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MAKING WITH CLIMATE DATA: MATERIALITY, METAPHOR AND ENGAGEMENT

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Introduction

This chapter reports on a practice-led research project investigating the tangible visualization (or physicalization) of climate data. Working with the Australian National University's (ANU) Climate Change Institute (CCI), the authors designed and produced an open-ended edition of data-objects: small, laser-cut climate coasters. Each represents one year's temperature data for a single location, in relation to the long-term average. This data translation concept was further developed through the design of a web application, which allowed for an expanded range of data and locations. It also broadened the reach of the project, and enabled users to customize and produce coasters of their own. Reflecting on this work and the contexts of data physicalization and climate communication three key points emerged. Firstly, that data physicalization – making data-objects – can make a useful contribution to the challenge of engaging audiences with climate change data, in the context of an increasingly polarized debate. Second, the affordances of materiality and metaphor are significant here. The material form engages senses of smell and touch, reframing prosaic communication of data as a more immediate encounter; while the metaphor or functional form of the coaster invokes an everyday context of conviviality and conversation. Third, a distinctive hybrid approach to data physicalization, where computational workflows for digital fabrication are adapted for the web is of significant value. We show how this combined approach worked to increase the audience and relevance of the project, as well as to validate the design of the tangible object. The makerly approach adopted here, based on software- and data-driven sketching and experimentation, alongside material prototyping, enabled movement between physical and screen-based visualization. As an instance of 'making data', this project operates within a broader networked context of cultural and technical data practices.

Making climate data physical

As mentioned above, this project originated from a conversation in late 2017 with researchers from the ANU CCI. Discussions of potential data visualization collaborations focused on the need to expand the climate-related discourse, to draw more people into the climate conversation and engage with them more effectively. As Bolson and Shapiro (2018) show, simply gaining the public's attention is a significant challenge; moreover, climate change discourse in the United States is increasingly polarized and partisan. Tranter (2013) shows the same dynamic at work in Australia. Conversations also touched on a growing weariness amongst our communities resulting from a continuous stream of confronting climate news – what Kerr (2009) called 'climate fatigue'.

In response to these overarching challenges and aims, we advocated for the potential of novel forms of data visualization, and physicalization in particular, as well as the value of localized, current data in contrast to the global and national overviews common to much climate-related reporting. Climate data visualizations ought to be attention-getting, inclusive rather than divisive, spark interest rather than fatigue, and motivate curiosity, interest and even action. CCI colleagues were supportive, and proposed a rapid, experimental visualization project: the design and production of a tangible visualization based on data detailing the City of Canberra's temperature in 2017. These data-objects would be small, robust and cheap to produce, and would be distributed at the CCI's 2018 Climate Update forum; a public event providing a snapshot of Australian climate change data, science and policy.

This response builds on previous projects by the authors, such as *Weather Bracelet* (Whitelaw 2009) and *Measuring Cup* (Whitelaw 2010), which demonstrate practical approaches to weather and climate data physicalization. Based on location-specific datasets, these objects encoded detailed time-series data in 3d-printed geometry, investigating the affordances of tangibility in representing environmental data; but they were produced in tiny quantities as self-initiated experiments. This project introduced two important new factors: the need for fast and affordable production at scale; and collaboration with domain experts strongly committed to both accurate representation and public engagement.

Given the need to develop a novel physical representation of Canberra climate data, in an edition of over a hundred, with a limited budget and timeframe, development focused on laser cutting as a mode of fabrication. Laser cutting was accessible, fast and flexible, and could involve affordable, sustainable materials such as plywood or cardboard. Based on previous experience with digital fabrication, work began with the sketching of potential designs. These sketches were not hypothetical concepts, but more like working prototypes. By using data sourced readily from the Australian Bureau of Meteorology and the coding framework p5.js[1] (McCarthy 2020), we were able to generate visual concepts through a process of code-based experimentation and iteration based on actual (rather than imagined) data. The visualization coalesced around a disc-like shape, where time-series data is shown as a set of radial line graphs encoding daily and monthly average maximum temperatures, as well as their relation to local long-term averages. The use of a radial layout for an annual time-series resonates with the annual seasonal cycle (and in turn the earth's orbital cycle), echoing the approach used in *Weather Bracelet* and *Measuring Cup*, where the radial layout of an annual cycle creates the outer edge of both forms.

