Attention To Detail: Annotations of a Design Process

Nadine Jarvis, David Cameron, Andy Boucher
Interaction Research Studio
Goldsmiths, University of London
London SE14 6NW, UK
initial.surname@gold.ac.uk

ABSTRACT
This paper takes the form of a photo essay that exposes the design process at a level of detail seldom found in traditional academic publications. With this format we document the development of a set of devices for exploring the microclimate of the home, with the intention of advancing current approaches to communicating (and understanding) practice-based research.

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Design process, practice-based research, photo essay, annotations.

ACM Classification Keywords
H.5.m [Information interfaces and presentation]: Miscellaneous - Design;

INTRODUCTION

In the wake of design practice being increasingly embraced and integrated into HCI research, there have been several attempts to better understand and evaluate what exactly design is. These range from descriptions of design as a research methodology [12] to accounts of intellectual rigour in design practice [11], as well as publications that examine the links between research and practice [5].

As designers working in an HCI context, however, we are often frustrated by how little space conference paper formats allow for reporting those aspects of our design practice which we refer to as 'material design', following Schön's [7] discussion of 'conversations with materials'. These processes often take a majority of the time used to develop projects, and produce a myriad of insights and lessons. Yet mention of material design is often reduced to a paragraph describing a basic form or a unique detail, shoehorned between a literature review and an ethnographic report of field research, meaning that more thorough design accounts are missing from archived contributions to knowledge. In our approach to HCI, design is embedded as an integral part of all our activities, from funding applications to dissemination. The underrepresentation of this process within traditional academic output is, in our opinion, to the detriment of the community's understanding of design and the particular lessons it offers, reinforcing notions that design is mysterious or a black art [11].

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In this paper we use the format of a photo-essay to describe the process behind the design of a set of three prototype devices, which are batch produced for twenty households. The aim of this paper is twofold: 1) as a detailed case study of material design that may be valuable to designers working on environmental sensors as well as those interested in design process and 2) as a contribution to how the research community understands design, as well as a challenge to the forms the community offers for its report. It should be noted, however, that because one of our purposes is to introduce and discuss photo essays as reports of material design, this paper is not a pure exemplar of the form. Most of the introduction and conclusion focuses on the need and nature of the format, where normally we would expect elaboration of project-related themes. Thus the concern here is to overview the materiality of design, the ways we learn from it, and the promise of photo essays, rather than to detail specific project findings.

The Indoor Weather Stations

Our account focuses on the development of a set of devices collectively called the Indoor Weather Stations. Each device is designed to explore a simple aspect of the microclimate of one's home, featuring digital sensing technologies and real-time digitally- or physically- articulated output. All three log the data that they measure and can replay the previous 24 hours of these recordings. The devices were produced for a long-term project exploring Third Wave HCI [4] that focuses on sensor legibility and interpretation among multiple users.

Our essay is arranged as an annotated [1] journey of the design process used to develop the devices. Though we overview the funding proposal, initial ideas and sketches, we move quickly on to the *development* of the Weather Stations as artefacts. We must emphasise that this paper focuses on only *part* of our design process. The detailed story starts from a point after the conception of the Weather Stations as part-fledged ideas, when we knew the hardware that we would use, the scale of the devices and the approximate form of each Station. We chart in detail our experiments, materials explorations, wrong turns, manufacturing tests, correspondence with suppliers, coding, hardware testing, 3D modelling, silk-screen printing, copper leafing, electronics engineering and the hundreds of prototypes. This section ends with images of the finished devices being delivered to our participants, as a useful punctuation point in a process that is still ongoing.

We conclude with reflections on our photo-essay and argue the benefits for using this format when reporting design practices in academic research publications.

Figure 1. The Weather Stations are three small sensing devices (for purposes of scale, these are shown here next to a UK two pence piece): The Light Collector (LC) displays the ambient light in the home as a continuously updating colour palette. The Temperature Tape (TT) reveals thermal gradients along a thermochromic printed ribbon while the temperature difference between two points – the *hook* and the *eye* – is displayed on a dial in the central spool. The Wind Tunnel (WT) senses micro drafts and emulates them over a miniature landscape. For clarity, we present each device separately in this essay though in reality they were developed concurrently. This is a curated rather than chronological account of their production. (The detail in these images is best viewed onscreen from the PDF or the Flickr album found at http://tinyurl.com/attn2detail**)**

SCOPING TERRITORY

Figure 2. The funding proposal outlined a framework of ideas concerned with revealing the microclimate of the home using legible sensors – a notion derived from earlier work in which sensor systems we designed were perceived to be ominous [2]. We imagined how sensors could be made legible with the addition of appendages that perform / materialise / amplify what is being sensed by their physical action, e.g. sensing draft might be made visible through the movement of featherweight paper attachments that respond to changes in air current. We also considered how the concept of legibility might extend to the power source. We proposed sensors that were low-powered, parasitic or even self-powered to express their energy production using, e.g. radiometers and sterling engines. A new Probe study [3] was carried out to deepen our understanding of how people view their domestic landscape. It took the form of a storybook with an incomplete narrative about a journey through the home, including prompts to encourage microclimate exploration. These exercises iterated our designs in small but important ways, each developing our understanding of the research terrain.

