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Prototyping Things: Reflecting on Unreported Objects of Design Research for IoT

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ABSTRACT

Prototypes and other 'things' have had many uses in HCI research—to help understand a problem, as a stepping stone towards a solution, or as a final outcome of a research process. However, within the messy context of a research through design project, many of these roles do not form part of the final research narratives, restricting the ability of other researchers to learn from this practice. In this paper we revisit prototypes used in three different design research projects, conducted over a period when the Internet of Things emerged into everyday life, exploring complex hidden relationships between the internet, people and physical objects. We aim to explore the unreported roles that prototypes played in these projects, including brokering relationships with participants and deconstructing opaque technologies. We reflect on how these roles align with existing understandings of prototypes in HCI, with particular attention to how these roles can contribute to design around IoT.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

Prototypes, design, research through design, research objects, things, Internet of Things.

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1 INTRODUCTION

In the exhibition catalogue for *The Curious Home*, Gaver recounts the project in reverse, drawing a vivid picture of "watching a film of a great wave hitting a beach, but played backwards" [13]. As this alludes to, final artefacts of a design research process are often left washed up on a pristine beach while many of the ideas and work that went into them swirl somewhere at sea—perhaps waiting to catch another wave onto another concept. The luxury of an exhibition catalogue like the one that accompanies *The Curious Home* is a familiar part of the design landscape, but for HCI researchers, this body of design work often goes unseen beyond the parts that help to construct a clean narrative. It is striking to compare the content and style of that exhibition catalogue [13] to the related research paper [15]. If one were to view only the research paper, a lot of design nuance and understanding of process would be lost, along with opportunities to further develop a community of practice around research through design (RtD) in HCI and promote these methods and approaches to others.

Accounts like these show us that the role of prototypes in a design research process are expansive and varied. An evolving understanding of this role can be seen across prototyping literature: while earlier interpretations focused on their role in representing a specific design idea [17], later discussion of prototypes explored their ability to "concretize and externalize conceptual ideas" [24], to include participants in the design process [33] or as a means of inquiry [42]. However, there remains concern that the objects themselves are underappreciated: in recent years, there has been

increased effort to consider the role of 'things' in HCI research, recognising that "the things of design research have remained conspicuously overlooked, under-engaged with, and, for the most part, absent from the CHI conference" [28]. The CHI workshop series on this topic [28], the Pictorials track at DIS and the Research through Design conference [41] represent different avenues for thinking more about the role of prototypes and other 'things' in our research.

This increasing focus on 'things' is perhaps to be expected at a time when the Internet of Things (IoT) has created a proliferation of connected devices into our lives. More than ever, interactive technologies are not just confined to screens, but might take a multitude of forms that lend themselves to the type of physical prototyping common in RtD. Our own design practice has used prototyping to support discussion and reflection around both the opportunities and challenges posed as the objects around us become smarter. Although this work has involved both highly resolved prototypes representing the endpoint of a design process and works-in-progress that were clearly waypoints towards these "finished" objects, there have also been many prototypes along the way that played other roles. These have often served to build relationships of understanding between us as design researchers and the people that we worked with, helping navigate the increasingly complex space of IoT between people, the internet and things.

This paper is our contribution to the ongoing effort to reflect the value of prototypes in RtD research, viewed through the lens of IoT in particular. We revisit the roles that prototypes played across three RtD projects, illuminating critical roles they played in brokering relationships with participants and deconstructing and demystifying technology. Our contributions are two-fold: 1) to support visibility of intermediate prototypes in research through design by sharing prototypes that played critical roles in three projects, contributing the visibility of design research methods in HCI; and 2) to reflect on the existing understood roles of prototypes in the design process from the perspective of IoT and their ability to contribute to its unique challenges.

2 BACKGROUND

Prototypes and other 'things', in all their many forms, have had a long relationship with HCI research and there have been a great number of attempts to classify and define their purpose [24, 29, 42]. Yet the language of the place of these 'things' in HCI research varies greatly—indeed, it has been said that perhaps everything is a prototype [3]. Before describing prototypes from our own design research practice and perspective, we will first review how HCI has understood the purpose of prototypes and other 'things' of research in the past.

2.1 The Purpose of Prototypes

Prototypes are traditionally seen as a stepping stone towards a final product in a solution-driven process: a purposeful way of spanning the distance between an idea and a product, which typically takes the form of a less developed version of what is to come [24]. For example, one model of prototyping used in HCI describes the role, implementation, or look and feel as key properties to be modelled [17]. This form of prototyping can be highly valuable in a situation where the objective is some final product, particularly in a commercial design context. Within this process, designers will typically explore many different alternative possibilities: the Design Council's Double Diamond model [6] represents a highly abstracted view of this process as two successive cycles of divergent and convergent thinking, where designers explore a topic widely before settling on a brief, then a wide range of potential solutions leading to a final product.

The Double Diamond's useful abstraction helps us to communicate the broad strokes of a design process, particularly to those who are unfamiliar with it, but the story it tells is not complete. In contrast to this clean model, design practice is inherently "messy" [36]: avenues are explored and abandoned, or collapse back into the final concept in unexpected ways. We have seen this disparity is our own research, there we have tended to draw a relatively linear path in the final research narrative, obscuring the messiness of a much wider exploration. So, what roles do prototypes play within this tangle?

