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► **To cite this version:**

Nathalie Bressa, Henrik Korsgaard, Aurélien Tabard, Steven Houben, Jo Vermeulen. What's the Situation with Situated Visualization? A Survey and Perspectives on Situatedness. *IEEE Transactions on Visualization and Computer Graphics*, In press. hal-03319648v1

HAL Id: hal-03319648

<https://hal.science/hal-03319648v1>

Submitted on 12 Aug 2021 (v1), last revised 23 Aug 2021 (v2)

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What's the Situation with Situated Visualization? A Survey and Perspectives on Situatedness

Nathalie Bressa, Henrik Korsgaard, Aurélien Tabard, Steven Houben, Jo Vermeulen

Abstract— Situated visualization is an emerging concept within visualization, in which data is visualized in situ, where it is relevant to people. The concept has gained interest from multiple research communities, including visualization, human-computer interaction (HCI) and augmented reality. This has led to a range of explorations and applications of the concept, however, this early work has focused on the operational aspect of situatedness leading to inconsistent adoption of the concept and terminology. First, we contribute a literature survey in which we analyze 44 papers that explicitly use the term “situated visualization” to provide an overview of the research area, how it defines situated visualization, common application areas and technology used, as well as type of data and type of visualizations. Our survey shows that research on situated visualization has focused on technology-centric approaches that foreground a spatial understanding of situatedness. Secondly, we contribute five perspectives on situatedness (space, time, place, activity, and community) that together expand on the prevalent notion of situatedness in the corpus. We draw from six case studies and prior theoretical developments in HCI. Each perspective develops a generative way of looking at and working with situatedness in design and research. We outline future directions, including considering technology, material and aesthetics, leveraging the perspectives for design, and methods for stronger engagement with target audiences. We conclude with opportunities to consolidate situated visualization research.

Index Terms— Situated visualization, literature survey, situatedness.

1 INTRODUCTION

In the last decade, *situated visualization* [defined in 64, 100, 105] has emerged as a research area and a concept that continues work initiated in the area of Ubiquitous Computing (ubicomp) and Human-Computer Interaction (HCI) [37, 81, 88, 98]. The central idea is to bring data visualizations into their context of use, to places and people by connecting data with the physical environment or physical referents that the data refers to [100, 105]. The area of situated visualization follows a strand of research agendas in visualization that are concerned with moving beyond traditional desktop applications [75] such as “Ubiquitous Analytics” [26], “Immersive Analytics” [3, 29], or “Situated Analytics” [27, 90]. The literature on situated visualization spreads across multiple communities and research areas including HCI, visualization, Augmented Reality (AR), ubicomp, and urban computing, as well as subtopics such as public visualization and data physicalization. This wide appropriation of situated visualization as a research concept has led to a disconnected terminology, implications, and visualization design, creating a highly fragmented and inconsistent research landscape. As a result, interpretations of what situatedness and situated visualization are, and how these concepts are understood in the current literature, remain unclear.

To investigate how the research community has adopted and used the concept of situated visualization, and to broaden the scope of situatedness, we present a two-fold literature review and case study analysis. In the first part of the paper, we contribute an analysis of the literature that explicitly uses the term “situated visualization”. We discuss and reflect on how these papers define situated visualization, the methods

and technology they use, the application domains of proposed situated visualizations, and the type of data and type of visualization. From an analysis of the corpus, we conclude that work within visualization and visual analytics using AR technology to place visualizations within the physical environment and using that environment as a direct visual reference is the most prevalent way of presenting situated visualizations in the corpus. A smaller strand of research focuses on community-oriented research within HCI by engaging with and displaying information within a community where data is collected. This illustrates the breadth of situated visualization research and the different ways of approaching and implicitly considering the role and importance of ‘situatedness’ and ‘visualization’ respectively. Upon closer analysis, we find that while situated visualization combines concepts and approaches from HCI and information visualization, current work has adopted and operationalized a mostly spatial understanding of situatedness.

In the second part of the paper, we present five perspectives on situatedness that include and expand on the dominant spatial understanding of situated visualization, building on concepts from ubicomp and HCI: space, time, place, activity and community. We illustrate these five perspectives with a case study analysis, introducing six case studies of situated visualizations that stem from the corpus and from selected examples to encourage the research community to think more systematically about broader concepts of situatedness. Through the case studies, we demonstrate how the perspectives can help to explicitly consider aspects of the situation in which the visualization is shown beyond spatiality alone and to recognize opportunities for a wider set of possible technologies beyond AR. We end with future directions, discussing how to leverage the five perspectives and consider methods for stronger engagement with target audiences, design considerations around technologies, and material and aesthetics, concluding with research opportunities to further strengthen the area of situated visualization.

2 APPROACH

The goal of this paper is to clarify the concept of situated visualization by using a two-fold approach. In a first stage, we examine the literature that currently self-identifies as situated visualization through a keyword-based literature survey. In the second stage, we look at the broader literature and analyze a selected set of case studies on situated visualization that, while they may not directly use the term, can be classified as concerning situated visualization and expand on the notions of situated visualization as covered in the corpus from the first stage. We use these case studies to exemplify five perspectives on situatedness

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Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org.
Digital Object Identifier: xx.xxx/TVCG.201x.xxxxxxx

that are based on concepts from ubicomp and HCI.

Given the variety and spread of the literature, we considered two strategies to analyze the literature on situated visualization: an open-ended interpretive approach and a keyword-based approach [25]. An open-ended interpretive approach examines research and examples based on the authors' knowledge of the research area and may include articles that could be analysed and interpreted as concerning situated visualization without necessarily being published with that focus. While this approach generates a broad and exploratory corpus, it also introduces subjective and less obvious inclusion and exclusion criteria and may introduce selective bias early in the process, as well as imposing a characterization that is not that particular publication's intended focus. A keyword-based approach is inclusive towards papers published under the theme of situated visualization and provides a clear cutoff. However, in topics that are new and emerging or cut across multiple communities with different terminology, it can yield a relatively small initial corpus and it is subject to trends and competition in keywords. To combine the strengths of both approaches, we have applied a keyword-based approach in the first stage (the literature survey) and apply an open-ended interpretative approach in the second part (the case studies). We tested different strategies for our keyword-based approach, including the use of seed papers of common definitions of situated visualization (e.g. [100, 105]). However, we found that there was a wide diversity of papers that cited those seed papers, including many papers that do not engage with the concept of situated visualization but rather focus on other aspects (such as AR applications). As a result, the papers citing those seed papers either did not fit our inclusion criteria or would already have been included, so this approach did not yield any additional valuable results.