Figure 3. Workbooks [3] were created to stake out our research territory alongside the production of paper maquettes and sketch work, illustrating and experimenting with some of our ideas. The workbooks moved through scale and focus on different energy matters – from over-arching themes that dealt with planetary issues to local issues of biodiversity, and spin-off workbooks that unpacked specific ideas, i.e. sensor legibility. Short-term field studies ran simultaneously to test living with sensor-technologies (developed by André Knörig) alongside larger scale field studies: a more focussed Probe study and a case study involving a whole street. Ideas about materialising energy, e.g. miniature grasses on indoor windowsills to highlight air leakage, emerged early on, eventually converging around ideas to do with the Weather Stations. It must be noted that we observed how some elements are more difficult to make visible than others, i.e. air quality, airborne particulate matter, temperature. These activities worked together in helping us open and explore an increasingly large design space.

ATTENTION TO THE LIGHT COLLECTOR

Figure 4. Initial experiments with an RGB (Red, Green, Blue) light sensor were frustrating due to the illegible of the sensor itself. We found it difficult to interpret due to the lack of real-time output physically close to the sensor (tests were confined to a laptop screen). We began exploring ideas for a handheld device that would incorporate a small OLED (Organic Light-Emitting Diode) with a light sensor that could be used as a kind of 'colour picker' (much like a physical Photoshop eyedropper tool). Through our own experiences of using the first electronic prototypes we developed more of an interest in sampling ambient light as it varies throughout the day. Shown here are initial forms for a device that instantly displays sensed light. Our starting point was the idea of a symmetrical output, with input (sensor) and output (display) formed of two identical bodies (much like the form of a diabolo toy). Through making we developed the language of these two elements, imagining one part directing light into another part that would become a vessel for collecting light samples.

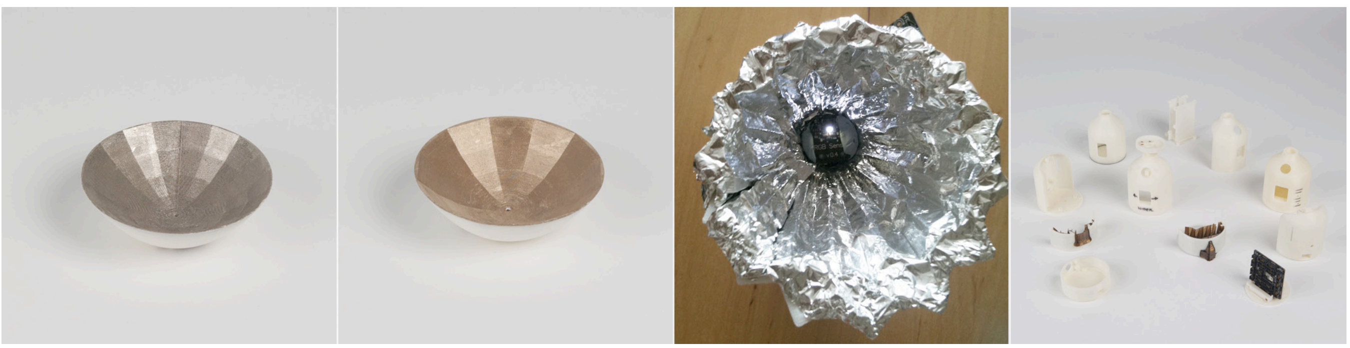

Figure 5. The concept of the LC emerged through the idea of recording ambient light samples for future playback. The RGB light sensor that we were using was a fairly anonymous electronic part and we wanted to make what it was sensing more legible. We started to develop forms that would suggest the funnelling (as opposed to focusing) of light down into the main body of the device, where collections of light samples would be displayed on the OLED. Many of these forms were modelled in Rhino and SolidWorks and printed in ABS plastic alongside other material explorations, in particular various reflective coatings on the inside on the funnel to produce complex reflections that communicate the theme of light around the sensor. Early prototypes revealed an aesthetic harmony between the ABS and other raw materials, e.g. thin metal leaf will maintain the grain of the ABS surface. With the volume of production also a consideration, the decision was made to leave the ABS in its raw 'unfinished' state (without sanding or spray-painting the surface).