As illustrated in Figure 1, the visualization design was developed through an iterative process of sketching, testing, prototyping, consultation and annotation. Fundamental questions addressed through this process included how much data to show, and how and where to show it. The design quickly settled on a layout where monthly values and averages are shown on the outer edge; this privileged the simpler and more legible monthly values, while the unlabelled daily data on the inner graph visually supports and validates these monthly averages. For consistency both daily and monthly time-series are shown as anomalies, that is, as difference from long-term monthly average. Values above the long-term monthly average are plotted outside the reference line, and below average values inside it. The above-average area of both graphs is etched, drawing attention to these signals of a warming trend.

Full scale paper prototypes were produced (Figure 1c, 1d) which proved invaluable in discussing design decisions with collaborators in the CCI. Based on these discussions the inclusion of daily minimum temperatures in the inner graph (Figure 1c) seemed to be an unnecessary complication that impaired legibility. Hand-annotation in the form of drawn notes on the laser cut prototypes proved useful, enabling quick modifications and visual notations of discussions around tick marks, labelling, and the alignment of inner and outer time series. The radial lines in the final design that mark out the months and their anomaly values are evident in Figure 1c. Similarly, the etching of the above average portion of the daily graph is shown here as an annotation.

Early fabrication tests (Figure 1e) played multiple roles, helping to resolve physical scale, as well as refining the graphical encoding of data and its translation into laser fabrication. A key discovery was the effect of combining raster (area) etching with vector etching (essentially a low-powered cut that scores the surface of the material). The vector etch provides a crisp edge that improves the legibility and detail of the daily graph (see Figure 1g). This process culminated in a design, generated through a combination of dynamic code-driven visualization (for the graph elements) and static typography and layout design to resolve type for labels, legends, data attribution and credits.

The idea of a coaster arose fairly organically through the visualization process. Early software sketches used the more generic term 'disc', with some variants

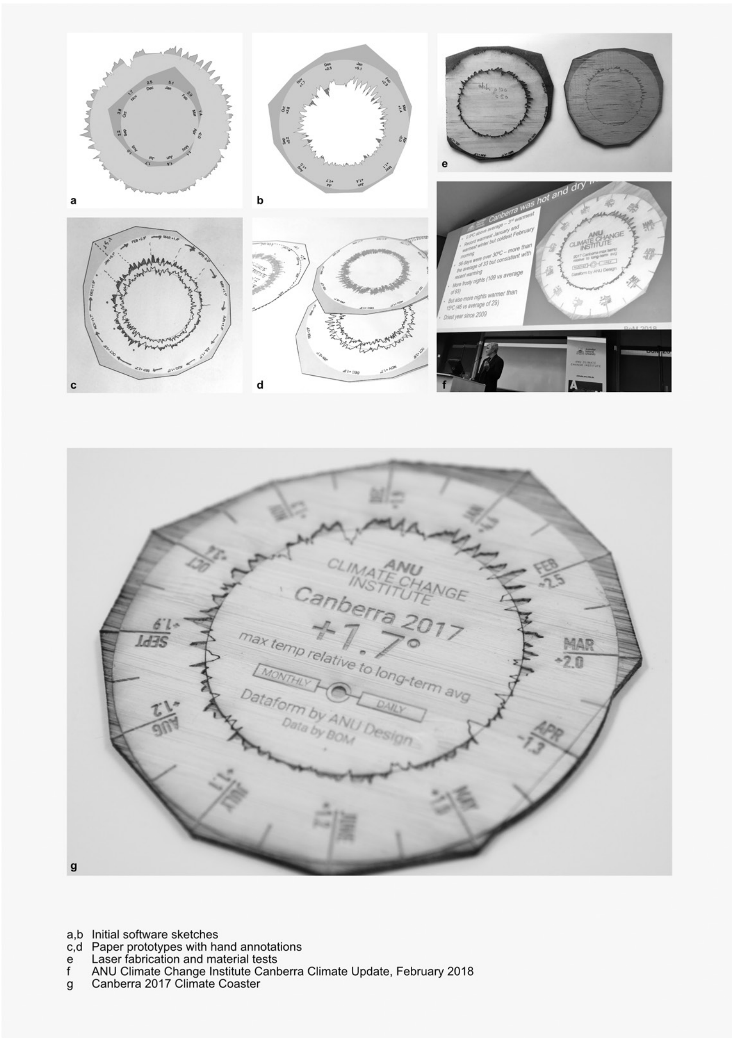

Figure 1 (a,b) Initial software sketches; (c,d) Paper prototypes with hand annotations; (e) Laser fabrication and material tests; (f) ANU Climate Change Institute Canberra Climate Update, February 2018; (g) Canberra 2017 Climate Coaster. (All works and images by Mitchell Whitelaw (a-d) and Geoff Hinchcliffe (e-g)).

