Examining Opaque Infrastructures with the Desktop Odometer

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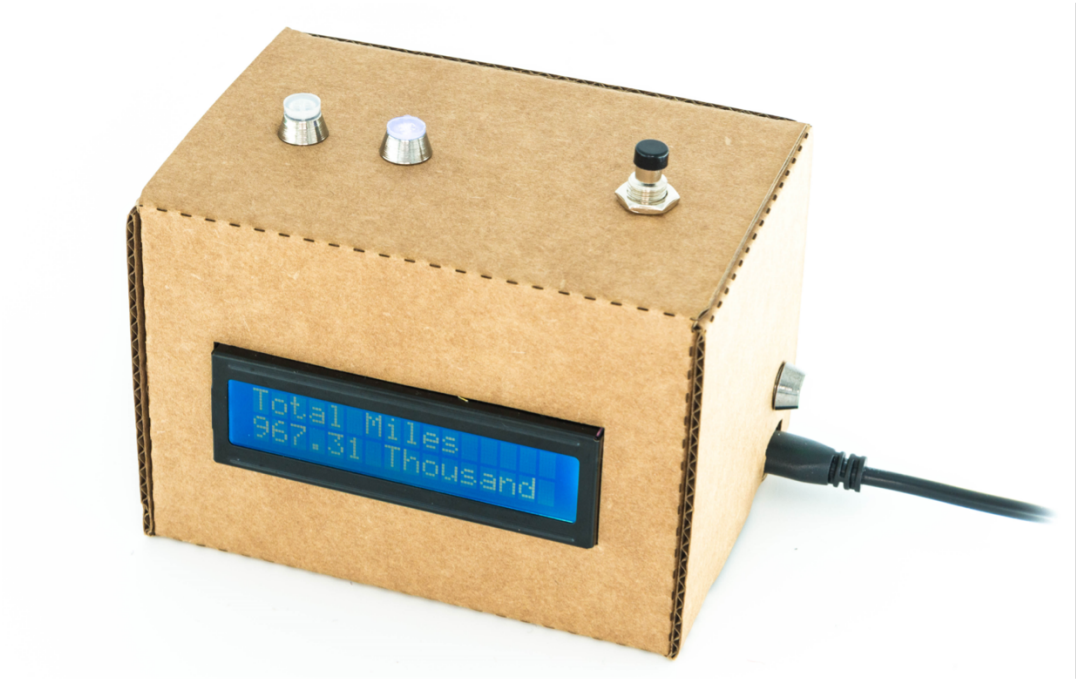

Figure 1: The Desktop Odometer Dimensions: 4"×2.5"×2.5"

ABSTRACT

The information we access on the Internet appears immediately but usually lives far away. The Desktop Odometer is a device that shows users the distance they travel when browsing the web by tracking the total miles between their current location and the server from which they are requesting information. In this work, we investigated internet infrastructures by designing and producing Desktop Odometers, selling them on Amazon.com, and receiving customer reviews. We present our analysis of customer reviews which reveal how customers describe their understandings of internet infrastructures after using the device. We also recount our RtD approach to making the device; we describe frictions we encountered when navigating other opaque infrastructures in our fabrication process, such as the Google Play store. Finally, we reflect on our use of Amazon.com and customer reviews as a method to engage participants in discussion about internet infrastructure through the sale and review process.

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CCS CONCEPTS

• **Human-centered computing** → Interaction design; Interaction design theory, concepts and paradigms.

KEYWORDS

Discursive design, Speculative design, Web, travel, Design Methods, Infrastructure, Opaque

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1 INTRODUCTION

When we started this work in autumn of 2018, the Alaskan Way Viaduct, one of the primary bridges connecting downtown Seattle, WA USA, to the greater metropolitan area was demolished. The replacement would not be finished for months. To avoid exacerbating the traffic congestion already present in the city, officials encouraged residents to work from home. Today, in a Covid-19 world, working or studying from home is fast becoming normalized, and many forgo traveling to the office and instead connect using Internet-enabled technologies like video chat and shared platforms. People use the web as means of transportation. The challenge, however, is that the web infrastructure is much more invisible than traditional transportation infrastructure like bridges and streets. This means that it is hard to know how it works, who maintains and pays for it, who profits from it, and how it impacts various communities.