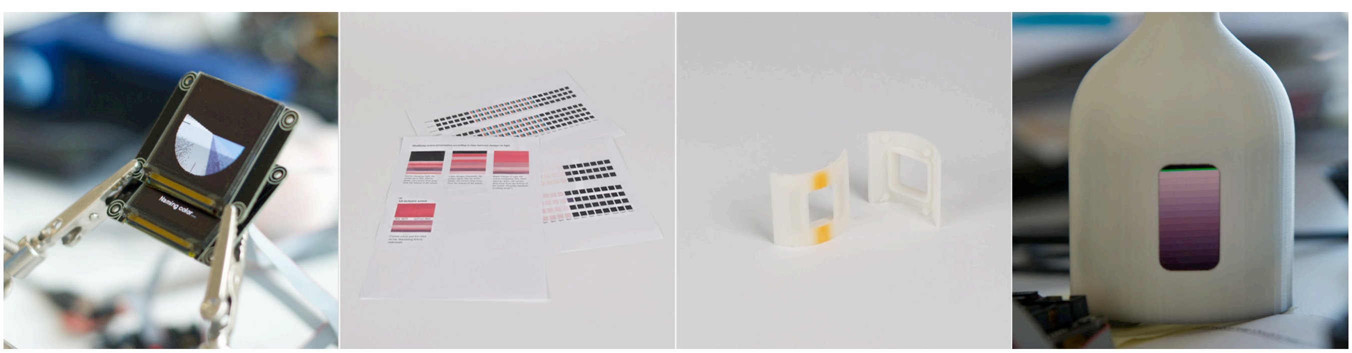

Figure 6. We began using the Microsoft Gadgeteer [10] hardware platform alongside experiments with form and materials. The ability to rapid-prototype electronic hardware configurations was particularly useful at this stage, allowing us to try various configurations. Shown here is the mock-up of a double-screen LC that displayed both a colour name (such as the RAL colour space system) alongside a RBG pie chart depicting the history of light samples. We also began to imagine how data collected with the LC could be used outside of the device, and started to produce mock-ups of printed colour swatches presented as a diary of collected light. Many versions of screen housing were prototyped, finally converging on the decision to mount the screen as far into the body as possible, alluding to the impression of light being captured inside the device. Shown in far-right image is a near-final solution of dividing the screen real estate into a series of horizontal strips, each representing a period of time. On screen is a sunrise recorded one morning in the studio, an accidental insight that occurred after testing the hardware overnight, which helped us decide on this kind of graphical treatment of the screen.

Figure 7. As well as iterating the design to finalise the proportions of the funnel and display window, there were a number of technical and engineering challenges to house the hardware. Having sole use of a 3D ABS printer allowed us to develop a bespoke articulated ball and socket joint (patent pending) to connect the body and the funnel, house the wiring for the light sensor and to produce a greater movement of the funnel, similar to an angle-poise lamp (allowing directional sensing). We were also keen for the copper leafing to have an uninterrupted finish inside the funnel (bar a small window onto the sensor) and this necessitated the development of a fairly complex hidden housing on the underside. Again the ability to print custom parts gave us the freedom to devise a method for installing the RGB sensor without mechanical fixings, making it possible to hide the part within the walls of the funnel.

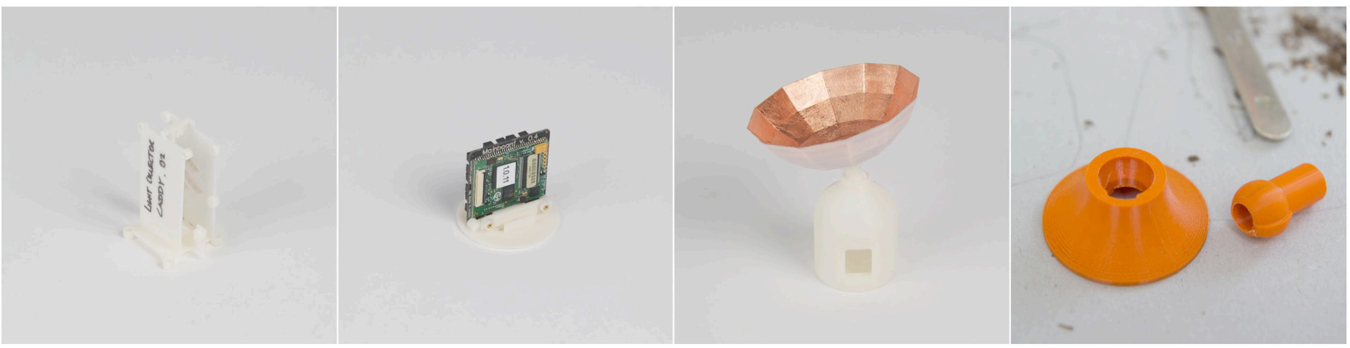

Figure 8. With Microsoft Research as a project partner, we were given CAD files of the Gadgeteer components before these parts were manufactured. This enabled us to work on various configurations of the many PCBs in the LC in the digital domain, and also allowed us to 3D print representations of modules for physical testing of fit and assembly. The internal layout of parts in the LC were continuously tweaked over several months, the tolerances were so tight that even a minor change would impact significantly on the whole arrangement. However we were keen to retain the original form of the LC, so even when the electronic layout demanded more space, we decided to trim wall thicknesses and fixings structures in the housing. This resulted in a greater understanding of the 3D printing process, including strength and friction tests, experimenting with tolerances and build orientations as well as adopting idiosyncrasies from the process such as print seams and contoured layering.

Figure 9. The funnel transformed during a number of iterations to fine-tune a variety of details. The testing of metal leaf and its various finishes and application methods was carried out in conjunction with the development of the LC to optimise the impact of the reflections of the facets. The aim was to achieve a result whereby the funnel acts as a light sensor in its own right, each facet becoming an individual light swatch. Simulated tests were completed in CAD software to explore the reflection of the facets so as to 'funnel' the light towards the mounted sensor whilst echoing the ambient light on the copper surface. Production methods continually evolved, an initial attempt to print the funnels in a stack over a holiday period failed as the support material between funnels compromised the surface to be leafed. Production funnels had to be printed individually, each taking 11 hours, necessitating the careful management of a printing schedule to avoid any downtime of the 3D printer.