including a quite un-coaster-like central hole. As the design developed around a radial data layout, laser cut from thin plywood, ‘coaster’ emerged as a more appropriate term. In doing so it clarified design aims that resonated with earlier investigations, of dataforms as small wearable or handle-able objects intended for an everyday context (Whitelaw 2012). Unlike *Weather Bracelet* (technically wearable but in practice uncomfortable) or *Measuring Cup* (a small and only semi-functional vessel) the coaster offered a simple form that could be functional while also unobtrusively occupying a commonplace desk- or table-top environment.

The first edition of coasters was cut from recycled bamboo plywood and given to attendees of the CCI’s Climate Update event in Canberra 2018. The coasters were greeted with great enthusiasm and observing them in the wild provided us with rich insights and affirmed the proposition that physical dataforms could be a catalyst for activating the climate conversation. The novelty of the coaster form, the texture of the bamboo and especially the smell of the wood served as easy access points for convivial discussion and reflection. People were animated by the physicality of the coasters and intrigued by their smell, but were also interested in their production and whether more could be made, whether they could be made for other locations and whether people could make their own. These questions were used to drive the next phase of the project.

Networked making

In order to make more coasters, for more locations, and ideally allow anyone to make their own, the code written to generate the coaster was converted into a freestanding web application.[2] Technically, this process was made easier by the fact that this code used Javascript libraries that run natively in a web browser. To address more locations, Bureau of Meteorology (BOM) data for 111 Australian sites was accessed, and the code adjusted to accommodate the dramatic range of temperature variations evident in these geographically diverse sites. An added benefit of using the BOM’s ACORN-SAT data is that it features historical data for much of the twentieth century, which allowed for the visualization of multiple years for each location (Australian Bureau of Meteorology 2020a).

Web visualizations were developed through a further process of data-driven sketching, focused on adapting the physical coaster design, to be tailored for the dataset and to handle the wide variation in data across multiple sites and years (Figure 2a, 2b). The final site took the form of a single page web app that allows visitors to generate coasters based on 111 locations over a thirty-year period, or to prepare and upload data from other locations (Figure 2c). The app offers visitors the option of downloading SVG files which can be used for laser cutting, as well as image files for printing or social media sharing (Figure 2d, 2e). As a simple Javascript application, it uses no database or server-side scripts, and instead runs in the user's web browser, loading data from CSV text files. All of the calculation and visual rendering are computed in the browser rather than on a web server, and as such, the app is lightweight, fast to load and responsive to the user's input.

In developing the app we looked beyond immediate functional aims (more coasters, more locations, more makers) and took the opportunity to leverage the affordances of the web browser to create an interface that is concerned with data visualization as much as user input. For example the map interface, which allows for the selection of a specific location, also uses coloured dots to visualize the annual temperature anomaly for each site, providing a unique national overview for the selected year. Similarly, a timeline graphs the annual anomaly for the selected location over a thirty-year period, while clicking the graph selects the year to be displayed (Figure 2c2). In addition to selecting an individual year, the app allows the thirty-year period to be played as an animated sequence in which the coaster visualization and interface elements transform and transition between states. The additional interface visualizations are based on the same daily maximum temperature recordings that underpin the coaster, with each visualization representing a different scale; the coaster shows daily, monthly and annual anomaly for a single year in a single location, while the map and timeline zoom out even further. This means that the map can represent an overview of 100+ locations (Figure 2c1), with the timeline showing daily maximum temperatures over thirty years.