In reality, the information we access on the Internet appears immediately but usually lives far away. A search for "holiday decorations" might take you from a server in Montana to India to Northeastern Canada. The Desktop Odometer (Figure 1) is a device that shows users the distance they travel when browsing the web by tracking the total miles between their current location and the server from which they are requesting information. Upon connecting the Desktop Odometer to their computer, users can see how far information travels while surfing the web in real time.

The Internet allows vast sums of information stored throughout the world to be retrieved almost instantaneously. The incredible speed at which the Internet operates obscures its own mechanics. Our goal was to create an artifact that would let people see part of those mechanics in real time [27]. The Desktop Odometer allows users to observe aspects of the Internet's elaborate and invisible infrastructure in relation to how they use it. In light of recent calls in HCI and beyond for a fairer and more open internet [25, 31, 38], we argue that HCI, design, and design research have a role to play in increasing public understanding of the infrastructure underpinning the internet. Though users might have an idea or an image for how the internet works, the effect of opening a direct window onto its inner workings is worth investigating. Design research may help prompt people to form a better understanding of the infrastructure they use every day.

Within HCI, the concept of infrastructure continues to build on Susan Leigh Star Since Star's seminal work [5, 13, 21, 27]. The word "infrastructure" refers to a system or group of systems that enable and control the operation of a society or enterprise. Infrastructures like sewers or fiber optics are often physically buried underground. By being infra- (or below), these structures are by definition rendered opaque and invisible to the majority of users [2, 8]. In Signal Traffic: Critical Studies of Media Infrastructures (The Geopolitics of Information), author Nicole Starosielski explains that opacity is not just a common characteristic of infrastructure, but rather an inherent feature, claiming, "Infrastructures are defined by their invisibility: most of us hardly notice them until they fail or breakdown. Public access to technical knowledge about infrastructures is not equal; rather it is guided and constrained by social hierarchies of gender, race/ethnicity, class, generation, and nation" [34]. For most individuals, the question is not if Internet-enabled technologies (e.g., tracking user data) will be integrated into their lives, but how they will be integrated.

The contribution of this work lies in the reporting of the design, fabrication, and sale of the Desktop Odometer as a discursive design artifact that investigates opaque infrastructures of the web by highlighting one facet of this infrastructure for the everyday internet user. We investigated internet infrastructures by: (1) Designing and batch producing 46 Desktop Odometers, and (2) selling the Desktop Odometer on Amazon.com and receiving Amazon.com reviews as a way to explore user participation. We report first on our Research through Design (RtD) approach to making the Desktop Odometer. Here we describe the fabrication process of creating a bespoke IoT product, our design decisions, and how these decisions influenced the way our product made visible certain facets of infrastructure. We also report on the frictions we encountered when navigating other opaque infrastructures in our fabrication process, such as the Google Play store, which consequently influences the landscape of IoT by serving as a gatekeeper for accessing games and software. Second, we report on our rationale for selling the Desktop Odometers on Amazon.com as a method to engage participants in discussion about internet infrastructure through the sale and review process. We present our analysis of customer reviews which reveals how customers wrote about their understandings of internet infrastructures.

2 THE INTERNET AS OPAQUE INFRASTRUCTURE

We begin this section with a brief description of how data is transmitted through the Internet. Building on literature on infrastructure, we then outline the processes by which the Internet has intentionally and unintentionally been made opaque to its users. We finish this section by presenting related works also aiming at making infrastructures visible.

2.1 Internet Innerworkings

Infrastructure refers to the material and organizational structures that both enable and control the operation of a society or enterprise. Infrastructure is deeply embedded in both material and immaterial facets of life [4, 16]. The Internet's elaborate infrastructure is distributed throughout the world; its materials, components, and systems include cell towers, satellites, antennae, fiber-optic networks, data centers, and more [19]. The Internet allows for information to be stored and retrieved instantaneously despite immense physical distances between these processes. The transmission of this information is facilitated by a robust network infrastructure. Contrary to popular depictions, the Internet is a heavily wired system. Even when using cellular networks, the transmission of information is primarily facilitated by fiber-optic cables. For example, when an individual searches the web using a cellular network, first, a server is notified of the request. Next, the server sends the information through a fiberoptic network until it reaches the cell tower nearest to the user. Afterwards, a cell tower transmits the information through the airwaves to the nearby user's cellular device, at which point the user can access the information they requested [9]. Satellites, antennae, cellular networks, and fiber-optic cables are all capable of transmitting data, but fiber-optic cables have become