ATTENTION TO THE TEMPERATURE TAPE

Figure 10. The Temperature Tape began with experiments that investigate temperature difference between two points. This was quite straightforward with electronic sensors, but we were keen to add a physical element that would expose the temperature gradient between these points with greater legibility. It was a challenge to develop this non-digital sensor as most off-the-shelf materials reveal much greater incremental differences - we needed something that would show minute changes (less than one degree centigrade) over a relatively tight range, i.e. between 16-28ŸC. We experimented with liquid crystal strips, thermochromic fabric and a variety of applications of thermochromic pigment, e.g. dying cotton thread to embroider fabric tape. Chemical experiments were carried out alongside thoughts of physical format, and we began exploring ideas to cover the ribbon cable between the electronic sensors in thermoreactive material.

Figure 11. To explore the notion of 'temperature difference' in the home the TT sensors needed to be able to exist in different locations at once. It was helpful to liken this quality with existing domestic objects which have expansive states e.g. cotton spools and reels. After exploring many manifestations we concluded by paying homage to the tape measure we had seen in the Eames Office (top left). The scale and proportions of the tape measure were more suited to house the 13 Gadgeteer PCBs and 5 meters length of tape. The interactions associated with tape measures was also useful to us, but unlike tape measures we wanted the TT to be predominantly left it its outstretched state. This meant careful consideration had to go into the appearance and legibility of the device, and how the device would interact with the domestic space.

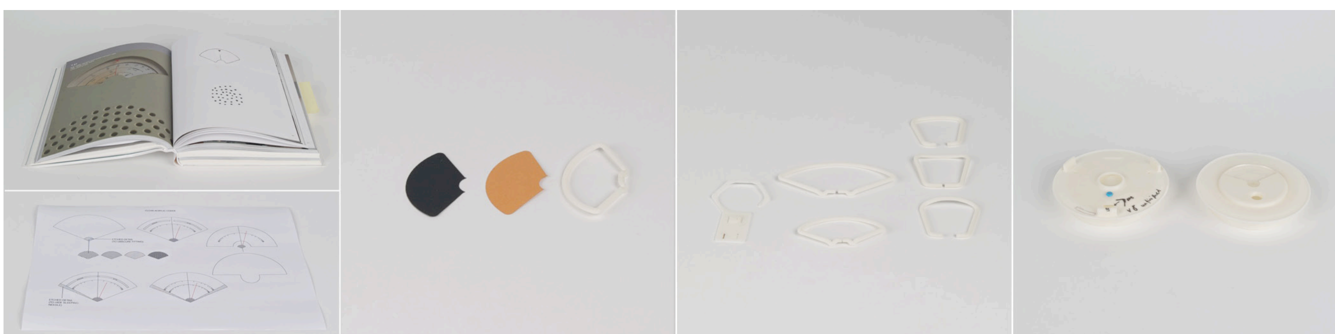

Figure 12. We decided to use an analogue panel meter for the read-out of temperature difference on the main housing. The motion of the needle dial movement seemed particularly appropriate for exploring reasonably subtle changes in sensor readings. It has an instrumental quality that we believe complemented the slower paced reaction of the thermochromic ink, enabling instant reaction when seeking out areas of temperature difference. The dial panel itself was influenced by the design of a Dieter Rams' Braun radio, with a number of sketches exploring a range of dial increments, proportions, angles and radii. This form was also considered for a handle on the device, until the design instead settled on a more spool-like detail, echoing the circular form on the front of the device. Not only did these observations help to develop and finalise the dial, but also provided a moment of reflection to consider the overall configuration and legibility of the TT, in particular the relationship between the front and back of the device.

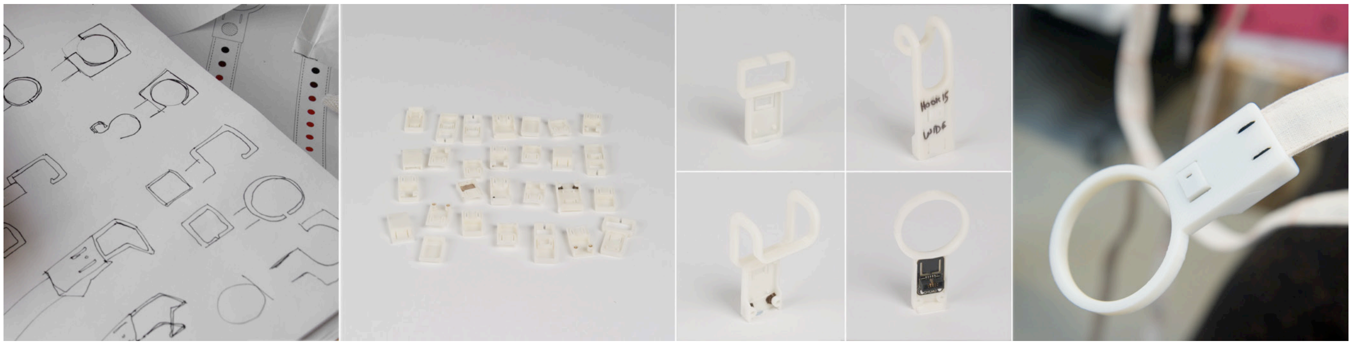

Figure 13. The hook and eye house the two temperature sensors. Both are designed to readily attach to different locations within the domestic environment. Multiple versions were tested in developing the final attachments to achieve the right balance between offering a universal attachment, whilst ascribing to certain conditions, e.g. we imagined how the hook might hint at being placed up high to allow volunteer users to vertically explore their domestic landscapes. A number of prototypes explored the structural integrity of the hook and eye whilst ensuring that they tightly housed the sensor and wiring. Ergonomics, scale and proportion were also studied. The connection between the fabric tapes and the ABS hook and eye presented a challenge. After many unsuccessful attempts, the tapes were eventually sewn in, bringing together the handcrafted tapes with the digitally manufactured ABS components. The final design of the hook and eye extended the slot cut into the PCB (necessary to prevent heat soak in the sensor itself) to emphasise the notion of air passing through the sensor.

