could attach the whiteboard sheets to magnetic surfaces or place them anywhere else in the warehouse using adhesive putty. We also provided three small e-paper displays (Figure 3b) as examples.

During the two-hour workshop, we visited several pre-selected locations based on our prior observations. At each location, we asked the participants to select whichever whiteboard sheets they preferred and create sketches of information that they would like to see during their work routines. Participants then placed the sketches in the environment wherever they wanted to have them available. Participants first ideated individually, then presented their concepts to the group for discussion. To wrap up, we summarized and discussed the ideas together with the participants who voted to select their preferred ideas. After the workshop, we coded the transcript of the workshop, sorted the photos based on ideas, analyzed the use of different form factors in participants' sketches, and finally created a summary of all findings with relevant quotes from the transcripts.

W2. Office Climate

We held this workshop as a pilot before the workshop at the food bank with the goal of evaluating the workshop format. The workshop procedure was the same as for W1 and we provided the same sketching materials. The workshop was *task-centered* and *ideation-centered*. It was set within the bounds of an office environment and people's work practices. In contrast with the food bank workshop, the ideation was open-ended to gather ideas freely without real-world constraints.

The workshop took place in office rooms and the hallway of our department at Aarhus University. Three participants, all HCI researchers, took part in the workshop. Before the workshop, we selected the different locations where the brainstorming and sketching sessions took place. We used a fictional dataset that consisted of environmental data (light, electricity, temperature, air quality, and noise) for every office. We provided a sample data sheet (Figure 3d) so that the participants could get an impression of the data. We also allowed participants to ideate using other data sources of their choosing.

In a 1.5 hour workshop, we visited three pre-selected locations at the office: inside an office room, outside an office, and inside a communal meeting room. We asked participants to generate ideas for visualizing the environmental data at each of those locations. After the workshop, we evaluated the workshop procedure and analyzed participants' sketches as well as their use of the different sketching materials.

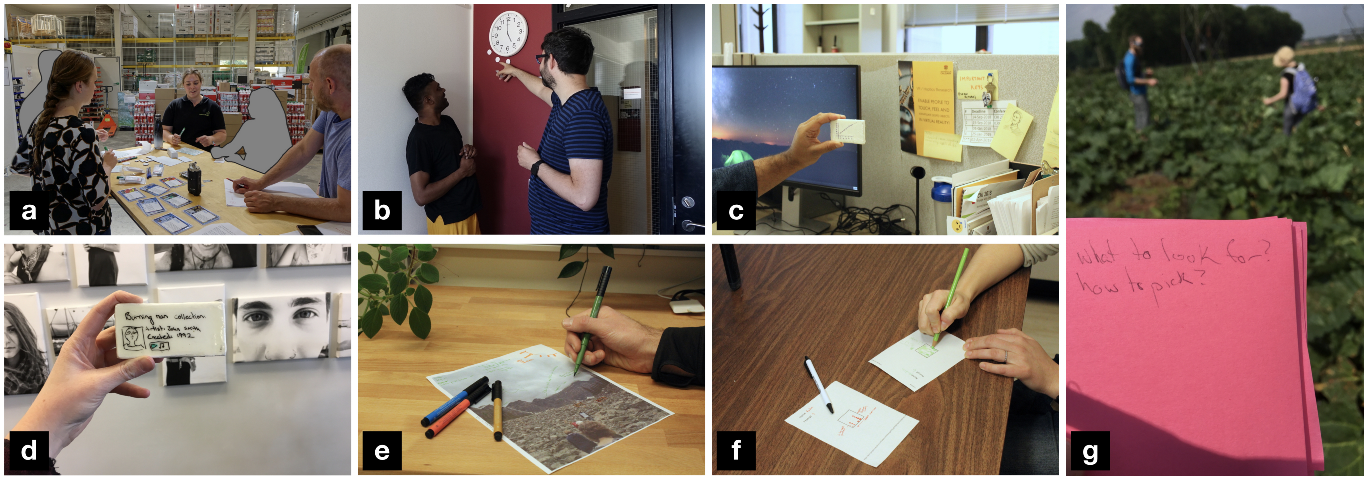

Figure 4. The workshops activities. (a) W1 Food Bank (participants who did not give consent for the use of their pictures are anonymized) , (b) W2 Office Climate, (c) W3 Tiles at Office*, (d) W4 Tiles at Home*, (e) W6 Photo Annotation*, (f) W7 Self-Tracker*, (g) W5 Agriculture. **Photo recreations.*

W3. Tiles at Office

We conducted this workshop to explore opportunities for situated visualization research in a more general set of university office environments. Participants used tangible magnetic whiteboard tiles as sketching materials. This material restricted participants' ideation to small situated devices, but the capabilities of the device were left up to each participant's imagination. This workshop considered a semi-defined form factor and a semi-restricted set of tasks in which we primed participants to both ideate and consider their current context and its restrictions. As such, we categorized this workshop as being in the intersection of the three focuses we have defined (*hardware, task, and ideation*).