Figure 2: The Desktop Odometer Photoshopped stock photo, Created for Promotional Purposes

the primary means of connecting users because they are capable of sending and receiving data far faster than satellites. As the demand for larger files (such as high-definition video and images) has increased, the use of technologies such as satellites and antennae has diminished.

2.2 Why is Internet Infrastructure Opaque? And Does it Matter?

Nicole Starosielski claims that one reason that Internet infrastructure is hidden from a majority of citizens is to ensure it remains secure from outside threats. In the U.S., Cold War era tensions and events such as the September 11th attacks have prompted governments to use secrecy as a strategy to defend network infrastructure [22, 34]. On the contrary, the most common disruptors of network infrastructure are not nefarious actors but rather fishermen who are unaware of cable routes and drop anchors on undersea fiber optic cables [34]. This example demonstrates how strategies of infrastructural obfuscation can result in disruption at the hands of unknowing actors. Ironically in some circumstances this strategy has also allowed for deterioration. Starosielski writes, "If cables remain invisible to policymakers, government regulators, corporate customers, business managers, and politicians, then critical decisions about infrastructure funding – which could make our networks more robust and accessible – will continue to be uninformed" [34]. Here Starosielski encourages us to consider whether making the internet's infrastructure more legible to everyday stakeholders may help lay the groundwork for building more public participation in these processes.

In certain cases, private corporations have taken advantage of the Internet's opaque infrastructure. In one example from 2008, Verizon had entered into an agreement to build a fiber-optic network intended to serve all of New York City's inhabitants. Reporting on the roll-out, author and investigative journalist Ingrid Burrington writes, "Verizon concentrated primarily on integrating fiber networks in new developments and already wealthy or gentrifying neighborhoods, bypassing, and at times outright refusing, to provide service to other neighborhoods or buildings with no reason given" [6]. Her reporting highlights an indirect relationship between transparency and equity: since fiber optic cables are buried underground, it was easy for Verizon to cover up the unequal application of a taxpayer-funded program without public outcry. There are certainly many other factors to consider, but perhaps increasing the visibility of these processes might serve as one step towards a more democratic process of conceptualizing and integrating network infrastructure.

2.3 Ways Opaque Infrastructures Are Made Visible

As we have discussed above, visualizing infrastructure may help to create a baseline understanding of the way it relates to a person's individual and community life. Visualizing infrastructure has become a common way for corporations, data analysts, designers, and artists to show an infrastructure's inner workings. For example, TeleGeography, a marketing research firm, created an interactive map of underwater cables that connect the global Internet (Figure 5). While this map does present cable routes throughout the world, it also portrays these routes as highly organized. Maps like TeleGeography's cast an overly simplistic depiction of cable routes. Twitter has created an interactive map that illustrates which smartphones are used in different parts of the world. In 2003, the artist Barrett Lyon created the Opte Project (Figure 3), a visual depiction of the Internet. In this work, lines representing communication between