Figure 14. We commissioned a set of bespoke thermochromic pigments to cater for the temperature thresholds that we were interested in. This enabled us to develop a novel layered application of this ink that gave the behaviour of stripes changing colour from black-red-orange-yellow with the ambient temperature of the room. The pigment was silk screen-printed onto calico fabric before being cut up and fed through a bias-binding maker and sewn together to house the sensor cable to create the temperature tape ribbon. Production samples were tested in extreme environments. Other important design decisions concerned the housing of the difference dial and the dial cover. Laser etching tests were carried out to achieve precise depths to make the dial graphics most legible. The dial increments were spaced at a non-linear scale to create more differentiation when the dial needle swings further towards one extreme. Engineering issues were also resolved - bespoke washers were made to account for slight differences in the hand-made panel meter to ensure an accurate fit into the 3D printed casing.

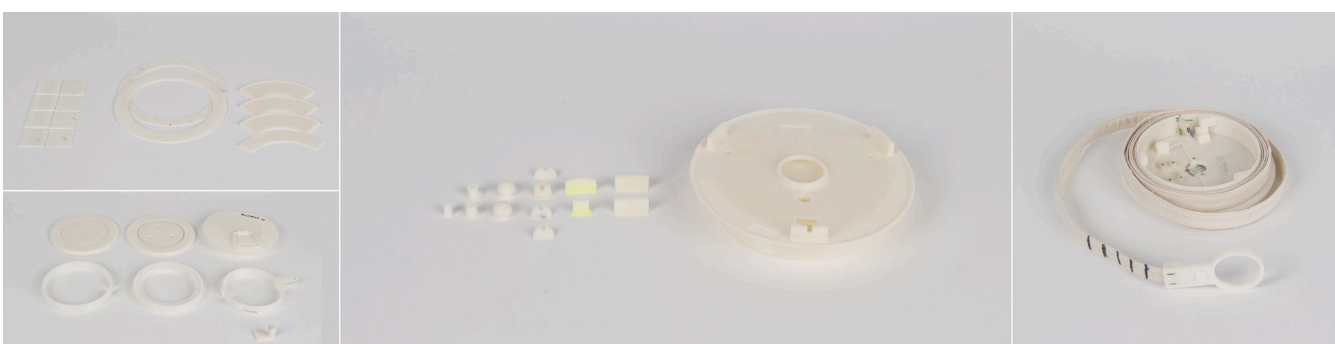

Figure 15. We explored a number of details for the TT in depth, including various textured surfaces, internal winding and ratchet mechanisms, various angles of radius with emphasis on print finish, different sized feet and various cable management systems. The feet allowed the device to be sat on a tabletop whilst providing enough space for a USB cable to protrude out of the back of the device with the wire neatly housed into the nearest foot. The TT demanded a number of Gadgeteer components that were carefully positioned within the casing. Mindful of the scale of the device and the length of production for such a large object on the 3D printer, the bosses and internal elements of the device were simplified to shorten print time and minimise post-processing and ease of assembly. Smaller samples of detail elements were often printed and evaluated during studio hours, while finalised production parts were scheduled for overnight or weekend builds. Many parts were often still in development whilst others were in production.