A final notable quality of the web app is that it pursues a different visual aesthetic to the distinctive bamboo texture of the physical coaster. The visual design of the app-based coaster seeks to respond to its browser context and uses colour and tone to accentuate the coaster form and the climate data it represents. The coaster visualization seen in the browser is an SVG image embedded within the HTML webpage. The SVG file format was used in the initial sketch because of its compatibility with a laser cutting workflow; but as a browser compatible image format, it could also be embedded in the app interface. A distinct advantage of SVG proved to be its portability; code-generated SVG graphics could be opened and edited using the desktop graphics application Affinity Designer (AD). AD was useful for tuning the visual aesthetics and allowed for the grouping and labelling of the different elements to be exported as an SVG image. These changes could then be returned to the web application and merged with data-driven graphics.

While the process of converting the coaster code into a public web app was made easier by the underlying Javascript code, the decision to use these libraries was not motivated by the intention of creating a website, which had not been included in the initial brief. The browser is not only a vehicle for websites but a highly accessible development platform and ecosystem. Modern browsers are powerful and as a platform, the web and its related technologies (HTML, SVG, CSS, Javascript, WebGL) are highly accessible. The browser as a development

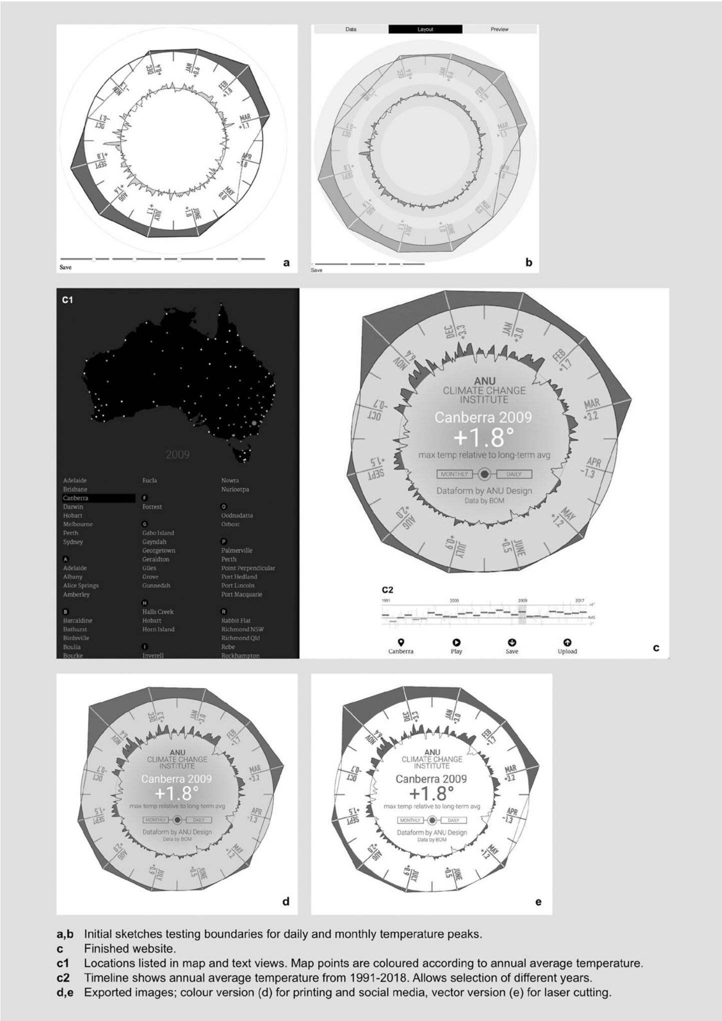

Figure 2 (a,b) Initial sketches testing boundaries for daily and monthly temperature peaks; (c) Finished website; (c1) Locations listed in map and text views. Map points are coloured according to annual average temperature; (c2) Timeline shows annual average temperature from 1991–2018. Allows selection of different years; (d,e) Exported images; colour version (d) for printing and social media, vector version (e) for laser cutting. (All works and images by Geoff Hinchcliffe).

platform is home to innumerable code libraries and generous communities of practice. This context makes it a compelling choice for a creative producer.