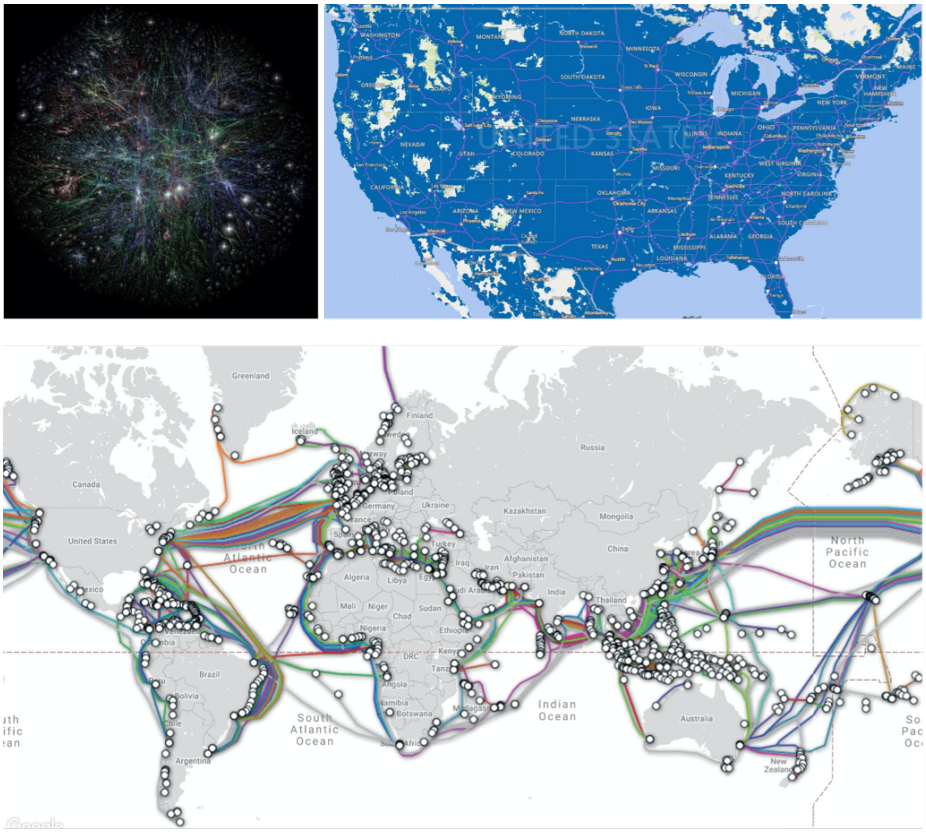

Figure 3-5: Top left: Map of communication between IP addresses. Lyon (ca. 2003) The Opte Project (https://goo.gl/VLCRBB). Top right: Submarine Cable Map. www.Submarinecablemap.com. PriMetrica, Inc., 2020. Bottom: AT&T 4G LTE Coverage Map (surecall.com/att-coverage-map)

IP addresses form complex networks. Lyon's work offers abstract representations of Internet communication signals.

Other maps intended to illustrate Internet infrastructure are coverage maps produced by large telecommunication companies (Figure 4). These graphics are used as a marketing tool intended to indicate the firm's robust network coverage. These maps present networks as a frictionless mesh enveloping entire countries almost as if unaffected by their particular geographies. However, these maps fail to depict the immense variations in coverage within specific locations. They also leave out the fragility of networks, as well as the vast amounts of labor necessary to maintain these networks.

In her book, Networks of New York, Ingrid Burrington reveals network infrastructure buried beneath city streets and subways in New York. Burrington assembles a list of visible above-ground indicators which can be used to identify the fiber-optic cables. Her list includes spray-painted street markings, inscriptions on manhole covers and color-coded marking on the walls of underground subway platforms. These markings enable Burrington to identify information about fiber-optic cables: the year they were created, their owners, the type of information they transmit, and the depth at which the cables are buried. Burrington's work successfully makes visible certain facets of New York's network infrastructure by decoding its secret language. In addition, her work highlights the hyperlocal nature of this infrastructure, and thus presents opportunities for establishing more accurate depictions of the web.

Within HCI, Gatehouse and Chatting [17] have shared their RtD process of creating Captive Portals (personal Wifi networks) or changing the wallpaper on a Kindle. In their paper, Gatehouse and Chatting report on the difficulties of working with the hidden infrastructures of Wifi and web-based services, showcasing how an RtD process might bump against larger opaque infrastructures, making them visible at those points of friction. Finally, we highlight the work of Wong et al. [37] who argue for creating speculative design that purposefully engages with the complex and long term lifeworlds technologies live in, in other words, the infrastructures they live in, to foreground social and political implications.

Our work continues to build on this large corpus of work aiming at making infrastructure visible. In the Desktop Odometer, we created an artifact that opens a window into a usually unseen infrastructure at the point of contact with its user—exactly at the moment of browsing the web. In this sense, our work offers a new angle to render this infrastructure interactable through in-the-moment, bespoke visualizations.