ATTENTION TO THE WIND TUNNEL

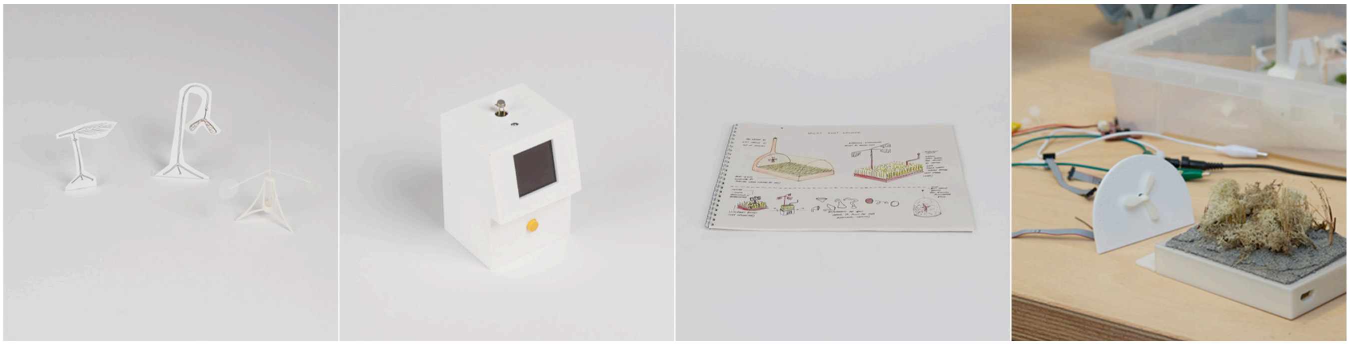

Figure 16. Initial experiments to develop a draft sensor considered electro-mechanically augmenting miniature wind vanes, an idea suggested in the original funding proposal. However a micro-gust sensing prototype developed by project partner Nicolas Villar demonstrated an entirely electronic alternative. This prompted the team to investigate ways of making these readings legible by developing a direct physical output for the electronic data. Ideas formed in workbooks focused on the development of a miniature environment where sensed drafts would be used to control the speed of a fan blowing through an artificial landscape, turning micro-gusts into dramatic events. The sketches soon evolved into maquettes, models and prototypes.

Figure 17. The first image shows a 3D printed propeller fan still enclosed in the support structure used in the machine's build process. This is one of a series of fans designed, printed and tested to find one that would achieve the most disruptive airflow. The final design was influenced by the blades of a conventional desk fan, which seemed to buffet the air the most (therefore producing the dramatic effect on the landscape). The image on the far right shows a miniature wind sock attached to a very small sewing needle, just one of the many props built to place in the landscape. Through this making we developed a greater understanding of crafting wind-catching elements from paper and how small drafts could be visually amplified.

Figure 18. One of the first landscapes produced was a miniature lawn and windmill. Many others were made that explored different processes and materials. Some attempted to replicate natural environments, others more artificial. We also considered producing a different version for each of the 20 WTs or even giving our volunteer users the tools and materials to construct their own. Eventually we developed a system of sandwiching finely laser cut polyester film within strips of material that would stack to form a contoured landscape base. This solution, while complex, formed a very delicate structure of artificial 'trees' that would bend down when the fan was at full speed but return to their upright position when the fan was off.

Figure 19. Many different motors were tried and tested within the housing, with consideration to both size and noise, eventually selecting a pager-style motor that was both quiet and low powered at speed. The draft sensor itself was a modified transistor that can get quite warm in operation and so needed to be protected to prevent touch. We designed and built a variety of cages to surround the part, each using as little material as possible to not impede airflow. It took many design iterations to come up with a solution that provided the best compromise of strength and safety, while maximising the flow. We decided to emphasise the input (draft sensor) and output (propeller fan) elements on the WT sensor and printed these parts in coloured material. These necessitated the need to print the cage with a mechanical fixing to attach seamlessly to the white component. With the experience learned from earlier 3D printing experiments, it was quite straightforward to print a reverse screw thread directly into the parts.

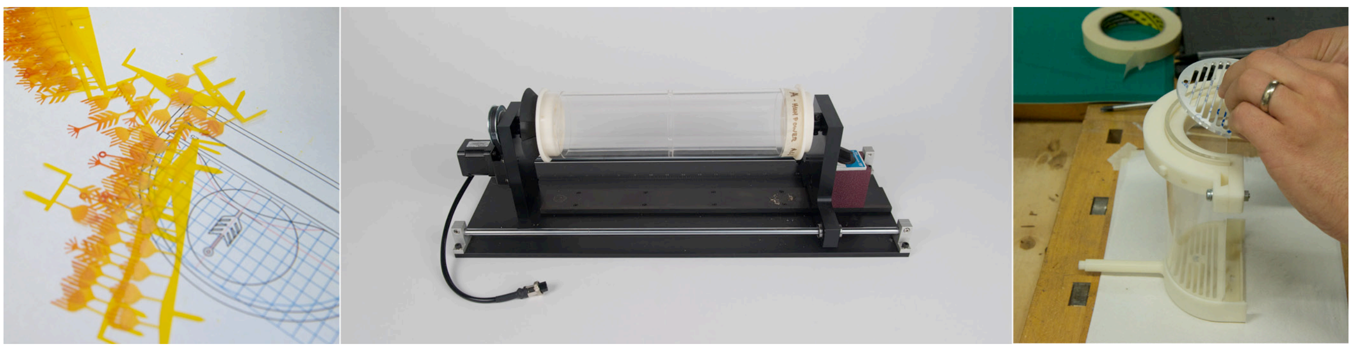

Figure 20. The use of digital manufacturing throughout this project provided a relationship between the design of various components, technical drawings, jigs and braces. Cross-section drawings of the WT's contoured landscape were extracted from the 3D CAD model when designing the 2D lasercut forest. Bespoke jigs were 3D printed to fit acrylic tubes onto a rotary attachment for the laser cutter. This enabled the semicircular acrylic housing to be cut from standard tubes. Similarly, braces and jigs were designed and 3D printed to aid the assembly of the endplate onto the WT housing, providing an accurate fit between parts.