2.2 Prototypes in Design Research

In design research especially, prototypes are not just waypoints on the journey to a finished output, but a tool for research themselves. Wensveen and Matthews [42] suggest that "if there is a unique character to design research in comparison to research approaches in other fields, it is likely to relate to the role of and focus on designed things as components of the research process". Their categorisation of prototypes includes prototype as an experimental component, prototypes as a means of inquiry, prototype as a research archetype and the process of prototyping as a vehicle for inquiry.

While the use of a prototype as an experimental component, for example to directly test a hypothesis or compare several approaches to a problem, is very common in HCI research, as design researchers we are drawn much more to prototypes as a means of inquiry. Here, the prototype is a tool that acts part of a larger inquiry—a means of learning about the world, rather than learning about the qualities of the prototype itself. Wensveen and Matthews point to technology probes [18] and provotypes [2] as examples of this, both prototypes meant to provoke some response that will improve our knowledge of a situation. Unlike more well-defined prototypes, these explicitly ask open questions and that might take research in unexpected directions. Technology probes intentionally liken themselves to cultural probes [14]—both designed objects intended to learn about participants and provide inspiration rather than answer questions themselves.

Also of interest to us are prototypes as research archetypes, used to illustrate and demonstrate some concept, perhaps critically. While tied more to the "showroom" [21] approach to design research that is less common in HCI than lab or field approaches, a strand of speculative and conceptual work has long existed in interaction design (most famously in the work of Dunne and Raby [10]). With speculative design and design fiction cementing their place as mainstream methods in design-led HCI research, the use of prototypes in this way is increasingly common. This type of prototype is marked by the designer's intent to communicate something, often about a particular issue, but also about themselves—Wallace et al. [39] reflect that their probes were designed not just to learn

about participants, but also to share their own values. Finally, while the act of prototyping itself as a means of inquiry is even less common in our field, we do see reporting of this becoming increasingly common as new publication formats better support it (e.g. Dykes et al. [11]).

Sanders and Stappers [33] provide us with an alternative taxonomy for prototypes, focusing on their role in the co-design process. These include supporting discussions around a theme, confronting theories and confronting and changing the world. They point to how prototypes in a co-design process can be used to share ideas to elicit feedback from participants and point to the differences in designing for (typically in speculative design) and designing with (typically in service design). While these distinctions do not hold in all cases it is a useful framing for a discussion of the modes of prototyping where a functional product may not emerge.

2.3 Designing Things for Concern

Finally, we want to draw particular attention to the growing use in HCI of things to negotiate ideas and concepts between people and complex situations. The challenge of designing for complex intersections of people, technology and society is even greater when there is a lack of alignment around issues amongst those involved [1]. Latour [23] argues that all designed objects are assemblages of things and the world is lacking the tools required to bring these things together in meaningful ways for matters of concern. Ratto [31] picks up on Latour's challenge by proposing Critical Making as a way of turning the relationship between technology and society from a "matter of fact" into a "matter of concern." How matters of concern become issues that publics can deal with, and what design's role in this space can be, is addressed by DiSalvo [7]. He posits that "issues themselves do not exhibit the agency to assemble people" and that design can contribute to how publics can become aware of issues.

In our own RtD practice, we have responded to the growing entanglement of the Internet of Things (IoT) in our lives. The complex, unknowable quality of the many interconnected aspects of IoT [25] is increasingly seen as a matter of concern. In an echo of DiSalvo's call to expose underlying structures, Duarte [9] argues that we need to *disassemble* these systems in order to reveal underlying socioeconomic reasons behind the way in which connected products are designed. Design has responded to this challenge both by exposing and speculating on current issues around IoT and by exploring its potential beyond current commercial activities [4, 8, 19, 20, 38]. In our own work, we have found a need to take people on a learning journey that enables researchers and participants to arrive at an initial shared understanding of issues from both sides.

3 REFLECTIONS FROM PRACTICE

To explore the wider roles of prototypes, we will revisit three different projects where prototypes were used in ways that were essential to the project but ultimately did not form part of the published research narrative. All of these projects are drawn from our own RtD practice and broadly respond to the challenges of emerging technologies in different contexts, especially related to IoT. We will not focus here on the design processes leading to the prototypes, nor on the final project outcomes that resulted from them. Instead, we focus on early and intermediate stages of the projects where prototypes were used to broker new relationships with participants and explore the landscape around each project's context.

All three projects broadly relate to the Internet of Things, a research context in which 'things' are central and the design of physical products has a renewed prominence. Underpinning our research is the notion that as IoT enables technology to come ever closer into our lives, the social impact it can have is significantly amplified. Seemingly simple devices marketed as speakers may actually be microphones collecting masses of personal data and drawing on sophisticated distributed networks. These complexities require the sharing of knowledge, experiences and understanding between researchers, designers and participants. In each of the projects we will discuss, prototyping provides us with a way of untangling these complex relationships of people, objects and the internet.

3.1 The Minions and TapWriter (2015)

Our first prototypes were developed as part of a project exploring radical new forms of IoT for the retail environment. The project was set against a backdrop of decline in UK high streets (downtown shopping precincts) as consumers move instead to online shopping and out-of-town retail parks, as well as a trend of increasing use of emerging technologies by major retailers, including facial recognition [44]. Our aim was to explore how IoT could be co-designed to provide benefit to shops and other businesses located on or near the high street, especially to small retailers who often benefit less from technology developments.