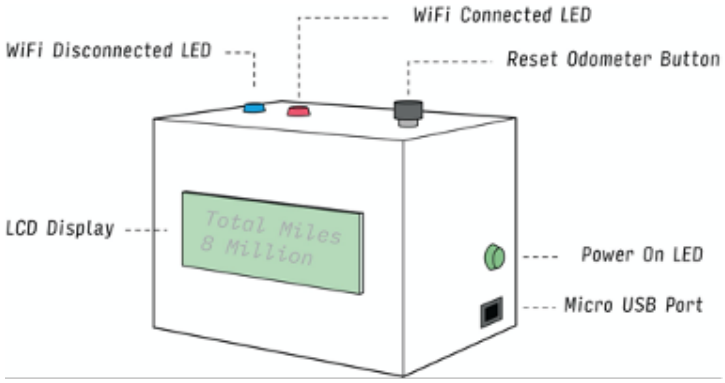

Figure 6: Desktop Odometer diagram

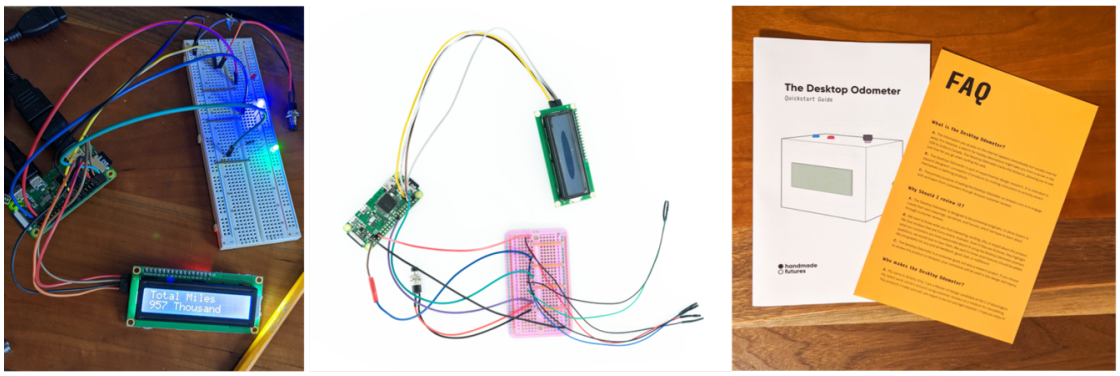

Figure 7-9: Left: Low-fidelity prototyping. Center: Desktop Odometer during assembly. Right: Quick-start Guide and FAQ pamphlet

3 MAKING THE DESKTOP ODOMETER

We took an RtD approach to making the desktop odometer. In section 3, we describe our process of conceptualizing, prototyping, and batch producing the desktop odometer. In total, between October 2019 and May 2020, we produced 46 desktop odometers. In this section we describe how we built the Desktop Odometer, including instructional materials (Quick-Start Guide and FAQ pamphlet). The entire production process took 12 weeks and we fabricated 46 Desktop Odometers in total. The Desktop Odometer displays a mileage counter on a 24 x 2 character LCD display. The housing is constructed from cardboard. Embedded in the cardboard housing are three LEDs which indicate the device's connectivity status (Figure 6).

3.1 Low Fidelity Prototyping

The making process began with Lo-Fi prototyping (Figure 9); this included selecting, assembling, and testing hardware. When assembling the prototype, we used solderless components to save time and money. Once all components were connected, we began executing simple functions, i.e., sending data from the device's microcontroller in order to operate other components such as the Serial Display and LEDs.

3.2 Software Development

We worked with a professional coder in order to develop the necessary software. Software development began by creating a way to track the distance between a user and the servers they ping while surfing the web. To do this, we created a downloadable web browser extension. The browser extension identifies an IP address associated with a given website, then runs that IP address through a website which identifies the zip code associated with the IP address. The program calculates the distance between the user's and the server's zip codes. Once this operation is complete, the browser extension sends this information to the Desktop Odometer.

A challenge in creating the Desktop Odometer lay in establishing device connectivity. For the Desktop Odometer to retrieve and display information calculated in the browser extension, the Raspberry Pi inside the device must connect to the user's WiFi. To simplify the process of connecting the Desktop Odometer to WiFi, we built a startup protocol that allows users to connect their Desktop Odometer to their home Internet through the Graphic User Interface (GUI) in the browser extension described above.