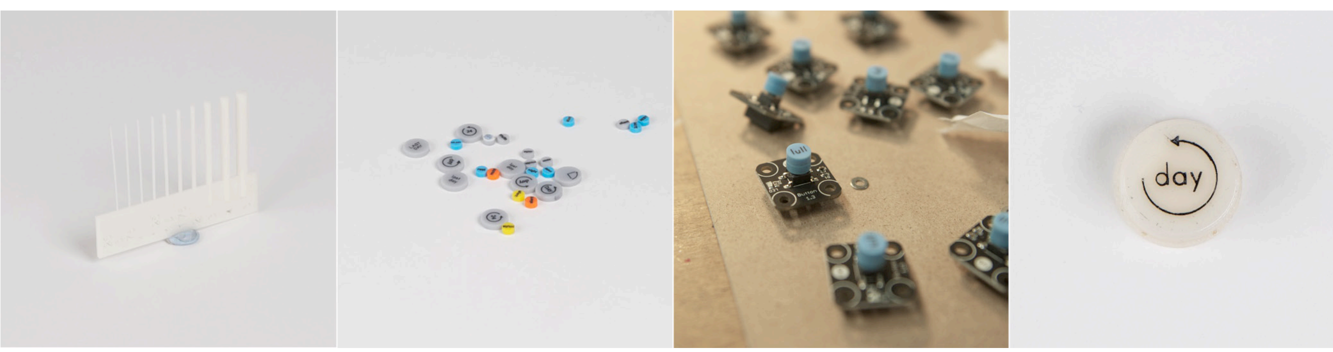

Figure 21. A vast range of materials and samples were produced throughout the making of the Weather Stations to take full advantage of in-house digital manufacturing capabilities. 3D printed swatches were produced early on as reference for thickness, strength, finish and the extent to emit light through the ABS. In designing the graphics of the 'Lull' (a sleep mode) button cap, a run of tests were made that helped develop techniques for laser cutting and laser engraving to ensure a clean and crisp finish. Similar tests were carried out on the 'Last Day' button (that replays the last 24 hours of collected data). This was an interesting process as this part was designed in conjunction with the in-house design of a bespoke Gadgeteer module. This component contained a button and LEDs which were arranged to provide animated feedback of when the replay function was in use. Having control of the design of both the button and the electronics was important not only to craft the quality of the light through the button, but also as we saw this function as being critical to the users' understanding of how data from the sensors was being archived.

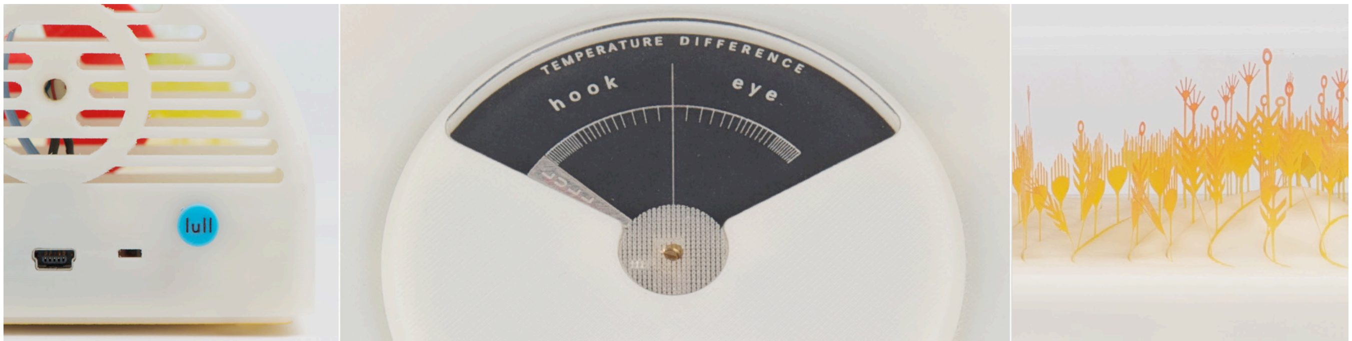

Figure 22. Every element of the Weather Stations demanded great attention to detail. A close up image of the WT demonstrates the crisp finish of the Lull button, the precise fit of the USB port, and the hidden rubber feet of the device that dampen any vibration whilst carefully float-mounting the WT on the tabletop. The Lull function on the TT presented a unique problem, as the dial moves to the far left in an unpowered state, which could read as an extreme temperature variation. We designed an etched Lull section on the dial cover to obscure the needle in this state. The trees within the WT forest were also carefully considered. Many varied in height and form so as to react differently to the gusts acting upon them.