For the second stage, we selected case studies based on our findings in the literature survey of the first stage. Our analysis of the current literature on situated visualization resulted in several themes, for example, in terms of applications, technologies, and definitions of situated visualization. We then curated and selected case studies that further broadened, expanded upon and provided contrasting perspectives on these themes to arrive at a broader categorization of situated visualization. The use of a curated set of case studies and notable examples to characterize and map out an emerging research area is a valuable approach that has been used before for casual information visualization [69], anthropographics [65], personal information visualization [45], and data physicalization [47]. The perspectives we develop are based on our analysis of the corpus as well as theoretical developments in HCI and ubicomp that we have selected to broaden the current understanding of situatedness for situated visualization.

3 A SURVEY OF SITUATED VISUALIZATION RESEARCH

We survey a set of representative papers from a range of different research communities based on a keyword-based literature search to give an overview of current research in situated visualization.

3.1 Corpus

To build our corpus of papers, we collected a list of 44 core papers with the following inclusion criteria.

Keyword search: we performed a keyword search in the ACM Digital Library, IEEE Xplore, and Google Scholar for papers that contain the term "situated visualization". We focused our keyword search on one search term to get an overview of research that self-identifies as "situated visualization" and to find out how different communities currently use the term without imposing a categorization on papers. While the resulting corpus did not include all possible publications that could potentially be classified as situated visualization, we considered this a reasonable trade-off in line with our goals. We also considered different regional spellings of the word "visualization".

Archival publications: we included full or short archival conference papers, journal and magazine articles, and book chapters. We excluded posters and workshop papers to focus on mature research contributions. Due to the broad list of communities in which situated visualization

research is published, we did not restrict papers to particular venues. Therefore, our corpus includes a broad range of venues (including among others CHI, VIS, AVI, DIS, and ISMAR).

Relevance: We excluded papers that only showed up in the keyword search because they cite papers with "situated visualization" in the title, and do not otherwise mention situated visualization in the paper. We also excluded papers that only refer to situated visualization briefly in related work and do not further engage with the concept. We included all types of data representations that came up with the keyword search in the corpus, including both visualizations and physicalizations.

3.2 Analysis

We analyzed and coded the corpus in several iterations. First, we started by determining initial coding categories based on coding a subset of representative examples of the corpus. After this first iteration, all authors collectively discussed the coding schema and the corpus of papers. We identified additional dimensions, and merged and subdivided existing dimensions where relevant. Next, all authors engaged in focused coding on all the papers in our corpus, iteratively refining and revisiting the coding schema where necessary. After collectively coding all the papers in our corpus, we ended up with five dimensions that we use to categorize each of the papers (Table 1). Similar to Fonet et al.'s [33] survey on immersive analytics, we included dimensions such as technology, data, and evaluation methods. The sub-categories of the dimensions were developed iteratively based on the corpus. The corpus was divided among all authors, in which the top-level categories were initially coded as free-text. Afterwards, each category was assigned to one author who then analyzed the categories holistically to develop the final set of sub-categories. Based on the coded papers in the corpus, we distilled a set of findings where we discuss how the term situated visualization is currently used in the literature, the technology and methods employed, the range of different domains in situated visualizations, and visualization and data types.

3.3 Findings

The corpus consists of a total 44 papers that we analyzed based on a set of five primary dimensions (see Table 1¹). The dimensions include *situated visualization definition*, *technology*, *type of data*, *method*, and *type of visualization*. We further describe our findings of the coding to map out the space of current research on situated visualization. Regarding publication venues, the corpus covers 27 different venues. We can categorize these and their respective communities in the following broad groups: Visualization and Visual Analytics (e.g. IEEE VIS, IEEE TVCG, Information Visualization, PacificVis, AVI, Journal of Visual Languages & Computing), HCI and design (CHI, DIS, Graphics Interface, Int. J. Human-Computer Studies), AR and 3D User Interfaces (3DUI, ISMAR, Handbook of Augmented Reality), Pervasive Displays, and Architecture. This illustrates that several academic communities engage in research on situated visualization, with the visualization and visual analytics, HCI and design, and the AR and 3DUI communities being the most prominent.

3.3.1 Definitions of Situated Visualization

The papers in the corpus can be split into papers that either define or expand the notion of situated visualization (column "Own definition" in Table 1) and papers that cite prior papers that defined situated visualization to frame their research. We categorized the papers based on which papers they cite and what definitions they use for situated visualization (see Table 1). While some papers cite multiple papers that contain definitions of situated visualization, we only considered the papers that were used to explicitly refer to situated visualization. For example, papers referring exclusively to the system contribution in SiteLens [100] are not categorized as using the definition.

The two most prevalent definitions of situated visualization cited in the corpus are White and Feiner's definition [100] (in some cases also White et al. [101]) and Willett et al.'s definition [105]. A total of 27/44

¹Survey data: <http://situatedvisualization.github.io/survey/>

formation [9, 10, 40, 104], or visualization of a phenomena close to an object, e.g. visualizing electromagnetic fields close to the object generating it [39].

Moving outside of AR-centric work, there is a broader catalogue of examples that include different technologies. A number of papers in the corpus (9/44) take an interest in exploring situated visualizations using more traditional display technology and another group (5/44) takes an interest in mobile devices. This includes several projects with a focus on displaying visualizations within semi-public and public spaces to engage people within proximity around locally collected data [19, 48, 74, 94]. Another part of the corpus, focuses on showing data through an analog medium (6/44) or as data physicalizations (6/44). Two of the projects present designs where the visualization is part of a physical object: a custom clock [21] and coasters [86] that show visualizations of people's activity. In these examples, the visualization is designed to fit the physical object and vice versa. Hull and Willett [46] use wood to integrate data into architectural modelling and Perovich et al. [68] use lanterns to visualize pollution violations in a local creek. These projects in the corpus focus on situating visualizations with and through objects and with consideration towards the place and more ephemeral engagements with the visualization. In addition, the work takes on a technologically inclusive perspective where it is the place that is instrumented, rather than the people (e.g. not requiring the use of head-mounted displays to view the situated visualizations). Finally, an important point in several of these projects that do not rely on AR is to make data public which in turn suggests technologies that can be viewed by everyone within proximity so that the visualization can become part of a shared reflection or public debate [19, 64, 68].