We held the workshop in a large research laboratory building with multiple different areas including office spaces, collaborative meeting rooms, hallways, fabrication labs, and a coffee area. Fifteen participants took part, all of whom were visualization or HCI researchers. Before the activity, we gave the participants an introduction to situated visualization. We prompted the participants to explore data they would find useful throughout their activities in the office.

We provided magnetic whiteboard tiles and fine-tipped dry-erase makers to the participants. These tiles (Figure 1c,d) came in two sizes ($5\text{ cm}\times5\text{ cm}\times0.5\text{ cm}$ and $5\text{ cm}\times10\text{ cm}\times0.5\text{ cm}$) and had the weight and feel of an electronic display of that size. The workshop lasted approximately one hour. We instructed teams of three to walk around the available space and consider the different tasks they complete in their environments, what information would be helpful to them, and how it should be displayed. The teams then sketched their designs on the whiteboard tiles and took pictures of each tile in-context. After the workshop, the participants took part in an informal discussion where they shared the ideas they generated and the different insights and challenges they discovered.

W4. Tiles at Home

We held this workshop to explore the opportunities for situated visualization research in a home environment. We prompted the participants to explore data they would like to see in their home and aimed to generate a wide range of ideas. Like in W3, the sketching material restricted the kinds of hardware participants could imagine. As such, we categorized this workshop to be at the intersection between *hardware-centered and ideation-centered* approaches.

Participants met for an introduction to the activity, then continued it individually at home. We included five participants, all of which had visualization research experience and were employed as researchers at a university. We did not brief the participants on situated visualization, but spent approximately 30 minutes brainstorming possible uses for the tiles together prior to the at-home portion of the activity. We prompted the participants to explore data they would find useful throughout their activities at home. Besides this prompt, we left the data that could be considered relatively undefined, as exploring this component was part of the activity.

Each participant received a set of several tiles (with the same characteristics as those in W3) and colored dry-erase makers. Once at home, participants used these to create visualizations tailored to various domestic locations and datasets. Throughout the week, participants updated their visualizations and moved the tiles to support different tasks. In a follow-up meeting 7 days later, participants shared and discussed their photos and ideas as a group.

W5. Agriculture

This workshop aimed at exploring situated visualizations in an outdoor environment on a pick-your-own farm. The workshop was both *task-centered* and *ideation-centered*—focusing on a specific task domain but encouraging open-ended ideation. We allowed participants to sketch using sticky notes rather than dictating a specific form factor. This more neutral sketching medium allowed them to imagine many different technologies that might enable visualizations in an outdoor setting.

We ran the workshop at a large pick-your-own farm, which included fields of seasonal crops (flowers, fruits, and vegetables), barns for livestock, stands selling pre-picked items, and a medium-sized grocery store. Fifteen participants took part, all of whom were either researchers or students with expertise in visualization and/or HCI. The participants had varying levels of experience with farms, including some who had grown up on a farm and others who had never visited one. We prompted the participants to explore data they would find useful at the farm—with some participants taking on the role of a farm employee and others imagining the customer or visitor experience. Beyond this prompt, we did not stipulate any specific datasets.

Each participant had a sticky note pad, a writing utensil, and a mobile device for capturing images of their sketches in-context. The participants self-selected into two groups, one of which examined the barns and the store while the other explored the fields and produce stand. The groups worked for 2 hours, completing and documenting sketches as they went. Later, the entire group worked together to integrate all of the sketches into an affinity diagram to distill the most interesting themes and visualization designs.

W6. Photo Annotation

The aim of this workshop was to explore a more diverse set of situated visualization forms across a wider range of locations by sketching on photographs. While we limited each participant to a small set of prompts during the sketching stage—the workshop as a whole was very *ideation-centered* and aimed to explore a wide range of tasks, environments, datasets, and potential technologies.