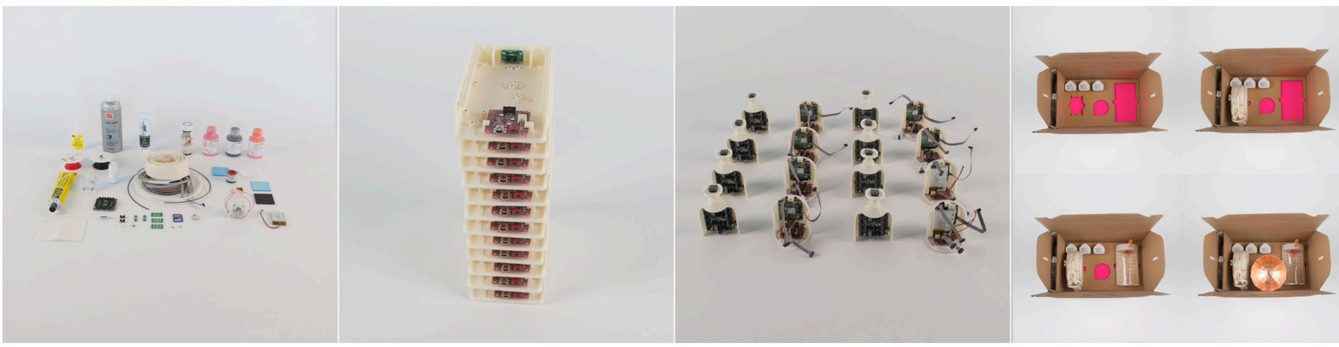

Figure 23. There was a huge variety of raw materials used in the batch production of the 66 devices, including ABS, thermochromic ink, schlag metal copper leaf, acrylic and calico fabric. In total we produced 760 unique parts from these raw materials to add to the thousands of ready-made parts including PCBs, cables, motors, dials, feet and mechanical fixings. The production of the devices was carried out in two phases: beginning with a small run which enabled us to tweak, make modifications to the design, and respond to hardware changes. Through this process we were able to precisely schedule the second run. As digital printing is inherently slow, designing a system for batch-production became a finely tuned negotiation between the printing time and the batching of hand-finishing processes. The final artefact hides within its machine printed surface the minutiae of detail and craft that exists within the CAD data. This contrasts with the more traditional elements of craft in the artefact, e.g. the hand-sewn temperature tape and the leafing which are more vocal about the labour involved in their application. These hand-applied processes ensure that each device is aesthetically individual - an important detail for participants to accept these objects as being for them, not about them.

TOWARDS FIELD STUDIES

Figure 24. It should be noted that a number of artefacts were designed alongside the development of the Weather Stations to enable and support their deployment - from recruitment posters and events to packaging and user-guides. At the time of writing, twenty-two participating households have been living with the Weather Stations for several months and we are in the process conducting field-studies. Having completed the design and production of the Weather Stations, we have been able to identify insights and opportunities for HCI research: 1) The importance of intimate experimentation with materials and technologies throughout the design process and allowing this to drive research and outcomes. 2) Digital manufacturing makes possible rapid material iterations in the development of a final design. Embracing this feature will push designs in unexpected ways towards a greater resolution than would have been anticipated at the outset. 3) The opportunities that rolling batch production and deployment affords to the ability to respond to participant feedback and hardware development throughout the manufacturing cycle.

CONCLUSION

This paper aims to spotlight the material design element of our research in all its detail. Through our presentation, we hope to have indicated many of the areas of investigation and learning addressed through this process. These include issues ranging from how we particularised the broad notion of 'sensor legibility' in three specific designs, to the many effects that rapid prototyping had on our process and the prototypes we made, to the crafting of affordances for use and integration of cultural referents in our prototypes. We hope we have conveyed that very many of the details of our design are thoughtfully resolved.

We present this paper as a photo essay, a sequence of images choreographed around a narrative further illuminated by figure captions. This is an established method of report in other domains. Ethnographic studies often make use of photographic essays to document projects [8] and the medium is often used by other disciplines to express new points of view [6]. There are several reasons for us using this format in the current context - photography is widely integrated into our practice as a means of communicating and documenting our design thinking, processes and field studies. For this exercise we decided to adopt a photographic style influenced by Taryn Simon's Contraband [9] - a series of 1075 photographed objects detained for inspection when travelling through JFK airport. The contraband items were framed within a large white space, exposing their fine detail. We approached the study for this paper in a similar way allowing us to interrogate the artefacts of our design process. We momentarily removed our objects from their current processes and photographed them under identical conditions, either individually or in collections. Composing the articles of the project enabled us to expose known connections between them, as well as revealing new associations that were not apparent to us before undertaking the study.

Photo essays seem to be appropriate for documenting material design on other grounds as well. Characteristic of this mode of design is that both issues and insights emerge from the multiplicity of detailed and heterogeneous decisions made by designers, and these issues and insights are embodied in the materiality of the designs themselves. Annotated photographs [cf.1] can reveal this sequence of decisions as they are manifested, and can express qualities or values that are difficult to express precisely through words.

Practice-based researchers / designers will look to real-world examples when designing. By revealing a captioned photography of the development of the Indoor Weather Stations we hope to impart knowledge about designing legible environmental sensors, and the design process itself, from the materials and means of our prototyping to (some of) the social, aesthetic, pragmatic considerations of our work.

It must be noted that just as the traditional academic paper cannot uncover every aspect of the design process, this photo essay cannot cover every detail of our decision-making. In part, this is because of the real-estate of the paper format, and in part it is because it is impossible to account for all the imaginative leaps and tacit [1, 7] influences acting upon the designers. Moreover, photographs cannot capture the dynamic nature of animate objects, their spatial and tactile qualities and so forth. Clearly, the design process cannot be wholly represented by images alone: as Bowers points out, 'artefacts and their descriptions are mutually reliant on their relationship to produce meaning'.

We are not the first to express the dilemma of how practice-based design researchers should legitimise or validate their research [11, 12]. We acknowledge that this paper will polarise opinion, yet we believe that it advances current approaches to communicating (and understanding) practice-based research. It offers an alternative to existing formats that takes from the discipline itself, rather than borrowing from others. Thus we suggest this is a way forward in terms of the documentation of research through design, one that complements existing academic frameworks, while in our opinion allowing a *better fit* for disseminating design research.

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