3.3.3 Type of Data and Application Domains

The type of data provides an overview of prominent types of data for situated visualization and common application domains.

One group of papers pertains to science and engineering applications. This includes *engineering data* (11/44) such as Building Information Modeling (BIM) and maintenance data [71, 103] or data on environmental corrosion [96]; *environmental data* (7/44) such as air pollution [100] or water permit violations [68]; and *science data* (7/44) such as honey bee behaviour [28], geological science data [104], or science education [91].

Another cluster of papers deals with situated visualization of data for the general public (19/44). This includes *civic data* such as public visualization of urban and locally-relevant data [18, 64, 94] and public data installations [15]; *personal data* such as visualizations in domestic settings [86, 97]; and *consumer data* in domains such as shopping [74]. Related to this cluster of papers are a number of articles that focus on visualizing *activity data*, in the home [86] or in workplaces [21].

Finally, there are data types and application domains that only occur a few times, which we grouped in the *other* category (16/44). This includes *GIS data* [59, 108], *medical data* [49, 58, 90], *education* [12], *sports* [2, 60], *business data* such as logistics data in warehouses [8, 34] and *instructions* for DIY tasks [99].

Note that for several articles in the corpus, the type of data or target application domain was *unclear* (6/44). These articles often present multiple possible applications [48] or domain-agnostic techniques [10, 63, 72, 79, 102]. Overall, our analysis shows that situated visualization has been explored for a wide variety of data from different application domains and for different settings. However, the level of depth in engaging with a particular domain varies widely. Some papers in the corpus engage in depth with a particular target audience and application domain, through initial engagement with a domain, iterative prototyping and design, and a real-world deployment. However, this is rather rare, as most application domains are primarily used as illustrative examples of the visualization technique. As seen in the *method* column (Table 1), the majority of papers in the corpus rely on lab studies (20/44), with a number of field studies (10/44) and only a handful of papers that involve co-design (2/44), design probes (1/44) or workshops (3/44).

3.3.4 Type of Visualization

In terms of the type of visualization used, we found that a large number of papers in the corpus provide little to no reflection on their visualization design rationale. For about a quarter of the papers (column N/A: 12/44), it would be a stretch to categorize them as a deliberately designed data visualization. Instead, these papers often only visualize single data points in-place. An example of this is Zollmann et al. [108], which only shows text labels for buildings. As a notable exception to this, the work of Morais et al. [21], discusses in detail how the data is represented and how the (custom) visualization was designed.

The most common visualizations are what we have referred to in Table 1 as *Standard* visualizations—those that can be easily generated using common tools such as spreadsheets. The majority of the corpus (25/44) relies on such standard visualizations such as line charts, bar charts, or heat maps. The second largest group (17/44) in the corpus use *Custom* visualizations—handcrafted or custom designed visualizations specific to the application domain, the context, target audience or the data that is being visualized. A small number of papers rely on what we categorized as *Artistic* visualizations (5/44)—visualizations that show data in an aesthetically pleasing way, where the data visualization remains in the periphery when it is not the primary focus of attention for exploration and analysis. This category is related to ambient displays, and is inspired by Redström et al.'s informative art [73] and Stasko's information art [87]. Examples in the corpus are Chemicals in the Creek [68], Time-Turner [86] and Valkanova et al.'s Gurgle water fountain display [94]. For example, in Time-Turner, data is visualized on physical drink coasters augmented with LEDs. While the coasters can be used to explore the data, the visualization was designed to invite curiosity and be visually unobtrusive. Finally, some papers in our corpus are surveys or cover a wider design space and discuss several visualizations and thus provide multiple visualization types [65, 105].

In summary, the corpus shows limited engagement with how the data is visualized. Few papers deliberately discuss how the visualization was designed and how it represents the data. The majority of papers in the corpus either use standard visualizations or only visualize single data points (35/44). This could indicate that the area of situated visualization relies on prior innovations in visualization by leveraging well-known and standard visualizations, and rather focuses on how the data visualization is situated instead of on its representation. On the other hand, this may also point to a lack of concern for how the visualization should be designed to be presented in a situated manner. Indeed, some of the counterexamples (e.g. [21, 68, 86]) employ a carefully designed visualization to ensure appropriateness for the intended target audience and context of use.

3.4 Summary of Findings

Next, we summarize our key findings from the literature survey.

Limited engagement with definitions. We observed that few papers in the corpus engage deeply with the existing definitions of situated visualization (Sect. 3.3.1). Most papers merely cite one of the prevailing definitions (White & Feiner [100] or Willett et al. [105]), but do not discuss in detail how they understand situatedness and situated visualization.

Limited engagement with how data is represented. We found that there is limited engagement with how data is represented and visualized in the corpus. Additionally, the majority of the corpus use standard visualizations, visualization as single data points or only information, or use visualizations as exemplars to showcase technical contributions. This may be also partly due to the view of almost any AR application being synonymous to situated visualization (e.g. ElSayed [27] and Schmalstieg and Höllerer [82]).

Limited engagement with target audience. There is limited engagement with and consideration of the target audience for the visualizations that are described in the corpus. This ties back to the prominence of lab studies as the most common way to study situated visualization in the corpus. Only a quarter of the papers in our corpus rely on field

studies, and an even smaller set uses multiple methods, such as initial engagements through workshops or deployments and field studies.

AR as the dominant technology. From a technology perspective, the vast majority of papers in our corpus relies on AR, with the rest of the corpus utilizing other technologies such as larger displays, mobile devices, or physicalizations.

A spatial understanding of situatedness. There is a close relationship between situated visualization and AR which has influenced the field and emphasizes technical contributions. This leads to a prevailing spatial notion of situatedness in the corpus which emphasizes spatial properties and relationships between visualizations, objects, and locations.

4 EMERGING PERSPECTIVES OF SITUATEDNESS

Our survey confirms that papers on situated visualization conceptualize situatedness primarily as a set of properties related to space and proximity between the visualization and objects or features of the environment.

Starting with applying and operationalizing known features – in this case location and spatial organization – before exploring additional perspectives, is a common strategy in research. For instance, early work within context-aware and mobile computing started by investigating location tracking to provide novel applications and services. However, the community quickly realized that “there is more to context than location” [83]. Zimmermann et al. [107] make similar observations and explore five operational features of context. While these focus on categories of contextual information, their work illustrate the need for expanding early conceptions of context, and here situatedness, into more useful analytical and operational categories.