3.3 High Fidelity Prototyping

Once the initial prototype worked consistently, we began planning for batch production. We sourced parts from Alibaba, Amazon, and

Microcenter to produce up to 65 Desktop Odometers (we produced 46 in total). The fabrication process involved copying the Desktop Odometer operating system to SD cards before inserting them into the Raspberry Pis. Next, we soldered the LCD display, the three LEDs, and reset button to a circuit board, then soldered that circuit board to the Raspberry Pi (Figure 8). For quality control, we powered on each device and went through the startup protocol to make sure every device functioned.

Next, we built the outer shells of the devices. The Desktop Odometer's housing is cut from sheet cardboard using a laser cutter. First, we placed the LCD display into the housing using hot glue to secure it. We then placed the Raspberry Pi into the box, followed by the circuit board. We put the LEDs into their positions and put the reset button in place secured by a hex bolt, then closed the lid on the cardboard enclosure.

3.4 Instructional Materials

We designed two instructional guides: a Quick-Start Guide and a FAQ pamphlet (Figure 9) to inform users about how to operate the Desktop Odometer and to outline our research goals. The Quick-Start Guide walks the user through the 14 steps in our setup process. For first-time users, this process takes around 15 minutes to complete. Most IoT devices made by large firms such as Google or Amazon can leverage highly developed network infrastructures to speed up the setup process. In contrast, the Desktop Odometer requires a bit more patience. The aim of our Quick-Start Guide is to streamline this process as much as possible. The FAQ was developed to serve two purposes: to explain that the Desktop Odometer is a product as well as a research tool, and to explain to the user how we plan to use customer reviews within our research. It was essential that buyers understood that any reviews they posted might be used for our research.

4 REFLECTIONS ON MAKING THE DESKTOP ODOMETER

In this section we report on obstacles we encountered and lessons we learned during the process of building the Desktop Odometer and its user interface. When we started this work, we anticipated that most of our findings would emerge from the customer reviews and reflect on the user's experience of seeing the physical distances traveled in their internet activity. However, the RtD process revealed unexpected barriers to entry within the platform infrastructure upon which connected devices rely, even before the object could reach users. We have included a discussion of these challenges to illustrate areas of opacity within cyberspace, in addition to opacity at the level of material infrastructure. We analyzed the RtD process by reviewing sketches, diagrams, and prototypes, as well as meeting notes, email exchanges, and photographs.

4.1 Design Decisions to Unveil the Opacity of the Internet

In making the Desktop Odometer, we navigated a series of design decisions towards finding a concept that would be evocative, easy to grasp, and would bring light to aspects of hidden Internet infrastructure. While we could have chosen to focus on energy consumed, scale of data archived, variability in speed, we chose to focus on the distance information travels while browsing the web. Our goal was to make the distance information travels more visible to users—the long distances traveled while surfing the web could be expressed in an understandable unit (miles, in our case), while also at a scale that pushes the imagination. Rather than using a map to illustrate the movement of information, we wanted to encourage curiosity and space for interpretation. As seen in our customer reviews (Section 5), displaying the distance on the LCD screen prompted users to consider the material infrastructure used to send information, the energy required to store and send information, the pathways information travels, and the ability of internet infrastructure to handle the requests of multiple users.

Our decision to work with spatial distance but not use routes or maps is also the result of our team learning more about internet infrastructure throughout the making process. Before starting this project, we knew far less about cable routes, and thus had a difficult time imagining other ways of making this facet of the web more visible. The simplicity of the device served as a first step for us as researchers to begin thinking more deeply about internet infrastructure and imagining new possibilities to understand the web. In this sense, the RtD process was in itself a learning process towards understanding how the web works, and how to eventually represent it.