Rather than being simply a by-product of the physical data-objects, the web app is an integral component of the whole coaster project. Making software production tools public is a unique attribute of the digital fabrication workflow that should be embraced and explored in other projects. The rationale and benefit of a public-facing website goes beyond facilitating DIY production and has the potential to expand a project in other significant ways. Through the development of the coaster website it was possible extend the reach of the work. For example the ability to transform a coaster based on location, year or user supplied data is integral to localized representation of climate data, but can also be considered a form of user customization; another compelling opportunity afforded by a digital production workflow. User customization has been exemplified in web applications which permit parametric manipulation of jewellery and clothing designs through sophisticated browser-based interfaces (see for example Nervous System, 2014). But where these apps focus on customization for personal expression, the modest levels of customization in the Climate Coaster app supported localization, exploration and validation, offering personally relevant insights into the data. The app allows users to generate a coaster for their town or city, and as importantly, provides opportunity to explore and compare different locations, to gain an appreciation of the variation between different regions, and ultimately to better understand the workings of the visualization and the data being represented.

Making conversation

In both tangible visualization and web app forms, the Coaster was successful in sparking interest and engagement across a wide set of different contexts, from community groups to government departments and environmental organizations, as well as other areas in the university. In considering these engagements as well as the media coverage attracted, the project showed how the combination of tangible data-object and customizable web platform helped create conversations around climate change and climate data.

In the months following the February 2018 Canberra Climate update, further collaborations with the CCI took place to develop a coaster for a Brisbane-based event. In another iteration artwork was provided to a local activist group Canberra Climate Action, to print paper coasters for distribution at the Canberra Multicultural Festival. The ACT Government's Environment Planning and Sustainable Development Directorate also commissioned additional Canberra coasters to distribute at public events. Following the launch of the web application in May 2018, the Sydney-based Investor Group on Climate Change commissioned 100 coasters for a workshop on climate risk and investment, co-hosted by a major Australian bank. In these cases the modest form of the coaster and its propositional combination of climate data – as shared concern – and low-stakes everyday object, helped carry it into different contexts and to different audiences.

The web application also brought the project mainstream media attention and combined with the novel appeal of climate data in coaster form provided the headlines for media both locally and nationally (ANU Reporter 2018; Green 2018; Sydney Morning Herald 2018). Also notable was the engagement from regional Australian media, who were interested to discuss local concerns, trends and patterns that the web app made apparent – such as the extreme warming anomalies observed in outback Queensland (Bhole & Varley 2018). These instances indicate that fine-grained localization can provide an effective channel for engaging with climate data, especially in often marginalized rural and regional areas.

Discussion

Tangible engagement

The ongoing public life of the Climate Coaster provides some evidence of public engagement in a cultural context marked by polarization and fatigue (Althor, Watson & Fuller 2016; Colvin et al. 2020; Kerr 2009; Smith & Mayer 2019). However the question of how data visualization can support engagement with climate change is complex; in a 2019 paper Windhager, Schreder and Mayr consider the design space of climate change visualizations focused on public engagement, and include the Climate Coaster web application in a sample of thirty-seven visualizations. The authors note that the conventional (objectivist) approach of information visualization – to 'abstain from everything but the chart' and 'just *show the data*' – is untenable in our troubled and polarized social context, where the 'inconvenient' message of climate change encounters many forms of resistance, from fatigue to psychological defence mechanisms and active disinformation (Windhager, Schreder & Mayr 2019, p. 4). In response they advance a multi-level model of cognitive, affective and behavioural engagement that spans attention, observation, exploration, reflection, opinion formation and action. The authors identify a brace of visualization techniques that address these forms of engagement. The Climate Coaster adopts many of these: aesthetic appeal to engage visual attention; animation (in the web application) to guide viewing. Windhager, Schreder and Mayr (2019) recognize the value of personalization or localization to engage users in analysis and reflection. This tallies with the experience in this project, and echoes work in climate communication such as Scannell and Gifford's study showing that a local framing of climate change messaging created greater engagement, particularly among those 'more attached to their local areas' (2013, p. 26). The Coaster design also adopts some of the visualization rhetoric that Windhager, Schreder and Mayr (2019) link with opinion formation. In the Climate Coaster project data is shown in a way that emphasizes the anomaly (difference from 1960–90 average), and visually highlights the warm (positive) anomalies through etching or colour. The data provenance, from the Australian Bureau of Meteorology, is cited to rhetorically emphasize the credibility of both the source data and its visual representation.