When exploring ‘situatedness’ beyond location and spatial relations, Dourish [22] made an important point: understanding context (and similarly situatedness) as a matter of spatial organization and cataloguing objects and relations reduces context and situation to a representational problem where information and (material) stability take precedence over the relational and dynamic aspects. Instead of being a product of metrics and spatial features, context arises from activity, in the sense that what meaningfully counts as context is what matters to the activity. This observation applies to understanding situatedness as well.

Suchman [88] made a related argument earlier when discussing the ability to model humans plans and reasoning: people can plan their activities but action is contingent on the conditions and environment in which it unfolds. Instead of conceptualizing use and action as carrying out intentional plans and following precise scripts, people act based on establishing a coherent and mutual understanding of action and meaning in unique material and social circumstances (situations). Suchman emphasizes language and social interaction as a primary mechanism for organizing activity. From this perspective, what ‘is’ the situation is a continuous achievement of social interaction. This is referred to as the *practical objectivity of situations*: when engaged in activities and social interactions we pay attention to what is important to the activity and interaction above less important aspects and things. Hence, what makes the situation mutually intelligible to the people involved in the activity is a product of how people make sense of activities and action through social interactions and language.

Based on these discussions on examinations of the additional factors and aspects of the context, and social and material circumstances that influence how visualizations can be considered situated, we introduce five perspectives of situatedness: space, time, place, activity, and community. We selected these perspectives based on broader theoretical discussions on situatedness in HCI, CSCW, and ubicomp and from emerging themes from the corpus analysis. The space perspective is derived from the largely spatial understanding of situatedness present in the corpus and Willett et. al.’s concept of physical referents. Place and activity are based on theoretical discussions on place in HCI (influenced by Dourish [23]) and activity theory [5]. The time and community perspectives are to a certain degree underdeveloped and implicit in the corpus (see Willett et al. [105] temporal indirection for time and work on public visualization for community [19, 68]), which we develop further in relation to situatedness.

By introducing six cases (C1–C6), we illustrate how these perspectives can be used. We will discuss and elaborate on the individual perspectives with the cases as examples.

4.1 Exemplars of Situated Visualizations: Six Cases

We analyse six cases (C1–C6) from the literature we find to be good exemplars of situated visualizations and physicalizations to illustrate the different perspectives on situatedness we have identified (Figure 1). While these cases may not all use the term “situated visualization” explicitly, we introduce them to expand on the key concepts developed in the works of our initial corpus.

C1 Corsican Twin [71] is a VR authoring tool for designing situated and embedded AR visualizations remotely for building management. Based on the concept of digital twins that are digital replicas of real-world objects and spaces, the tool enables authoring of AR visualizations for large or difficult to access environments in a remote setting. People can create visualizations in VR in a 3D model of the interior of the target environment and afterwards view the created visualization in AR in the physical space through a head-mounted display.

C2 Situated Glyphs are small context-aware displays that show activity-specific information [51, 95] to support work activities of healthcare professionals. The project explored the use of small wearable, mobile, or fixed displays that show relevant information to support interleaved activities involving multiple individuals and different types of equipment in the context of healthcare work.

C3 Cairn is “a tangible apparatus that enables situated data collection, visualization and analysis” of FabLab activities [36]. Its creators present it as an alternative to questionnaires and data collection techniques, while also materializing FabLab activities and fostering reflection on them. Cairn’s physicalization consists in tokens visitors stack on a tabletop to record and display the type of activity they conducted in the FabLab, what resources it involved, what they learned and taught, and how much time they spent in the lab. The project has been implemented in a FabLab in Paris and has been adapted in the NYU Makerspace [56].

C4 Chemicals in the Creek [68] is a community-based physicalization in the form of an interactive installation. The project consisted of deploying connected lanterns representing water quality violations by industrial facilities during a public event. The installation itself was the result of two years of collaboration between researchers, citizens and activist networks, assembling data, deciding how and when to display it, and debriefing the event with the public afterwards.

C5 Activity Clock [21] is a wall clock that integrates data on the number of people typically present in a cafeteria of a research laboratory over a day. The visualization is made out of paper inside a plastic wall clock and has been deployed over the course of the week.

C6 Public Polling Displays [14] is a project about public visualizations on small distributed public polling displays that present a civic issue through data driven narratives, which has evolved into an interactive citizen participation survey display device [17]. In collaboration with a neighborhood committee in Antwerp, the researchers distributed multiple small e-ink displays on house facades of residents that presented perspectives on local issues consisting of a visualization of air pollution levels based on PM25 sensor data, a public polling question and results from the hosting resident, supporting infographics or textual annotations, and a personal statement of the hosting resident.

4.2 Perspectives

To expand the concept of situatedness, we introduce five key perspectives (space, time, place, activity, and community). While these five perspectives are complementary and could be considered for each of the case studies, we highlight selected case studies that are more prominent and relevant for particular perspectives than others.