4.2 Google Play: Barriers to Entry for Atypical IoT

During the process of creating the Desktop Odometer, we encountered logistical difficulties which revealed opacity at multiple levels of internet infrastructure – that is, not only at the level of physical infrastructure, but opacity "within" the immaterial internet. We found such challenges interesting for the purpose of this research, as they added dimensionality to our understanding of the complexity and multiple 'planes' of web infrastructure. One of our difficulties lay in the attempt to publish the browser extension which is necessary to use the Desktop Odometer. In the initial design for the Desktop Odometer, we planned to make the browser extension available for free on the Google Play store. However, the extension was repeatedly rejected by Google Admins, who cited a variety of issues. These issues included concerns about our use of non-proprietary software, a lack of a privacy policy, and the non-patented status of the device. To comply with these policies, we drafted a privacy policy and rewrote the browser extension code to protect users' private information using modern data encryption techniques. Despite these edits and 12 attempts to seek help from a Google admin, the extension was never published. In each attempt to reach a solution, we were sent a boiler-plate email listing the issues we had already addressed. As a workaround solution, we offered our browser extension to customers on the first author's personal website, which required additional steps for users to go through to install the device. We also wrote a detailed Quick-Start Guide to assist customers in setting up the device and browser extension. This solution required extra communication with our customers and may have made it more difficult for novice users to understand and even find our product. The Desktop Odometer was made less visible to consumers due to its absence from a prominent

software marketplace, even if it was available on Amazon.com for retail. We also acknowledge that these additional steps may have resulted in fewer total reviews due to the added difficulty in the installation process, even if a user purchased the device intending to use it and leave a review. This may be part of the reason that only 21 of our 46 participants reviewed the device.

Of course, Google has these policies in place to protect their users from potentially malicious IoT devices, and that impeding small IoT makers through these policies is likely an unintended consequence. However, we suspect that these policies may still effectively block independent IoT makers from offering their devices on Google's platform, because the approval process is opaque and Google offers little assistance to device makers attempting to comply with its policies. We were reminded of Sarah Ahmed's metaphor of a well-worn path in Living a Feminist Life, which she uses to explain how established models create barriers to non-normative ideas while strengthening the hold of the status quo. She writes, "When it is harder to proceed, when a path is harder to follow, you might be discouraged; you might try and find another route. A consciousness of the need to make more of an effort can be a disincentive. Just think of how we can be dissuaded by perpetual reminders of how hard something would be" [1]. Through control of a dominant marketplace and lack of independent seller support, Google passively maintains a particular path which may favor a narrow institutional model of smart devices, or at least heavily favor IoT makers with the resources to litigate such challenges.

5 DISSEMINATION THROUGH AMAZON MARKETPLACE

While the process of making the Desktop Odometer was important in building our understanding of the internet's vast infrastructure, as discussed above, one of our goals with this project was to engage others in these reflections as well. In this work, we aim to encourage users to think about how the internet works, in particular, to consider the distance traveled by information as people surf the web. Through a speculative artifact, we hoped to create a space for discourse with people. Methodologically, our work builds on the discursive traditions of Discursive Design, Speculative Design, Design Fiction, Experiential Scenarios, Speculative Enactments and Material Speculations.

Discursive Design refers to the production of artifacts whose foremost objective is to create discussion and reflection [35]. While design is often used to generate products addressing user needs, it may also serve as a tool for inquiry—expressing ideas and theory, exploring alternatives, and creating discourse. Like discursive design, Speculative Design can be used to provoke future-oriented thinking for future planning, but is often used as a critical approach, calling attention to current or potential issues. Speculative inquiries are often focused on investigating the integration of emerging technologies in everyday life. Speculative Design has often been presented in the context of gallery spaces (for example the work of Fiona Raby and Anthony Dunne [10, 11]) or as short films (as in Design Fiction works [3]). With a strong presence of authorial voices, the role of the viewer is at times passive – on the outside looking in.