Notably, we did not situate this activity in the target environment. Instead, participants sketched in a large meeting room, using a variety of photographs (containing scenes from bathrooms to dirt bike races) printed on $8\frac{1}{2}$" × 11" paper. Again, fifteen participants took part, all of whom were researchers or students. We prompted participants to consider specific technologies (mobile devices, small/large embedded screens, augmented reality, etc.) and motivations (recollection, reflection, decision making, etc.). Before the activity, we primed participants' level-of-detail by showing them an example scene we had sketched beforehand. We did not specify a dataset and allowed participants to generate their own.

Each participant received a printed photo, two prompts, and a set of colored pens. Participants sketched for 10 minutes, then transitioned to small group discussions to further develop their sketches and ideas. Afterward, the entire group shared and discussed their designs, ideas, and insights while integrating all of the sketches into an affinity diagram.

W7. Self-Tracker

We conducted this workshop to examine the design of situated tracking tools for personal informatics. This workshop was *hardware-centered* and focused specifically on situated visualizations for small e-paper displays. The prompts explored a wide range of tasks and data.

As in W6, we conducted this workshop in an office meeting room, rather than in the target environment. Twelve participants took part in the activity, all of whom were either students or researchers with visualization experience. Before starting, we introduced participants to the concept of situated visualization and demonstrated a low-fidelity prototype of the target hardware. This prototype (Figure 3a) consisted of an e-paper display and physical buttons inside a cardboard housing.

We distributed paper cutouts with the same dimensions as the e-paper displays (4 cm×4 cm) to all participants, along with two colored pencils in the same colors supported by the target display. To begin the activity, we handed out a random example use case to each participant. We created the set of examples to cover a wide range of possible self-tracking applications. Participants had two minutes to sketch a design for each prompt, and repeated this step several times with additional prompts. After these initial design rounds, we held a round table discussion in which the participants shared their designs. We then asked participants to design again, this time considering their own personal data. This stage of the activity was more free-form, and we gave participants 15 minutes to generate as many designs as they wanted. After the workshop, we analyzed the designs that participants had generated, sorting them based on recurring design elements and organizing them to reflect emergent design dimensions.

REFLECTION AND RECOMMENDATIONS

Through conducting these seven design workshops, we explored a range of different activities, materials, and prompts for situated visualization design. Each of these specific workshop formats uncovered particular strengths and limitations of the employed methods, as well as opportunities for further research. In this section, we summarize our observations from conducting the workshops, and identify key challenges and benefits of these design activities for situated visualization design. We structure our reflections using the three genres of activities (ideation-centric, task-centric, and hardware-centric) that we examined in our workshops.

We distilled these reflections based on iterative analysis of photographs, participants' sketches, and researchers' notes, as well as transcriptions and translations of audio recordings (when available) from the workshops. The researchers directly involved in each workshop first analyzed the qualitative data and artifacts from their individual activities. All authors then iteratively integrated findings from all seven workshops to produce a final set of opportunities, challenges, and reflections.

Ideation-Centered Activities

Flexibility of Whiteboard Sheets & Tiles

The magnetic whiteboard sheets and tiles we used in workshops (W1–W4) proved popular with participants and resulted in a variety of visualization designs that integrated with existing objects and infrastructure. In workshops W1 and W2, where we provided a variety of whiteboard sheet sizes and shapes (Figure 1), participants were free to select sheets to suit their personal preference. Participants in the Food Bank workshop (W1) mostly used larger, rectangular display sizes that simulated tablets and smartphones (the most used form factor was the 8.9" tablet size). In the Office Climate workshop (W2), meanwhile, participants used a more diverse set of display sizes, and gravitated strongly towards the 3.5 cm round sheets. We speculate that this difference may be related to

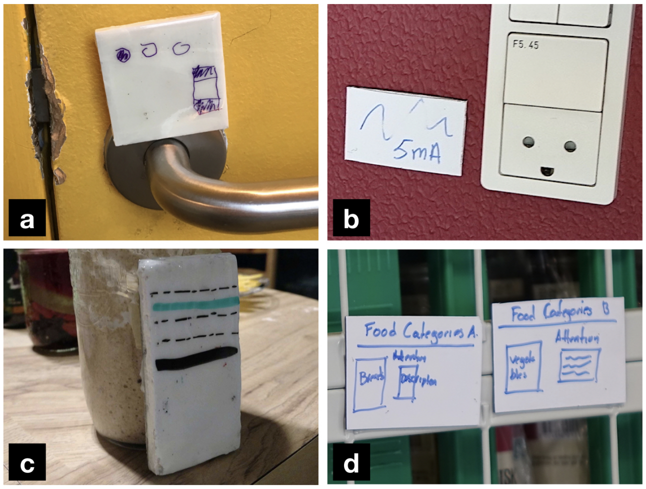

Figure 5. Whiteboard tiles and sheets. (a) Tile from workshop W2 (Tiles at Office) on a magnetic surface, (b) sheet from W2 (Office Climate) on a wall with adhesive putty, (c) tile from W3 Tiles at Home leaning on an object, (d) sheets from W1 (Food Bank) on a magnetic surface.