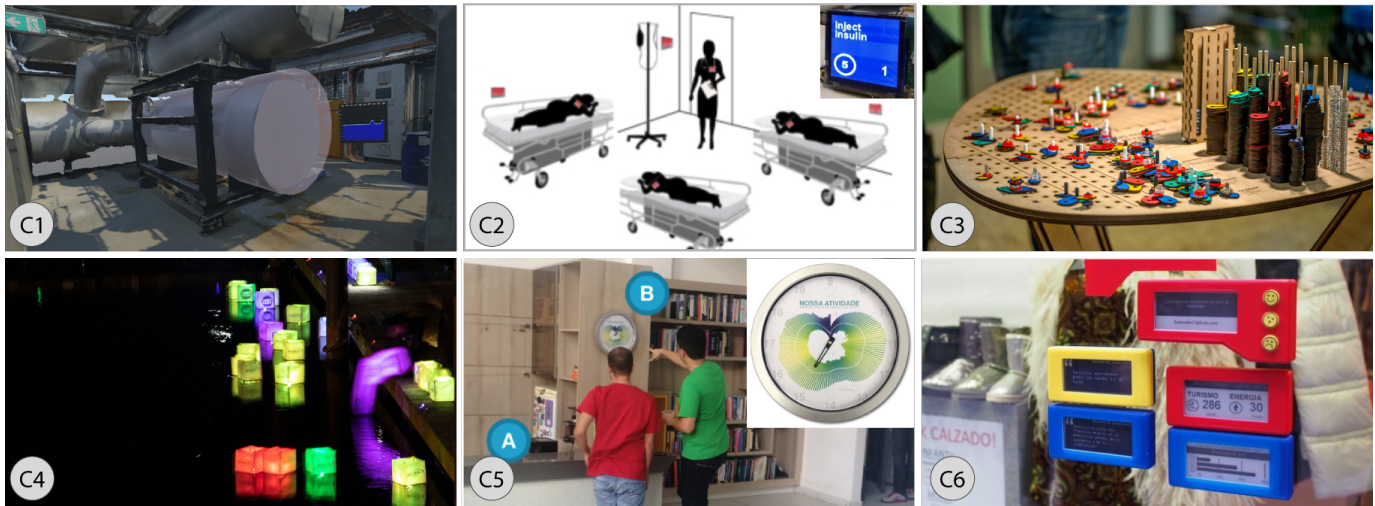


Fig. 1. Case studies: **C1** Corsican Twin [71], © 2021 A. Prouzeau; **C2** Situated Glyphs [51, 95], © 2012 IEEE; **C3** Cairn [36], © 2021 P. Gourlet; **C4** Chemicals in the Creek [68], © 2020 W. Campbell/IEEE; **C5** Activity Clock [21], © 2020 IEEE; **C6** Public Polling Displays [14, 17], © 2021 J. Coenen.

4.2.1 Space

The space perspective is implicit to most works reviewed in Section 3, and focuses on the spatial organization and relationship between the physical environment and situated visualizations. Framing situatedness as a problem of spatial representation implies that the unit of analysis is the placement of visualizations with regards to spatial properties and features in a three-dimensional environment (e. g., location, proximity, distance, and physical structure). This spatial perspective resembles many similar attempts to sense and represent context in context-aware computing and recently in proxemic interaction [38].

The space perspective is explicitly represented in the key definitions by White and Feiner [100] and Willett et al. [105], in particular in Willett et al.'s concept of physical referents. They approach situatedness as a relationship between physical referents and physical representations of data. They position this relationship within an extension of the data visualization pipeline that includes both a physical and logical world where physical referents are a “physical object or physical space to which the data refers” [p.462 105]. The emphasis, thus, lies on the proximity between data representations and physical referents which is used to distinguish between situated and embedded visualizations and to determine the level of “spatial indirection”.

While space, by definition, plays a role in all the cases, there are cases where it is a particularly useful perspective to consider that can be helpful to examine other aspects of situatedness. **C1** (Corsican Twin) is a good example in which spatial situatedness is key in understanding the connection between the physical space, the visualization and the activity it is intended to support. In **C1**, visualizations about the equipment and the site are situated by pairing equipment with data streams from associated sensors. The visualizations, as overlays, create a direct relationship between data (such as volume in a tank, see Figure 1, **C1**) and physical referents (the machinery). Here, it is crucial that the spatial relationship is mapped as accurately as possible. However, as we further discuss in the activity perspective (4.2.4), closeness is not always desirable from a design point of view. For instance, when there is no direct spatial relationship to physical referents, or when the visualization blends different data from different referents, direct spatial closeness might not be optimal or even appropriate.

The Situated Glyphs project **C2** distinguishes between three types of spatial placement of glyphs in the hospital: entity-centric, activity-centric and space-centric. Inspired by Pederson’s situative space model [67], these three variations consider space beyond physical distance between the visualization and the entity of interest, recognizing that people’s activities and context of use are important to consider.

Going beyond purely spatial relationships between data and physical referents that focus on displaying data where it is produced, Willett et al. [105] touch upon the concept of a semantic relationship between

data and physical referents which introduces the importance of tasks and observational goals of the viewers and the meaning people put into situated visualizations. In the following sections, we expand on the spatial perspective on situatedness by introducing the additional perspectives of time, place, activity, and community to better consider how people make sense and interact with their environment.

4.2.2 Time

Taking a temporal perspective puts the emphasis on the relationship between when data is recorded and when it is presented. The projects reviewed in our survey tackle time in various ways, ranging from displaying only live data, to historical or cumulative visualizations. Willett et al. [105] note that, as for space, one can consider temporal indirection, defined as the distance “between the moment in time a physical presentation is shown and the original time it refers to”. In Newtonian or naïve physics, this corresponds to the notion of a linear and directional flow of time, leading to a global ordering, and to observers sharing the same time reference [78]. Adopting a linear time-flow perspective means that to be situated, visualizations should minimize temporal indirection [105], i.e. display data as it is captured. This is a particularly strong design constraint, which is relaxed in most situated visualizations. Since one cannot physically go back in time, traces or cumulative data is often displayed instead.

Yet, temporal data can be structured and thought of in a variety of alternative non linear ways [1]. In **C5** (Activity Clock), the situated visualization adopts a circular 12-hour clock view to represent the average number of people in a cafeteria at a given time of the day [21]. With data spanning three years aggregated in a static clock-like visualization, is it the daily cyclical rhythm of the cafeteria that is conveyed rather than a linear evolution. By setting up the display in the cafeteria, the authors situate the visualization in space, yet the interviews of observers also reveal that they interpreted the visualization reflecting on their temporal knowledge of local routines, of their individual habits, and of the social temporality of the cafeteria.

The question of temporal relevance, changes and synchronicity, has been important to social sciences scholarship. As sociology was defining itself as a discipline, in the early 20th century, “social time” [41] became a central object of inquiry. This involved considering time as neither fully objective, nor subjective but rather socially constructed. This enables to account for multiple temporalities that are constitutive of lived experiences. Social time can still be found in metrics, for instance, in agreed upon time zones, or shared 24h time-frames, rather than reliance on solar time. Taking into account social time leads to another perspective on temporal situatedness. Temporal relevance (rather than proximity) relates to activities, shared cultural references and conventions, habits, needs for coordination. Temporal situatedness

is constructed through the interactions between individuals, groups and their objects of interest. In **C5**, cafeteria breaks become temporal references, in between events and periods, they are activities associated with a place and with people, but also something of broader social and temporal meaning: a break in the workday and a time with associated experiences and cultural conventions.