However, IoT was—and largely remains—a term most shopkeepers and other non-specialist audiences were unfamiliar with. Unlike today, when we can point to well-known examples of consumer IoT, there were very few examples we could use to help participants understand the true nature of the project. The prototypes we describe here were used in the early stages of the project to demonstrate the capabilities and potential of IoT, while simultaneously brokering relationships between the project team and potential participants.

3.1.1 The Prototypes. The first family of prototypes built for the project were designed to each represent a single function or digital interaction (Figure 1). Our intention was to create playful single-function IoT devices that served as sketches of the ways that IoT could be used in a shop, café or other customer-facing high street business. We connected these to the internet using an Electric Imp IoT controller, which allowed a very fast reaction in response to web input. Some of these used outputs (a receipt printer that printed messages, an LED ring whose colour could be changed and a thumb that could be raised and lowered, all remotely through a web interface), while others were inputs (an infrared sensor that detected nearby movement and an RFID reader, both of which reported to a web interface). These intentionally referenced existing shop interactions like a till receipt, contactless payment or a bell that sounds when a customer enters. We nicknamed the devices *Minions* after the popular cartoon characters, due to their yellow colour and dedicated tasks, and because we wanted to convey a sense of playfulness and humour rather than utility.

We introduced the Minions in two open gatherings where local business owners were invited to discuss the future of technology on

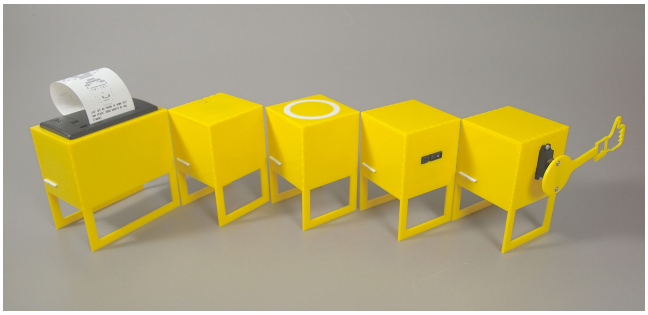

Figure 1: The Minions each showcased an individual web-controlled input or output, including a thermal printer, LED lights and motors.

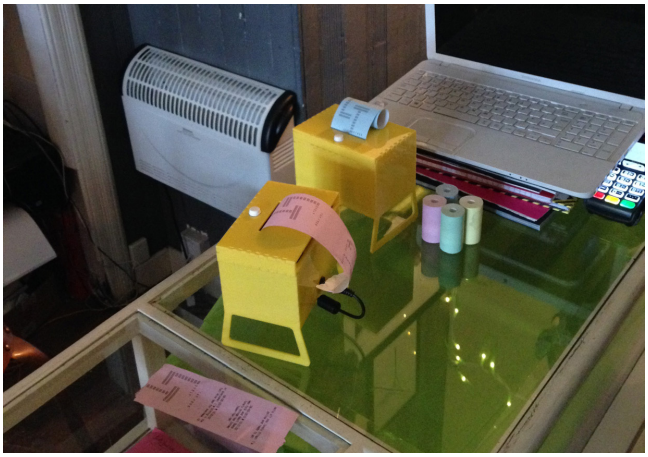

Figure 2: TapWriters deployed on the counter in a small interiors/gift shop.

their high street. As a result of the meetings, we recruited five shops and two cafés to work with us on the next stage of the project. The Minion that the partners overwhelmingly identified with was the internet-connected receipt printer. Consequently, we expanded this concept out into a dedicated social network of devices (Figure 2), in which any message sent through the web service would be printed across the entire network. Borrowing from simple social media interactions (e.g., liking), we added a "tap" button that would send a predefined message ("a tap has been received by <business name>"). The language of a "tap" rather than a "like" was deliberately neutral—more a mark of recognition than approval. We named these devices *TapWriters* and built a network of eight devices: seven that were deployed in different businesses across the city for a month and a final device that resided in our design studio.

3.1.2 Reflections. In this project, we were dealing primarily with participants who had little existing knowledge or experience with IoT and other emerging technologies. The challenge for the project was to engage with business owners, who had the potential to be resistant to the idea of change, and to engage them with a design research project that was approaching retail from a very different perspective to their own experiences. While we naturally wanted to understand *their* experiences, the nature of the project also required that we draw them out of their comfort zones and engage with unfamiliar technologies. We achieved this by effectively deconstructing IoT, breaking it down into simple pairings of inputs and outputs that were by themselves easier to understand and respond to. As we will see in subsequent projects, this deconstruction of otherwise opaque technologies has been a powerful way of helping participants to craft their own narratives around IoT. This allowed us to have initial, informed conversations about IoT in order to recruit participants for the next stage of the project. There was a general sense that the Minions were welcomed as bespoke objects made for them, mirroring the boutique nature of their businesses. This contrasted sharply with mass manufactured devices that raised associations with global retail brands.