participants' level of prior experience with various devices and interfaces, a phenomenon known as legacy bias [34]. Some participants in W1 also mentioned choosing the larger sizes when they were unsure of what they wanted to draw and how large it would be.

In the Food Bank and Office Climate workshops (W1, W2), we combined the whiteboard sheets with adhesive putty to allow participants to place the sheets on non-magnetic surfaces. For instance, in the Office Climate workshop (W2), participants used the adhesive putty to place sketched displays around a wall clock (Figure 4b) as well as attach them to walls (Figure 5b) and objects like plants.

In the two workshops in which we did not provide adhesive putty (W3, W4), we noticed that the need for magnetic backing limited the locations that participants considered. Some participants gravitated towards metal surfaces and restrained themselves to placing sketches in those locations, rather than exploring potential alternatives.

In general, we found that using whiteboard sheets and tiles had a number of benefits when compared to more traditional sticky notes. The whiteboard sheets made it easier to update sketches, since participants could erase or alter subsets of the designs without starting over. Meanwhile, drawing on paper led to sketches that were rarely changed or updated. In the Agriculture workshop (W5), our one activity that involved the use of sticky notes, we observed that sketches tended to be more simplistic, relied more heavily on text, and were unlikely to be updated. In contrast, participants using the whiteboard sheets and tiles in workshops (W2, W3, W4) (and to a lesser extent in W1) often updated their sketches multiple times and remained engaged with each sketch longer.

Inspiration from the Environment

Conducting workshops in the same environment in which the visualizations are likely to be deployed can guide design activities and help to generate new ideas. For instance, participants in W2 were inspired by a variety of objects in the office and explored ways in which situated visualizations could complement them. This included positioning sketched displays next to a power outlet (Figure 5b) and alongside the office nameplates in a hallway. We also observed that participants' familiarity with a space had an impact on the types of ideas they generated. In W4, when participants created ideas in their own homes, the ideas were more specific, personal, and unique to their daily tasks. In contrast, many participants in W3 (while familiar with similar office environments) were visitors, and their ideas focused more on generic uses of the space. We observed a similar phenomenon in W6, where participants sketched on top of generic photographs of common environments. Again, their ideas tended to focus on general use-cases for those kinds of spaces, rather than specific ones.

Specificity and Constraints

We explicitly varied the specificity of the design prompts across several of the design activities. We provided more open-ended directions in workshops (W2–W6), but framed W1 around existing tasks in the food bank and constrained participants in W7 to design for a specific self-tracking device and specific kinds of data. We observed that when we provided participants with specific prompts they generated more concepts and established a stronger sense of initiative that led them to build on past ideas, iterate, and explore. This meant that even when these constraints were later lifted (as in W7, where participants were eventually freed to imagine a wide variety of data types), the quality and quantity of ideas appeared to be much higher than when we did not provide prompts. This aligns with past suggestions that applying "decisive constraints", which force decisions and instigate creative turning points early in the design process, may help accelerate ideation and encourage innovative solutions [2]. We also observed a similar effect in the Photo Annotation workshop (W6), where the participants who imagined very specific use-cases in their scene and focused their design considerations on them tended to generate more fruitful and diverse visualization concepts.

Task-Centered Activities

Unfamiliarity with Sketching or Ideation Practices

We observed that participants' prior exposure to and confidence with sketching and ideation activities influenced their ability to translate ideas into detailed sketches. Our workshops showed large contrasts between participants who had a background in HCI and visualization research and those that did not (including domain experts like the volunteers and employees at the food bank in W1). Researchers tend to be used to participating in such workshops and may have prior sketching experience. The influence of familiarity with ideation and creativity methods and processes is a common challenge in such workshops, as also noted by Halskov & Dalsgaard [15].