While Windhager, Schreder and Mayr (2019) do not address tangible or physical visualization, the nascent literature in that field supports both the functionality and engagement values of data-objects. Jansen, Dragicevic and Fekete (2013) provide evidence that physical visualizations can be more efficient than on-screen equivalents, attributing this to the role of touch and physical manipulation. Tangible visualizations have also been shown to be more memorable than screen-based displays (Stusak, Schwarz & Butz 2015). In a major review, Jansen et al. (2015) summarize the benefits of data physicalization, such as its exploitation of active perception and engagement of non-visual senses. This echoes observations from this project: the coasters sit around on tables and bookshelves, at times they are handled and regarded absent-mindedly, they insert themselves into other conversations, they even prevent hot drinks from damaging precious table surfaces. This persistent presence is a key feature of physical dataforms as Jansen et al. note; 'since physicalisations can be anywhere and are always "on," they can be used as ambient data displays and support casual visualization.' We agree that 'data physicalisations pique interest, and this interest could in turn be leveraged to have people spend more time and effort exploring and understanding important and complex data' (Jansen et al. 2015, p. 3230). Similarly Sosa et al. and colleagues argue that '[data-objects] are particularly suited for design activism' through enabling access and supporting sense-making, providing 'a verifiable backdrop where conversations and dialogue led by the public can be grounded and articulated' (2018, p. 1693). This usefully summarizes the aims of the Climate Coaster: to provide access to relevant data, in a verifiable and engaging form, in order to prompt and support a public conversation. While the Climate Coasters cannot hope to *solve* climate communication, such devices can be used to reconvene the conversation in an effort to diminish the polarization that has come to characterize the climate discourse.

Metaphor and materiality

The novelty of tangible data is one driver for engagement – in this case the Coaster's functional form worked to bring detailed data (in an unfamiliar form) to a wide audience. In analysing how tangible visualizations map data to physical forms, Zhao and Moere (2008) use the concept of metaphor, drawn from the field of tangible computing, to describe the way recognizable physical forms can provide a bundle of pre-existing concepts. Such forms should be distinct and identifiable (provide a 'single mental image'), provide physical and cultural affordances or cues for interaction, and be widely known or familiar (termed 'intuitiveness') (Zhao & Moere 2008, p. 345). In applying this lens to the mapping of data to form, Zhao and Moere focus on metaphorical distance, and classify physicalizations according to the 'closeness' of their data representation, and familiarity of their physical forms.

By this formulation the coaster form is a metaphor; certainly it provides a single, familiar mental image, as well as a set of affordances for interaction. Moreover, it brings with it certain cultural affordances, connotations and contexts. Zhao and Moere (2008) inherit metaphor from the domain of human computer interaction, where it serves a functional role focused on familiarity, tapping users' pre-existing knowledge to make interaction 'intuitive'. In this case metaphor is equally a discursive or poetic strategy. It exploits familiarity, but also makes a proposition about how and where the object belongs. Found on tables in a pub, a cafe or living room, the coaster is an artefact of a convivial social setting. This object signals its intention, to prompt conversation about local climate in these settings – at the same time putting the proposition that climate data can, in fact, be represented in coaster form. In fact it is a functional coaster, so metaphor begins to lose its meaning here; rather the form is a functional type strategically appropriated.

The material affordances of the form are also significant. In observing people interacting with the coasters, we can see how they are physically *encountered* before they are *read*. The process of touching, feeling and smelling, establishes an affective setting within which the more prosaic, and often confronting, climate data is regarded. As a contrast, consider the context of the climate chart embedded within a news article reporting on the latest dire Intergovernmental Panel on Climate Change (IPCC) warnings. In that context, the graph must be concise and economical in its delivery of key findings. The climate coaster is unambiguous in its representation of temperature trends, but when encapsulated within a typically benign domestic object it invites a slower and more reflexive consideration of the data. Rather than only reading the data, people use touch to *feel* the peaks in monthly temperatures. Smell also proved to be a significant characteristic: daily temperatures are burnt into the surface of the bamboo and above average temperatures burn more material and produce a stronger smell. People could smell the cumulative effect of days exceeding the long-term average as well as feel the peaks of the monthly anomalies. In Australia this data is stark: the average maximum temperature for 2017 was a full degree above the long-term average; 2019 was the hottest year yet recorded, at over 1.5 degrees above average (Australian Bureau of Meteorology 2020b).