Living with the TapWriters for a month helped the participants to gain a deeper understanding of what roles these devices might play in their shops—and whether it actually interested them. Messages ranged from trivial (e.g., "hi", "how are you", "what's the weather like") to jokes and more complex uses. For example, the owner of one shop began sending coffee orders to the café across the street, while another shop sent discount vouchers to other venues to entice potential customers. At the same time, seeing the messages ourselves and visiting shops to perform maintenance helped us understand the rhythms of small businesses. Although many of the businesses slowly disengaged from the network over the month of deployment, these prototypes both helped us to identify the right participant to build further collaborations with, and for other potential participants to learn enough about the project to make an informed decision not to take part further—and having learned a little about one potential future for IoT and the high street.

By comparison, the owner of a boutique eyewear shop maintained a high level of interaction and his enthusiasm became an avenue for deeper engagement. This relationship ultimately became a central pillar of the latter half of the project and he was closely involved in co-designing *Self Reflector*, a highly resolved bespoke research product for his shop [40]. This product—a mirror that guessed the age of the customer and played music from their adolescence—bore no resemblance to the prototypes we described above. But the close relationship that developed through these earlier prototypes was essential to the development of the research product, which drew heavily on the shop owner's personality, especially his love of music, and the unique aesthetic of the shop itself. Without this earlier work, the final outcomes of the project would have been very different.

3.2 Provocative Voice Prototypes (2017)

Our second case study originates from an advocacy project around the voice enabled internet in collaboration with Mozilla Foundation. The project responded to the rapid proliferation of smart speakers and voice assistants into peoples' homes, often with little consideration of their potential privacy implications. At the time of the project, we were beginning to see emerging news stories relating to "creepy" or invasive behaviour from these devices as a result. Our intention was to open a conversation about what preferable futures might look like in this space, taking cues from Mozilla's Internet Health Report [26] to understand what a 'healthier' relationship

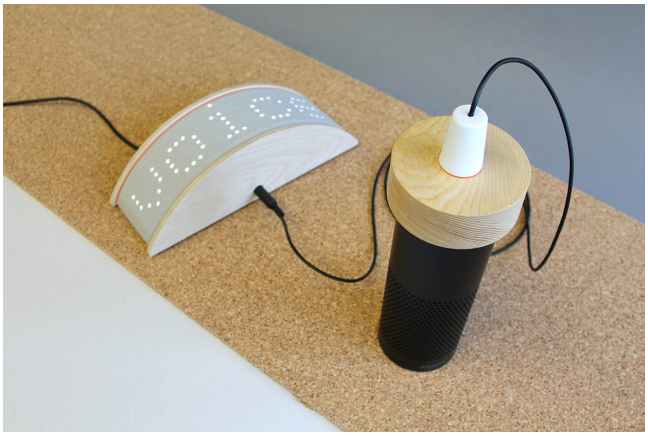

Figure 3: The Agent 'intercepts' and makes transparent the activities of voice assistants.

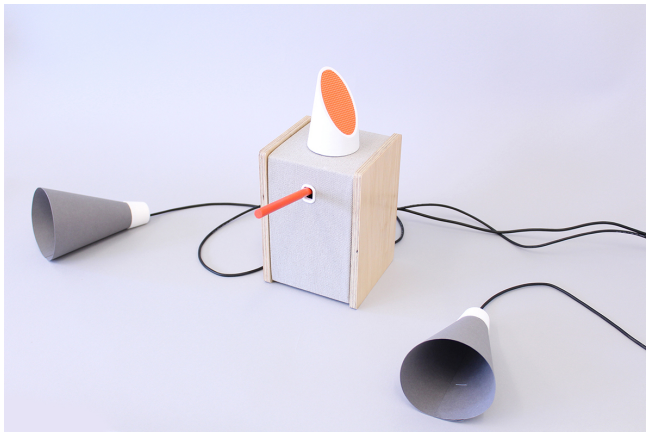

Figure 4: The Actor exaggerates listening behaviours.

Figure 5: The Advisor posed questions about privacy and security.

with voice technologies might be. This conversation was ultimately intended to inform the direction of future advocacy activities in this space.

Our collaborators were largely technology and advocacy experts with considerable expertise relating to the health of the internet, but less specific experience in understanding the voice enabled internet and the design of physical objects. RtD was not an approach generally used by our collaborators at that time. Our intention was therefore twofold: we wanted to develop an understanding of what mattered to them and by extension what futures they should advocate for, while also demonstrating to them the value of an RtD approach to identify new directions for future technologies.

3.2.1 The Prototypes. Because of the high level of participant expertise, we felt comfortable taking an intentionally provocative approach to the project, creating prototypes that posed questions and enabled open discussion. The purpose of these artefacts was to highlight potential issues and encourage debate. We created research prototypes with three distinct personalities that deliberately exaggerated and drew attention to issues around IoT and a voice enabled internet. However, at the same time we wanted to avoid overly negative, dystopian visions.

The *Agent* (Figure 3) worked on behalf of users to make hidden information flows more visible. The prototype was a cap that sat on top of an Amazon Echo and detected when the device activated in response to its wake word. The cap was connected to a scrolling LED display that would then show further information about what happens behind the scenes and what data voice assistants share with the cloud. Messages related both to the current interaction with the device ("Alexa is now active listening") and to voice assistant technology in general ("it takes 10,000 hours of recorded speech to train a voice assistant").