In the workshops we conducted with HCI and visualization researchers (W2–W7), we observed that participants with this background had no difficulty generating many different ideas and translating their ideas into detailed sketches (Figure 6a). In contrast, participants at the food bank (W1) often had difficulty translating their idea into a visual form, and as a result, reverted to describing their ideas as text notes rather than

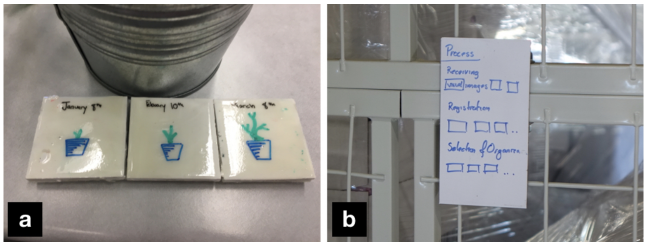

Figure 6. Level of detail of sketches. (a) Recreation of a detailed sketch from W4 (Tiles at Home), (b) Text-based sketch from W1 (Food Bank).

sketches (Figure 6b). While we repeatedly encouraged participants to draw what they would like to see, the set of concepts that participants ultimately generated was much less visual and less detailed than in the other workshops—including W2 which used the same materials, prompts, and overall procedure. We suspect that this uncertainty may have also affected the form factors that participants at the food bank selected. Often, these participants would pick the largest whiteboard sheets available because they had difficultly determining how much space a visualization was likely to take, or because they wanted additional space for taking notes. At the Office Climate workshop (W2), which included trained researchers, this was not an issue. We observed similar behavior in W4, where teams with less visualizations experience tended to generate more text-based "visualizations" while teams with greater experience in visualizations generated more and richer variations.

Possible approaches for overcoming this lack of familiarity with ideation and sketching activities could include starting with a warm-up exercise before the workshop, to get people acquainted with sketching and brainstorming [13]. Employing a mix of researchers with a visualization background together with domain experts may also prove fruitful, although there is a risk of having the researchers dominate the ideation process.

Practical Concerns Hinder Task-Centered Ideation

Holding the sketching and ideation activities at the location in which visualizations are likely to be deployed can increase generation of ideas relevant to those spaces. However, we observed that it could sometimes also restrict ideation, especially when participants were reminded of the limitations posed by existing infrastructure, rules, and work practices. For example, in the Food Bank workshop (W1), participants' concerns about the potential cost and robustness of displays caused them to quickly eliminate some possible display locations, such as on pallets in the warehouse.

A related consideration is how much the experimenters restrict the ideation process to the actual data that is currently available. In all workshops, we allowed participants to use both data that we provided (such as the data cards and sheets in W1 and W2) as well as other useful data participants imagined could be collected. While we cannot compare with activities that constrained the data participants could use, our findings suggest that being flexible in what data can be used facilitated idea generation.

Situating Design Without Domain Expertise

In the Agriculture workshop (W5), we explored the task domain of a farm with a set of participants who were all visualization researchers, but had varying levels of domain expertise. While a few had existing connections to agriculture, such as growing up on a farm or frequenting pick-your-own farms, many had no connection to the domain. This difference in domain expertise translated into a very wide spread of design ideas, tailored to the participants' respective experiences. Participants with a deeper background in agriculture designed visualizations that supported routine farming tasks like irrigation management and pest-tracking. Meanwhile, those with less expertise sketched visualizations tailored to visitors and non-experts, including situated maps and views for identifying different plant varietals.

This divergence highlights the tendency for participants in situated design tasks to focus on designing for their own personal experiences of a space, rather than the experiences of others. As such, including participants with a wide range of experiences may help produce more diverse application concepts during early-stage ideation. However, including participants who represent the perspective of the ultimate users of a system or who have a deep understanding of the target domain is likely to be critical in task- and hardware-centered activities.

Information Visualization or Just Information?

In more task-oriented activities like W1, we noticed a tendency for participants to produce designs that revealed small amounts of information via text labels and color, rather than via more complex visualizations. These included designs that displayed expiration dates on a box of goods, used a specific color to indicate that the content of a box should be distributed to schools, or provided visual instructions for new volunteers. One participant in W1 specifically requested that displays not show too much information, providing quick snapshots of the data rather than supporting detailed data analysis.