In **C3** (Cairn), the physicalization strategy consists of stacking tokens to represent events happening in a FabLab, with the most recent being on top [36]. The time of data capture and the time of visualization are blended, as the visualization is created by manually capturing events. More importantly, the physicalization creates a shared temporality inside the FabLab, as the manual assembly can also provoke encounters or discussions about recent events or distant ones, that resurface and become “present” through stories told around the table.

This aspect of shared experience is also important in **C4** (Chemicals in the Creek). While the visualization is ephemeral, lasting only one evening, it exists within multiple time frames: the public event and the lifelong experience of pollution of local inhabitants. With the physicalization being created for this specific event, temporal situatedness could be considered high although the data captured is several months old. Moreover, as environmental pollution unfolds over very long time scales, the notion of temporal indirection [105] may not be the most relevant to assess the situatedness. The pollution sensed months ago may still be present in the environment years in the future.

To sum up, a linear or cyclical perspective on time, in which time is considered an objective non-reversible arrow, “flowing equably without regard to anything external” [78] can be useful. Yet in many cases, temporal situatedness has more to do with the way data connects to the temporal experience of the viewers.

4.2.3 Place

Taking a place perspective means paying attention to a location while breaking away from a purely spatial perspective and representational approach. A place is shaped by its history, its local identity and the meaning it has for its inhabitants [93]. Hence, visualizations become situated if they fit within and represent not only relevant data, but the unique aspects of a particular place, such as data collected by the inhabitants or local cultural heritage. Place as a perspective becomes particularly relevant in relation to the urban- and place-based visualizations that are contained in the corpus.

Several papers discuss aspects of situatedness in relation to and with reference to places. For instance, Vande Moere & Hill [64], Valkonava et al. [94], and José et al. [48] all discuss aspects of place, local identity and culture in relation to situated visualizations. The meaning of place is usually contrasted with the meaning of space. Whereas space is the spatial structure of the world, a space becomes a place by gaining meaning through living in it, the people occupying the space, and its historical context. Harrison and Dourish describe the difference as “we are located in *space*, but we act in *place*” [42, p.69].

Examinations of place are frequent in HCI that build upon various traditions but share a common focus on how we experience place [13], place as a unit of analysis [32] and the challenges in designing for places [53]. All of these works introduce place as more than a simple backdrop or ‘context’ for activity, but as a meaningful relation people have to a locale through its socially and culturally embedded meaning.

In **C6** (Public Polling Displays), the concept of place plays a role in how the displays are situated and how data is collected. To engage with the public polling displays, to vote on the presented local issues, and to understand displayed data, only makes sense if the person viewing the visualizations has a relation to the place in which they are deployed. People who have a relationship to the place are residents, neighbors, visitors, and daily commuters to that particular neighborhood who interpret the visualizations in hyper-contextual ways. These polls and displays have a dual role: they collect and display local information about the place, but they also define what is of local relevance, i.e. what is a place. It is through this interaction that the place takes its shape and the visualization becomes situated.

There are similar principles at play in **C4** (Chemicals in the Creek). Here, the visualized data is important to the place where the installation

is presented. While the data is not directly related to the dock where the installation and event took place, the place of the event created an opportunity to make people aware of how water permit violations influence the creek, the people, businesses, and homes. The project goal was increasing community ownership over the waterfront and creating a place for communication within the community. It is through the event, in a given location, with people sharing a matter of concern by creating an ephemeral place, that the physicalization becomes situated.

With **C5** (Activity Clock), people’s collective presence in the university cafeteria and general activity patterns in terms of coming and going are visualized on a wall clock. This visualization is designed for collective reflection and to support social engagement, which fits well with the character of the place in which it was deployed – which people frequent to get a drink and often socialize in. People’s interest in the data is tightly coupled with the attachment to the place of deployment, situating the visualization by creating meaning to the locale.

Overall, the place perspective emphasizes situating data in within places that are relevant to people through their embedded socio-cultural meaning which provides opportunities to create meaningful relations between data and places.

4.2.4 Activity

From an activity perspective, situatedness implies that visualizations are not used in isolation but are embedded and connected to a wider set of human activities of target audiences. As visualizations move into everyday environments, designers need to consider why people conduct certain activities, how visualizations can meaningfully mediate these activities, and how they relate and connect to broader activities conducted across spaces, over longer time spans, or via collaborations.

These considerations of socio-cultural aspects of design have been developed in depth in HCI research through Activity Theory [50]. Activity Theory describes “activity” as a complex relationship between a person and their goals that is mediated by socio-cultural and historical context and tools – such as an interactive device. Because of this mediating function of technology, Bødker [5] notes that people do not act *with* but rather *through* computer interfaces. Interactions with computers are done to support or mediate real-life activities that involve shared practices with multiple people and different tools. The importance of people’s activities in the situation at hand means that designing and evaluating situated visualizations requires a deep understanding of people’s activities in a specific context as the relevant activities determine the appropriateness of particular designs, representations, placements, or technologies that are considered for the situated visualizations.

As an example, the Corsican Twin project **C1** [71] takes into account common work activities of Building Management System (BMS) engineers and maintenance technicians when designing the situated visualizations. Examples of these activities include analyzing the current state of the system or the temporal evolution of specific variables. An initial study showed several benefits of the situated visualizations such as the usefulness of only showing localized information and showing documentation in-situ. However, later expert feedback highlighted how the activities of workers impacted spatial aspects of the situated visualization. For instance, some participants wanted to place visualizations near the sensors rather than near the equipment as that is where technicians would focus their attention first. Data about distant systems was also deemed useful to bring into the site for comparison and context. Several participants tended not to place visualizations on objects, but rather placed visualizations in 2D on nearby walls and surfaces to make the data more manageable. This shows how the work activities of people in different roles within the space guided the ways in which it was useful for them to situate data and visualizations which, in turn, influenced the placement of visualizations.