The *Actor* (Figure 4) was a slap-stick comedian that exaggerated the act of listening. It responded to concerns about when and how much voice assistants are listening to us and explored ways of making transparent the behaviours of the device and its associated services. Two cones attached to the device by long wires each contained a microphone, and when an increase in volume was detected in either microphone, the top part of the Actor made an exaggerated rotation towards the source of the noise, while nodding a wooden "nose" in time with speech. The overall effect was uncannily lifelike and many participants found the interaction both playful and humorous.

Finally, the *Advisor* (Figure 5) was a more conservative character that asked and responded to questions about voice assistant privacy and security. It posed ethical dilemmas and asked users to make a yes or no response. For example, one question asked: "do you think there should be an age of consent for voice services?" At the end of the series of questions, a thermal printer printed a summary of how other users had responded to the same questions, which users could then rip off and take away.

3.2.2 Reflections. With these prototypes, we want to draw particular attention to the use of humour and contrast across the family of devices. The Actor was intentionally humorous, with exaggerated movements and a slightly ridiculous form, which was emphasised by its contrast to the more conservative characters of the other prototypes, especially the Advisor. This humour was effective not just to highlight that the prototype was an object for discussion, but also to draw attention to the more subtle, almost invisible ways that real voice assistants inform users of an activated microphone.

This level of humour fostered an openness in conversation between the researchers and experts, acting as an icebreaker that could lead to deeper conversations. The nature of advocacy normally lends itself towards problematising voice technologies, but inserting humour into the prototypes allowed us to take a playful look at what other opportunities might exist in this space. This did not mean ignoring the problems, but rather working through them in a more light-hearted way.

This project also made clear the value of physical things over other mediums. Early in the design process, we shared a presentation of early concepts with an audience comprising mostly engineers. At this stage, it was difficult for them to understand the purpose of the designs and responses largely focused on technical issues around implementing them in reality—treating the ideas as solutions rather than discussion pieces. Through this medium, we were unable to communicate that the individual components were part of a bigger picture. However, once working prototypes were shown at a later event, the intention of the concepts became clearer and participants were more easily able to hone in on the issues each one raised.

Having the prototypes to use and interact with allowed meaningful debate about the value of physical things in advocacy campaigns and a far more varied and open conversation that looked not at problems or solutions, but rather at possibilities and future challenges. The presentation made the purpose look like product development, while the prototypes made the purpose to stimulate conversations around future development. Creating a family of prototypes woven around a single theme helped to support individual critique of each element. This allowed each prototype to focus on one topic and exaggerate it, while having three separate narratives allowed us to focus on only what was required and not embellish or add features that would confuse the message in each prototype. When sharing them with users, this helped to focus on the most relevant aspects of each prototype, while also freeing participants to be more critical of each concept (as suggested by Tohidi et al. [37]).

While the original intention of these voice prototypes was to inspire and inform an advocacy campaign that reported on contemporary challenges for the voice enabled internet, the prototypes instead fostered a conversation that looked at the future of voice. As a result, the final output of the campaign was *Our Friends Electric*, a speculative film using more refined speculative voice assistant concepts [32]. However, these final products were not evolutions of the concepts described here. As in the Minions and TapWriters, the research paper associated with that project did not describe these earlier prototypes, instead focusing on later parts of the process that were most critical to understanding the final objects themselves and the advocacy objectives of the film.

3.3 Deconstructing Biometrics (2019)

Our final set of prototypes are drawn from an ongoing project exploring how communities in rural India could articulate the kind of futures that they might want from emerging IoT technologies. The project grew from a concern that developing countries are often recipients of technology that might not reflect their way of life, ushering in a new kind of Digital Colonialism [22]. Through this project, we aimed to help understand what different forms of IoT might be useful to people living in rural India, specifically to the Soliga people living in the Biligiriranga Hills.

However, before we could start looking at the future, we needed to explore and understand the present situation. Early stages of the project focused on Aadhaar, a controversial biometric identification scheme used to access a range of public services in India using fingerprints, iris scans and facial recognition. Despite having intentions to make access to basic welfare easier, it has also caused significant problems for people in need [5, 34]. While there are issues for biometrics anywhere in the world, they are exacerbated by the living conditions in rural India: for example, finger print readers can struggle with fingertips that are worn from manual labour, while unreliable power supplies and connectivity introduce obvious problems for digital technologies. As Aadhaar becomes essential to everyday life, there is a risk that this might further limit the opportunities of some of the poorest people in the country.

3.3.1 The Prototypes. During the first year of the project, we developed a series of prototypes for use during UnBox Festival, an arts and technology event in Bangalore run by Quicksand, a Bangalore-based design studio. Each of these single function prototypes was designed to expose one of the many ways that a combination of sensors and algorithms could be used in relation to our bodies and identity. These included a camera (for facial recognition), a fingerprint reader, a pulse oximeter (for measuring heart rate) and a galvanic skin response sensor (for measuring skin conductivity, i.e. sweat). We will focus here on the camera and fingerprint reader, which were the most well-developed of the prototypes.

The facial recognition prototype (Figure 6) used a Raspberry Pi to take a photo and connect to the Face API from Microsoft's Azure Cognitive Services. This attempted to identify demographic details (e.g., age and gender) and facial expression, which were outputted using a thermal printer. These were housed together in a custom-built enclosure, which included a mirror for positioning oneself and a handheld capture button reminiscent of an old-fashioned camera. Alongside this, we provided a range of props including masks, fake moustaches and eyebrows so that attendees could attempt to manipulate their results. The intention here was to encourage participants to reverse-engineer how the algorithm was working. What facial characteristics were being used as proxies for age, for example, and could they be manipulated to yield a different result?