Making data: Workflows and networks

The Climate Coaster project shows how data physicalization and everyday data-objects can contribute effectively to the engagement challenges that Windhager and co-authors identify. It also provides a useful case study in makerly physicalization as a technical and creative process. Jansen et al. (2015) identify the technical complexity of physicalization workflows as a key challenge in the field. Workflows here are the sequences of technical processes (such as data preparation, visualization design and fabrication) that making with data demands. In response Swaminathan et al. (2014, p. 3845) and collaborators have presented a tool with an 'integrated workflow', intended to 'lower the barriers to producing physical visualizations'.

Recognizing the value of this work, the Climate Coaster offers a contrasting model of process. Swaminathan et al. (2014) seek to design a 'pipeline', a seamless chain of technical processes delivering a predictable outcome. By contrast this project was developed through formative cycles of sketching, prototyping and conversation. Experimentation with materials and processes played an important role. Finally the technical opportunities of a Javascript toolset were exploited, with public data sources used to rework the project as a web application. This was a crucial move, significantly amplifying the project's impact and utility, but also representing a kind of diversion of the physicalization pipeline: appropriating a technical process and translating and adapting it for a new context. We characterize this approach as *makerly*. While the maker movement has linked this term firmly to physical fabrication, it can be applied equally to software based practices founded on practical experimentation, bricolage and sketching. This project shows how a makerly approach can situate physicalization within a broader, networked context.

This networked context includes technical protocols and infrastructures – the standards and languages of the web, for example – but also entails an expanded social context for the circulation, representation and interpretation of data. In an immediate sense the coaster web application depends on public data sources, available online. It also participates in a networked context where data visualization is an active form of cultural practice and consumption. As Eric Roddenbeck of visualization studio Stamen argues, visualization is a cultural medium in its own right (Rodenbeck 2018). As a public form, the emerging culture of web-based visualization is most potent when it deals with data as a matter of shared concern. The proliferation of visualization and data journalism in online news media in recent years shows this clearly; a nascent, multidisciplinary 'data practice' is arising focused on the cultural, political and creative potential of data in an increasingly digitized culture (Whitelaw 2017). The question of access and agency in this domain is crucial: we recognize the privileged position that enables our own work – including technical knowledge and experience, and ready access to expensive equipment. There are promising signs of broad participation in making with data; community craft projects such as Tempestry, creating knitted visualizations of temperature data, lead the way (Tempestry

Project 2020). In this spirit makers are invited to upload custom datasets as well as download and produce their own coasters. Rather than simplified technical workflows, the future of making with data as a matter of community and culture in a distributed, networked context.

Conclusion

The climate change discourse has demonstrated that scientific facts alone will not necessarily change understanding, and in some cases, may even entrench contrary beliefs. Clearly there is a need to recalibrate the climate conversation, and as Windhager, Schreder and Mayr (2019, p. 7) argue, to 'go beyond the study of cerebral visualization design' and consider 'elements and strategies of cognitive, affective, and behavioural engagement'. The Climate Coaster project demonstrates that physicalization can be used to respond to the same challenges and offers unique opportunities for eliciting affective and reflective engagement. It shows how physicalization can be used to achieve a balance between prosaic and poetic modes of representation and engagement; from an object that is read to one that is encountered. The coaster metaphor, along with the object's physical properties, seeks to prompt reflective consideration. Most critically, the coaster seeks to move the conversation from an insurmountable global scale to something more approachable, local and familiar. The coaster brings climate data to a personal scale; it lives in domestic space on tables in kitchens, living rooms and offices, and it makes climate data something that people can touch, feel and even smell.

Built from the same browser-based workflow as the tangible visualization, the Climate Coaster web app has proven to be a crucial component of the whole project. The web allowed the project to reach a vastly increased audience and to connect with national media organizations. Situating the coaster alongside the software that generates it allowed an audience to appreciate the provenance of the coaster objects and to gain much deeper insight into the data being represented. Being able to explore and interrogate the data, to see how it changes between locations and time periods, adds significantly to the veracity of the physical coaster.

Finally, this project offers a case study in making data: partly in making data tangible, and the creative agency this entails; but also in the cultural and technical contexts that surround and support this makerly practice. The Climate Coaster relies on a model of networked making that is open and inclusive. If as Roddenbeck argues, visualization is a cultural medium for our time, it's crucial that making with data be as broad, diverse and accessible as possible.

Notes

1. p5.js is an open source Javascript library for creative coding, created by Lauren Lee McCarthy. See http://p5js.org
2. http://gravitron.com.au/climatecoaster

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