Similarly, Situated Glyphs (**C2**) [51, 95] are visualizations that are designed for a work context, in this case to assist nurses in a hospital setting. While the entity-centric, activity-centric and space-centric placements were informed by initial fieldwork in the ward, when conducting studies in the hospital with nurses and the prototypes, a number of additional issues emerged. The nurses were very positive about being shown overviews and information relevant to the activity at hand, and

appreciated automatic documentation of performed activities. However, it was clear that the specific constraints of the workplace and the activities performed in it influenced many aspects of the design, in particular display placement. Entity-centric glyphs were not deemed to be as useful due to concerns about safety and practicality of wearable displays or displays that were fixed to objects or individuals. While hands-free operation was convenient, there were many issues with placement of displays around equipment that would often be moved around. The most promising and flexible solution seemed to be a hybrid mobile system that could be carried around and placed in an appropriate location while performing activities, such as a display that could be attached to a wall. Moreover, it was crucial to remain in control and be able to cope with unexpected situations and frequent interruptions. This case shows that a variety of aspects surrounding individual and collaborative activities as well as shared practices in the workplace determine the appropriateness of certain technology, placements, and visualizations.

Overall, these two cases illustrate that there are several aspects of situatedness related to people's activities – such as shared work practices, social and safety protocols, unexpected situations and interruptions – that go beyond spatial aspects and can have an important influence on the suitability of different spatial layouts. These case studies highlight that a deep understanding of people's activities is important so that the technology and visualizations can be properly appropriated and integrated with people's existing activities.

4.2.5 Community

Taking a community perspective puts emphasis on the community of people who are the audience for and/or co-creators of visualizations centered around local issues and shared concerns [e.g. 20]. This perspective supplements place and activity by empirically foregrounding the community and local issues. Existing work on situated visualization that considers a specific group or community as the audience of situated visualizations focuses on “anchoring” the situated visualization within a specific community. Focusing on how a particular community uses and appropriates technologies in their activities is a common topic in HCI research [6, 11], including work that explores engaging with (urban) communities and local issues [20] as well as research within public visualization [64, 84, 94]. The community perspective is closely related to the place and activity perspectives as a place gets its meaning over time with and through a community and the activities that are happening within that community. The perspective of community is concerned with initiatives that focus on supporting a community in its activities, and using technology to support coordination around a shared concern. In projects that focus on supporting communities through situated data visualization such as **C4** (Chemicals in the Creek) or **C6** (Public Polling Displays), community members are involved throughout the design process, starting with early engagements to understand matters of concern, and then transitioning to activities that actively involve community members in the design of the technology, typically using participatory design or co-design methods. In the context of public visualization, Schoffelen et al. [84] discuss how visualizations can reveal the backstories behind facts from different perspectives, which – when carefully designed to be readable and transparent – can allow for engaged discussions and reflections within a community.

In **C6** (Public Polling Displays) [14], the situated visualizations were designed to address shared concerns around local issues that the community members found important, and were placed on house facades. In the study of the system with a neighbourhood committee for a street in the city of Antwerp, the shared concern was air pollution, with the neighbourhood committee aiming to get the street blocked for non-local traffic. Community members who hosted displays with visualizations on their facades could add their own backstories to the visualizations to support community-driven dialogues. The spatial location of the visualizations had an impact, but the social aspects of that location were just as important. For example, the perception of and trust in the visualized data was affected by the social relationship between the passerby and the visualization-hosting community member, either in a positive or negative way, depending on the hosting member's social standing with the passerby and in the community at large [14].

For **C4** (Chemicals in the Creek) [68], the shared concern was raising awareness of spills and pollution in the Chelsea creek. The community that the researchers engaged with was GreenRoots: an environmental justice organization in Chelsea, Massachusetts. The researchers created a one-time performance to foster trust and connection among community members on the topic of water quality violations. The performance acted as a ceremonial event for witnessing data that supported shared reflection and recollection about the spills. Here, the situated visualization and the community build on each other: the visualization is situated partly because it relates to a shared community concern, and the visualization fosters community development.

In **C3** (Cairn) [36], the physicalization targets the community around a FabLab in Paris and their shared concern is reflection on and documentation of the activities that happen in the FabLab over time. Gourlet et al. [36] note that Cairn enables “*new collective reflections*” and allows community members to discuss what they “*are as a community in front of a landscape that describes our practices [i.e. Cairn] and with an experienced, thus, negotiable code.*”. Thus, Cairn acts as a facilitator around a shared interest of the members of the FabLab community involving the community members in the data collection process.

Overall, the community perspective emphasizes situating data in relation to communities of people to support engagement with local issues and concerns, often by involving the community in a participatory process.

5 DISCUSSION

The perspectives we presented in the previous section are complementary ways of approaching situatedness. Space – as the most prominent perspective in the corpus of research we reviewed – is a useful starting point when designing situated visualizations as it provides the foundations for placing visualizations in the world. However, considering other perspectives on situatedness is key in addressing common challenges (see e.g. [29]) and enable designers to take into account broader considerations into their design, and improve the experience of situatedness for observers or users of the visualizations. Reflecting on our survey and the perspectives, we discuss technology, material and aesthetics, leveraging the perspectives for design as well as methods for stronger engagement with target audiences.

5.1 Technological Considerations

Norman controversially stated: “technology first, needs last” [66], arguing that technological innovation often leads to new conceptual inventions and the development of potential use cases. Our survey suggests that we may be witnessing a similar movement in situated visualization. A new wave of commercially available AR technology is sparking interest in the development of situated visualizations, which may lead to novel use cases. It is reminiscent of how the advent of mobile computing led to the emergence of ubiquitous computing.

While novel technology can enable novel use cases, it should, however, also not foreclose the use of alternative, sometimes more appropriate technologies. Although AR may be well suited to personal and private situated visualizations, collaborative AR technology is still in its infancy. Public displays may be better suited for collaborative, shared or public situated systems as such systems already support spontaneous interactions, do not require personal equipment, and can be used collaboratively. Static posters or data physicalizations do not need power, and can be made sturdy enough to be left alone for long time periods. E-ink displays have low power requirements and can be integrated inconspicuously into a variety of different environments [8, 14], while chalk's transience facilitates lightweight updates and local adoption [4, 52].

Work on situated visualization would benefit from engaging in deeper discussions on technological choices related to the case or target domain, without defaulting to one technology or another. Technology alone, whether it is AR or chalk on the street, does not make a visualization situated, solely on the basis that it displays data in proximity to its source. To situate visualizations into an environment, technological choices should consider the target audience and the context of use.

Moreover, these technological choices are conditioned by the underlying infrastructure that is available. To work smoothly, AR requires

robust computer vision techniques and indoor location tracking in order to determine its location and recognize surrounding objects. As demonstrated in **C1** (Corsican Twin), having access to richer building and object models enables much finer augmentations and situatedness. Likewise, public displays often require a wireless and electric infrastructure to be in place in order to be installed without problems. In other projects such as Mill Road [52], constraints on not touching the city infrastructure led to picking chalk rather than a more durable medium. Situated technologies, whether AR, public displays, or lower-tech, cannot be thought of without also considering how they will interface with the environment and the technical infrastructure they should fit in.