The fingerprint sensor (Figure 7) was housed with a small LCD display inside an off-the-shelf project box, powered by an Arduino. By placing a finger on the sensor and pressing the 'Enrol' button, participants could train the device to recognise a new fingerprint, which would be stored locally on the device and given a unique ID shown on the LCD display. When the same finger was placed on the sensor again, the same ID would be shown. As with the facial recognition prototype, we provided materials that participants could use to try and deceive the sensor and experiment with its limitations. In this case, materials included plasticine and latex, which could be used to create fake fingertips.

3.3.2 Reflections. The biometric prototypes partly responded to our previous use of newly available web-based facial recognition algorithms, which we had used uncritically and without engaging with some of the issues that these technologies created. For example, we had not taken into account issues around algorithmic bias

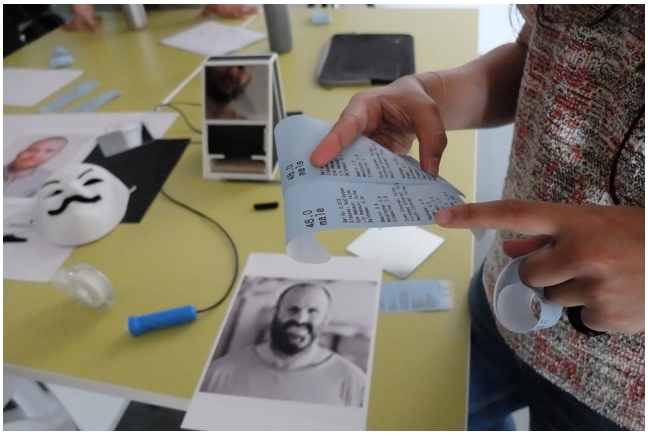

Figure 6: A participant compares two outputs, with the facial recognition prototypes and props in the background.

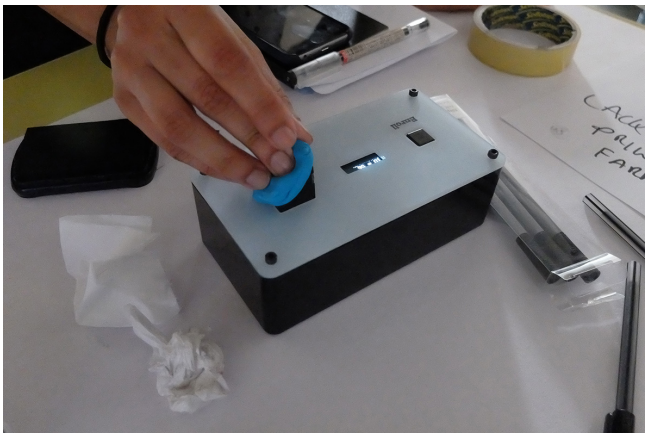

Figure 7: A participant attempts to manipulate the device using a plasticine 'finger'.

and race, or how images were being used by the service provider. To some extent, these biometric prototypes initially aimed to problematise the technologies associated with Aadhaar and bring these issues to the surface. However, we found that the workshop using the prototypes was instead characterised by curiosity and experimentation. While we think this was partly due to the nature of the festival and the structure of the workshop (e.g., providing playful props), the prototypes themselves also had a role in this.

As the Minions did for IoT in general, the prototypes deconstructed biometric technologies, separating them from the context of a government-run identification scheme. Instead, participants were able to treat each of the component technologies as actors in their own unexpected and nuanced stories. While we expected a backlash to this kind of technology, particularly in relation to vulnerable low-income communities, we saw instead more positive, hopeful futures emerging. For example, a social enterprise working with coffee growers from a protected tribal forest community envisaged how fingerprints could be used to provide stronger forms of authentication and marketplace protection for this vulnerable population. These outcomes were in fact much more closely aligned with the overall goals of the project than we had originally intended or expected from this piece of work.

This deconstruction also allowed for more exploration of how the technologies work. We do not typically have the opportunity to interrogate biometric technologies when we encounter them in day-to-day life, but the prototypes allowed participants to develop a greater understanding of both the capabilities and limitations of the technologies. For example, initial responses to the facial recognition prototype were often characterised by disbelief—either at how correct the output was, or how wildly inaccurate—followed by attempts to manipulate the results one way or another. At one point, part of this prototype's casing fell off (the open front can be seen in Figure 6), providing a glimpse "behind the curtain" and revealing that the contents of the device were unexceptional, with much of the "smartness" being housed on Microsoft's remote servers. While unintentional, it demonstrated the potential value of scrutability and transparency (perhaps literally) in such prototypes.

Finally, it also served to sensitise the research team to local issues in unexpected ways. One participant, a biologist researching human–elephant conflict, immediately asked whether the device was capable of recognising and identifying individual animals. He had a similar response to the heart rate prototype, describing the relationship between stress levels in humans and elephants. These perspectives are far outside the typical discussions that we have about biometrics, but in the rural areas where he worked interactions between humans and elephants were a regular occurrence and a matter of concern for humans and elephants alike. As well as providing another example of a more positive narrative, here the prototypes also played a key role in sensitising us to an issue that is far outside our own life experience and potential ways that issue might intersect with emerging technologies.