While these simpler designs may have been a byproduct of participants' limited visualization expertise, a similar theme also emerged in W7, in which participants were familiar with visualization design. Again, many of the designs they created showed data via very simple representations (counts, timestamps, ratios, etc.). Follow-up discussions made clear that this trend was deliberate. Participants stressed that small displays should be used to show simple information that viewers could parse at-a-glance and felt that more complicated visualizations of the data would be better served by more feature-rich mobile or web-based applications.

These examples highlight the advantages of situated displays that use clear, minimalist, and glanceable encodings to communicate task-related information while minimizing complexity. As such, we suspect visualization designers should be cautious not to bias participants too strongly with complex visualization designs prior to sketching, particularly when considering situated tasks that are not analytic in nature.

Proximity to Physical Referents

Results from the workshops showcase how placing situated visualizations close to their physical referents (and thus reducing *spatial indirection* [44]) may not always be the most practical or desirable solution. For example, in the Food Bank workshop (W1), participants noted that placing a visualization showing frozen food items inside the freezer room where they were stored would have been problematic because workers spent only short amounts of time in that cold environment. Meanwhile, in the Self-Tracker workshop (W7), participants debated where to position displays to prompt behavior changes like exercising more, eating more healthily, or meditating regularly. Often, participants concluded that displays should be placed in highly visible locations where they would be seen regularly, rather than in the locations where the activity (exercise, eating, meditation) would take place. For example, a person who hoped to cycle more might place a visualization of their cycling activity near their car rather than near their bike, providing a reminder and opportunity to reflect each time they chose to drive.

Hardware-Centered Activities

Limitations for Prototyping Interaction or Advanced Features
While the sketching media that we used in our workshops were useful for generating visualization designs, they were all limited in their ability to simulate interactions and dynamic behavior. Although these aspects can be explored in later phases of the design process with high-fidelity prototypes, the static nature of the sketching media may reinforce the notion that the small displays are static or non-interactive. As a result, these media may discourage participants from brainstorming dynamic, interactive, or context-aware visualizations. For instance, during the Food Bank workshop (W1), participants never considered the possibility that displays could be mobile or that they might adapt to changes in time, location, or activity. In contrast, participants in W7—which used a combination of paper cutouts and a low-fidelity prototype of an display with physical buttons (Figure 4a), generated almost exclusively interactive designs.

Interesting future opportunities for situated prototyping include using live video prototyping tools such as Montage [27], as well as digital sketching tools that could permit participants to draw directly on top of active devices and small displays. Considerable potential also exists for workshops that examine the intersection of hardware- and task-centered design, which we did not examine in any of our activities (Figure 2). For example, examining a specific high-fidelity hardware platform (such as 2.7" interactive color e-paper displays) within a task domain like a food bank or warehouse could help encourage more concrete yet practical design ideas.

Sketching Mixed and Augmented Reality Visualizations
While our workshops focused primarily on situated visualizations that use small displays as a target platform, other hardware platforms exist for situated visualization. Whiteboard tiles and sheets work well for ideation and prototyping of situated visualizations with small displays, but do not scale well to other platforms such as media facades, projection-mapping displays or mixed and augmented reality systems. Moreover, immersive visualization designs created on physical sketching media like these can be difficult to photograph and document in-context—a challenge that was especially evident in the outdoor environments in W5 (Figures 1g and 4g).

There are a number of possible sketching and design activities for these hardware platforms that could be interesting avenues for future research. For instance, sketching on glass, acrylic, and other transparent surfaces could help participants explore visualization designs that overlay visualizations on top of objects and environments. By using camera- and stylus-equipped tablets, participants could also capture images of their environment and then sketch on top of them in situ, leveraging context and details from their surroundings while still sketching creatively. We observed several emergent examples of this behavior in W3, where some participants took photos using an iPad and then annotated them on-location using a note-taking app. This allowed them to explore AR/MR visualizations that layered data on top of existing items and spaces, including soft and amorphous objects like plants.

CONCLUSION

This paper represents a first step towards a collection of design methods tailored to the unique challenges of creating situated visualizations. Our experiences suggest benefits and tradeoffs of these workshop formats and highlight opportunities for sketching activities to support richer ideation, needs elicitation, and hardware-centered design for situated visualizations. So far, we have primarily used these activities, materials, and prompts in the early phases of the design process. However, many of the same concerns faced during early-stage design—including understanding the relationships between situated visualizations and real-world objects and environments—remain similarly challenging throughout the broader design and prototyping cycle. We look forward to extending this initial set of design methods and hope that this work encourages others to use these kinds of activities to further explore the space of potential situated visualization designs.

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