5.2 Material and Aesthetic Considerations

In addition to considering which technology to use, when fitting a visualization within a place, material properties also have to be considered. In **C3** (Cairn), for instance, the artefact itself is fabricated in the FabLab so its material properties match with the surrounding space. In the area of public visualization, Street Infographics [16] integrates demographic information about a street into in the form of an addition to a street sign which uses the existing urban infrastructure to present information. Similarly, in projects like Mill Road [52] and Tidy Street [4], visualizations are drawn with chalk on the pavement and street, which integrates the visualizations with the urban environment. Fitting a visualization within the environment is not only a matter of the choice of technology or medium, but also of the visual representation itself. Rodgers and Bartram's [76] energy feedback visualizations show the value of an artistic and aesthetically pleasing representation of data that is designed to fit within a home environment to match with people's personal preferences. Similarly, **C5** (Activity Clock) highlights the importance of an aesthetic fit for visualization designs within the space the data is displayed in. This is line with work on ambient displays [106], aesthetic requirements for information visualization [57] and projects on public information displays [94] that all show that material and aesthetic aspects are important considerations when designing visualizations that are to be situated and fitted within a specific environment. While there is a balance between choosing a technology and visual representation that offers the functionality needed and a good material fit within the environment, considering materiality is an important lens for choosing how to display and visually represent situated visualization.

5.3 Leveraging the Perspectives for Design

These perspectives do not suggest to simply examine new types of referents [105] for designing situated visualizations, such as for the community perspective, replacing physical objects as referents with community elements (actors, places, matters of concern). Our goal is to open up the discussion within the different research communities that use situated visualization to explicitly consider and more deeply engage with broader characteristics of situatedness beyond spatial aspects, as discussed in this paper. This contributes to expanding and clarifying the scope, definition and applicability of situatedness for visualizations.

Rather, we argue that the different perspectives of situatedness expand research stances on situated visualization and are beneficial to develop situated visualizations that are driven by their context of use. We position these perspectives as vantage points that supplement each other from a theoretical, methodological, and design angle. They play a role as starting points in design – who to talk to, where to go, what to consider – and act as deliberate generative strategies throughout the process. They invite participants and researchers to ask – what would be important to consider in terms of situating visualizations if space, time, community, activity or place is the primary unit of focus? Each perspective foregrounds different aspects of situatedness and focusing on one should be a deliberate choice in the design process. To account for the different perspectives when designing for situated visualization, new approaches and research in design methods are necessary [7].

To broaden the view on situatedness beyond spatial aspects alone, it is important to expand on methodological approaches. While lab studies are used to gain an understanding of how people interact with and perceive situated visualizations, in order to design and account for situatedness in all its richness (across the perspectives), it is essential to

engage with the context and the audience the visualization is intended for. This often starts early on in the research process, by engaging in fieldwork to understand the target audience and the environment in which the visualization would be deployed, as we observe in several of our case studies (e.g. **C4** [68] and **C6** [14]). The realism of lab studies can also be improved by conducting them in an environment that closely resembles the eventual deployed environment, as with the on-campus research space with sensor data in Corsican Twin (**C1**) or studies in the hospital ward in Situated Glyphs (**C2**).

An ecologically valid methodology that situated visualization researchers could consider is “research in the wild” [77], i.e. creating and evaluating new technologies in-situ, observing how people react to the new technology and how they change and integrate the technology into their lives. Beyond evaluating a visualization design, many design constraints will also only become apparent by taking into account the environment in which the visualization will be deployed. This requires the use of and further research into developing in-situ (and participatory) design tools and methods, which some researchers have started exploring [8, 14, 24, 44, 95]. For example, Bressa et al. [8] explored the use of several situated design and visualization sketching exercises, including the use of magnetic whiteboard sheets and tiles mimicking the form factor of small displays. Ducros et al. [24] similarly explored situated design exercises and tools, where being in-situ provided tacit knowledge about the place, enabling designers to leverage design opportunities such as spatial features, objects, and social activities that were taking place. Moreover, in several cases (e.g. **C1** and **C2**), the need for flexibility in use and spatial placement of the visualizations emerged. Without the use of in-situ methods in an ecologically valid context, it is difficult to understand how the target audience will appropriate the situated visualizations, or how the visualizations may need flexibility to account for unexpected circumstances.

Situated visualization is grounded in a long history of computing visions and ideas. Kruger's [55] responsive spaces (1977), Weiser's [98] ubiquitous computing (1991) and Fitzmaurice's [31] situated information spaces (1993) were early influential visions. Projects like Prante's Hello.Wall [70], Tollmar's virtually living together lamps [92], the MIT Tangible Media Group's ambient displays [106], Columbia University's work on the Touring Machine [30], and Situated Documentaries [43] are situated visualizations done under different themes and concepts. Similarly, the recent grand challenges in immersive analytics [29] and arguments within the visualization community to move “*visualization beyond the desktop*” [75] and focus on opening up the domain for casual information visualization [69], public physical data installations [35] and personal visualization [45], suggest an important focus in situated visualization moving forward.

6 CONCLUSION

The surveyed corpus, selected cases and historical examples within the research communities highlight “motor themes” [see 54] for discussing and identifying research areas that span the broader literature and research gaps in narrow topical surveys. Expanding on the understanding of situatedness is an important motor theme here, but our work identified additional themes that motivate and inform future work. We emphasise exploring technologies for situated visualization that account for the presented perspectives, paying attention to the aesthetic and material fit when developing situated visualizations and multiple design considerations, ranging from identifying and developing methods that fit the perspectives to examples of design processes that can better inform design and practitioners. These present fruitful avenues for research and new applications to drive situated visualization forward.

Situated visualization sits at a sweet spot between technical, conceptual, and empirical research. With many technologies and theoretical traditions to build on, it has the potential to develop as a promising area at the intersection of multiple research communities with a common interest in bringing visualization into people's everyday environments.

ACKNOWLEDGMENTS

We thank Susanne Bødker for providing feedback, Ida Larsen-Ledet for title suggestions, and David Ledo for helping with Table 1.

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