4 DISCUSSION

Research publications lend themselves towards telling a clear story, working towards some concluded endpoint through ideas, sketches, prototypes and insights in a clear and linear way. Yet in presenting a clear narrative we can miss the richness of those prototypes and participant interactions that added to the wider research story, but which did not serve as clear waypoints towards a final idea or research finding. By revisiting these projects, we have aimed to shine light on some of the prototypes in our own work around IoT, contributing to a wider discussion about the role of things and prototypes in design-led HCI research. Having reflected individually on these projects, we will conclude by discussing roles that emerged across all three. While these roles are by no means new or unique to our work, designing in the context of IoT has led them to manifest themselves in different ways that we believe are valuable in extending our understanding of prototyping, particularly as design research increasingly aims to tackle issues around these complicated technologies.

4.1 Deconstructing and Reconstructing Technology

One of the principal ways that prototyping helped us to interrogate IoT was by deconstructing complex technologies into smaller, more

understandable units. The prototypes that we built were never intended to address all of the many sociotechnical facets of the relationship between people and technology, but instead to focus on individual parts of a larger puzzle, including individual technologies or aspects of their usage. IoT presents a straightforward image to the user, but is actually constructed from much less clear combinations of sensors, materials, algorithms, cloud-based services and designed intentions (social, political and economic). A camera that is not connected to the internet is probably just a camera, while a camera connected to the internet is probably an automated surveillance device (which is well illustrated by Karen Hao's back-of-the-envelope explainer for AI [16]). We have found that communicating this complexity through working prototypes that serve no direct purpose other than to expose a single aspect of IoT was a powerful way to open a conversation.

Our use of these prototypes is most similar to Wensveen and Matthews [42]'s *research archetype*, aiming to embody a concept. However, whereas research archetypes often serve to complicate and problematise, taking the familiar and making it unfamiliar, designing for IoT required us to do the opposite. Prototypes like the Minions took the unfamiliar and attempted to *refamiliarise* it, deconstructing impenetrable or intimidating technologies and placing them in familiar contexts. It might be argued that there is no shortage of attempts to problematise IoT, which is a powerful and important role for design. But we see design's role in the IoT landscape as not just highlighting problems, but also creating opportunities to envisage more positive futures.

We saw this happening on multiple occasions across the projects we have covered, where individual deconstructed units became a building block for more complex conversations and which participants could use to build their own stories around. We saw this most clearly with the biometric prototypes, where the individual technologies of a problematic government programme were reconstructed into more positive visions that might empower rural citizens and even animals. In this case, the prototypes essentially familiarised participants with what, for example, facial recognition was capable of, freeing them to create new contexts and scenarios. Although these were not toolkits, we are reminded of Sanders and Stappers' [33] collections of components that allow non-designers to participate in the design process. The prototypes in our projects offered broad starting points not just for discussion or some specific task, but for imagination and storytelling. There is no shortage of stories being told about the future of IoT by researchers, designers, technologists, business analysts and science fiction authors, but designing for IoT with participants means allowing them to tell their own very different stories.

4.2 Brokering Relationships

Much of the work that we have described here would not have been possible without building close relationships with our participants and collaborators. These relationships are critical in all participatory research, but as IoT reaches into increasingly wide-ranging spaces, designers will need to understand these contexts. Across the three projects we have worked with participants and audiences with very different levels of experience, ranging from shopkeepers with no experience of IoT through to engineers and world-leading experts with deep knowledge of the subject. While the aims of the prototypes share a common ground in opening up discussions and providing hands-on experience, the way in which these discussions were opened needed to be different.

Early prototypes played a key role in brokering these relationships not just by demonstrating potential for technologies, but also by communicating something about ourselves and the way we work. The Provocative Voice prototypes, for example, bridged a divide between the designers and engineers unfamiliar with our way of working. The prototypes in our process are inherently shaped by the people who built them and imbued with our methods, interests, capabilities, aesthetics, sense of humour and most importantly our values—much more so than prototypes designed primarily to test technologies. We have found that we were able to communicate the intention and processes of our research in a stronger way than a visual presentation might otherwise do. This points to the power of a lived experience, even briefly, with an artefact that provides a much richer and deeper understanding of that idea.

Another role of prototypes in brokering relationships has been in drawing participants out of their comfort zones and enabling them to think about technology in different ways. We can see this across all the projects, with shopkeepers thinking about unfamiliar technologies, participants in India considering biometrics outside the context of Aadhaar, and engineers discussing voice assistants without a problem-solving mindset. Each of these enabled us to gain new insights into the participants, their views on and relationships with technology, and to understand how we might use other types of object at later stages of the project. In particular, we want to highlight here the value of playfulness and humour as powerful tools for creating common ground and a strong indicator of shared values. Sharing a joke, however small, is a connected moment between people and with the prototypes. This has acted as a leveller between the different stakeholders on a project.

In this sense, we see a role for prototypes that occurs much earlier in a co-design process than is typically acknowledged. Mirroring cultural probes and their role as "a kind of gift" [14] or as a way of sharing the designer's values [39], these prototypes were an initial tool for introducing ourselves, broaching a conversation with participants from quite different backgrounds to ourselves and opening opportunities for them to tell us about themselves. While this role of probes is long-established, we think that the power of prototypes in this role is underappreciated.

4.3 Changing Roles in a Changing World

As we have seen, prototypes and other 'things' play many roles across the design process, from the early, probe-like roles described above through to highly-resolved deployable research products [28] that eventually emerged from some of our projects. While these prototypes vary in terms of their fidelity, amount of technology, or the length of deployment, we would define *completeness* as the main way in which these prototypes change over the course of a project. Probes are intentionally incomplete and ask the participant to complete and return them, whereas research products are deployed as completed objects that participants then reflect and report on their experiences with. The prototypes that we have discussed in this

paper sit somewhere in between: they are not complete, but they are complete enough to tell their own story.

The rapidly changing nature of the IoT landscape itself introduces an additional factor to this role. These technologies have progressed dramatically even over the short time we have been working in this space, and so our prototyping practice has needed to evolve as well. While we could replicate the effects of early IoT products like BERG's Little Printer using simple off-the-shelf technology, as we did with the Minions, the emergence of more complicated forms of interaction, especially voice, meant we needed to explore new ways of representing IoT, exploring it in more oblique and less literal ways, as we did with the Provocative Voice prototypes. While Sanders and Stappers [33] talk about prototypes that "confront the world", when designing with IoT must confront a world that changes rapidly and look ahead to future worlds that might arrive even over the course of a project.

As the technologies and the ways we rendered these prototypes changed, so did their goals. While key roles like brokering relationships remained, other aspects of their role changed from introducing the concept of IoT, to exposing aspects of how devices work, to disentangling technologies that have become embedded in everyday life. The Minions served as simple explainers of the potential for IoT, opening up a discussion with local shopkeepers on what benefits they could see from an emerging technology that they had not experienced before and were not able to experience with off-the-shelf products (Amazon's Echo did not launch in the UK until 2016 and few IoT products had entered the public's awareness before that). We were therefore making prototypes to confront a world that, to the business owners, was unknown. This is a completely different world to the one we wanted to confront with the experts using the Provocative Voice prototypes several years later, where it would have been inappropriate to use prototypes to introduce and explain IoT. However, while these experts were accustomed to confronting the current technology realities of the voice enabled internet, they were not considering the social futures that will develop as the technology proliferates. The voice prototypes helped us to confront issues around consent and privacy that will increasingly emerge around these technologies. By the time of the Deconstructing Biometrics work, we were aiming instead to confront a world that had very much arrived and was making its way into the everyday workings of a country.

4.4 Contributing to Complex Problems

Finally, we want to return to the growing role of prototypes in exploring matters of concern and reflect on the roles our prototypes played in this. There can be a tendency, as exemplified in the Double Diamond model, to see some 'solution' as the end point and contribution of a design process. This is why when we look back from a concluded research object there is a pragmatic tendency to include only the prototypes that served as defined points in a clean narrative to that particular endpoint. However, there exist complex problems that are difficult to 'solve' or bring into a clean focus by normal means: problems embedded in complex systems with multiple feedback loops and long latencies [27]. IoT certainly falls within this category and the capacity of research through design to contribute to these complex problems is well-recognised [45].

Each of the projects here are driven by complex problems—the decline of high street retail, digital colonialism and the proliferation of inscrutable devices. With the prototypes we have discussed, we have sought ways in which we can expand the conversation or narrative around the problem, leading to more nuanced understandings. We would argue that while these prototypes do not present solutions—and do not attempt to—they instead attempt to expand the capacity of multiple stakeholders to work towards future solutions and make their own contribution to the complex issues at hand. We saw this across all of the projects in different ways—raising awareness of emerging technologies and trends, providing people with opportunities to create new stories around them, and new methods of advocating for different futures.

This is echoed by Oulasvirta and Hornbæk [30] who argue that "practical problem-solving capacity can be thought of in terms of how and how much better the problem can be solved by the relevant stakeholders". Particularly with the Provocative Voice prototypes, we can see the capacity of our partners being increased by new perspectives on voice assistants, leading to new forms of advocacy projects that they had not attempted previously. We can see the activities carried out around the prototypes as "design-games" [12] and the artifacts themselves as "boundary objects" [35], which work together to create space for discussion and speculation between participants and researchers. Within the particular context of our work, Wong and Mulligan [43] have recently surveyed the ability of design to inform or support users, explore people and situations and present critical alternatives, rather than just solve privacy issues. We can see aspects of each of these possibilities at play within the prototypes in this paper.

5 CLOSING REMARKS

This paper has revisited three Research through Design projects focused on IoT to examine the roles of prototypes that were omitted from the final research narratives. By doing this, we have aimed to contribute to the evolving understanding of RtD practice in HCI research and particularly how the challenges of IoT impact these roles. As our field deals with ever more complex emerging technologies, we must also continue to evolve the methods we have of supporting public understanding and engagement with these issues. Across these projects, prototyping helped us to bring people into a shared space of understanding and to engage more deeply with emerging technologies. Our aim here, and our call to the HCI community, is to support further critical reflection on things that do not become a step in the process or a solution to any problem, but which have still been critical in helping us reach it.

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