Since the introduction of practices such as Design Fiction and Speculative Design, designers and researchers have aimed at shifting their positions of power by broadening participation, often through embodied ways of knowing and material approaches [29]. Designers and researchers have developed and refined a variety of approaches to engaging people more viscerally in 'futures' conversations. Candy and Dunagan [7] claim, "we must bridge the 'experiential gulf' between inherently abstract notions of possible futures, and life as it is apprehended, felt, embedded and embodied in the present and on the ground" [7]. In line with this call, methods such as Experiential Scenarios [7] or Speculative Enactments [14] create scenarios in which people actively take part. For example, Eldsen et al. developed an event called Metadating, which was essentially a speed dating event in which personal data was the focus. Describing the event, the authors wrote, "Rather than making a dating website, or constructing a Design Fiction on the basis of our speculation, we chose to run a speed dating event. Crucially, this put live social interaction with data at the heart of our study, along with consequential experience" [14]. Another approach used to help ground speculation for participants is Material Speculation [36] where design artifacts, representing an alternative world, are placed within a specific everyday experience in order to actually engage with it [36]. One example of Material Speculation is James Pierce's Camera Obscura 1C, a camera that allows users to take as many digital photos as they want, but to access and look at the photos, one has to break the camera to retrieve the SD card. Pierce distributed the Camera Obscura 1C via Craigslist, local retail partnerships, community bulletin boards, as well as guerilla tactics such as "droplifting" (leaving a product in a retail store) [18, 24, 32].

Our work builds on this trajectory in recent discursive and speculative design: we aim to create an artifact (the Desktop Odometer) that is functional and physical for people to experience (similar to material speculation). We also aim to open up new places for speculation to be experienced in the everyday: in a space that is at the same time private (often at home), and public (via Amazon customer reviews). In the following section, we describe our methodological approach in selling and studying the Desktop Odometer.

5.1 Methodological approach

5.1.1 Selling the Desktop Odometer on Amazon.com. This research was conducted in the U.S., and this was a major factor in choosing a deployment strategy, as we were limited from the start to using marketplaces available the U.S. While there were many to choose from, we knew that the scope of this research would be limited to the customer base of whichever platform we chose. We prioritized familiarity to an American consumer base, which led us towards Amazon, rather than other less familiar companies such as AliBaba, Wish, etc., even though some of these may have had a larger global distribution. Ultimately, we chose to use Amazon to generate user feedback because of its large size and its familiarity within the U.S. marketplace. Though we could have instead chosen to list our product on a marketplace geared towards smaller artisanal goods like Etsy, Craigslist, or even a personal website, we chose Amazon for a number of reasons: (1) it is one of the largest online marketplaces in the world and it has become a prominent platform to buy technology products, such as IoT or personal computing; (2) Amazon helped shape the Desktop Odometer's identity as a product; selling it on Amazon.com, rather than on a personal website, encouraged users to think of the Desktop Odometer as a real product, rather than a design project or speculative concept;

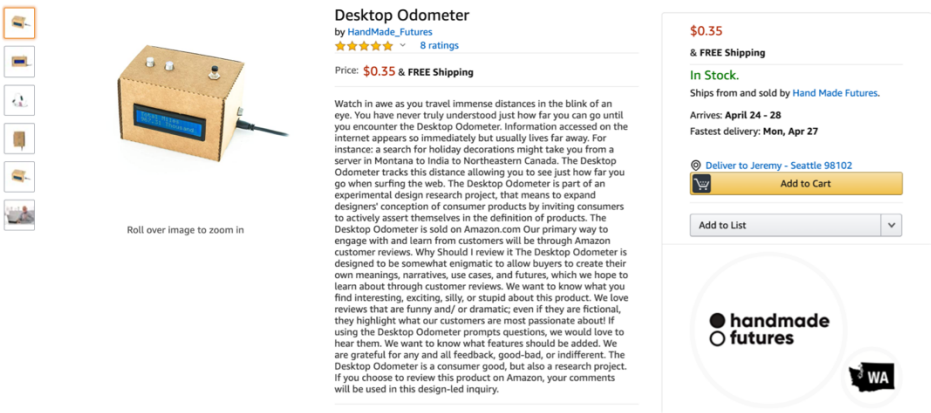

Figure 10: Desktop Odometer, product listing page on Amazon.com

(3) we wanted to inject design research and discussion about the research into a setting where it could be seen by many – not just the HCI community; (4) we saw a delightful irony in using Amazon as a place to sell something that was intended as a research artifact: creating a tension between the values of knowledge production and those of capitalism.

The Desktop Odometer was available for purchase from January 2019 to June 2020 for $0.35 (USD) (Figure 10). This price was selected somewhat arbitrarily and did not cover production costs but was intended to allow almost anyone curious about the Desktop Odometer to purchase it. On the product listing page, we included a description of the Desktop Odometer, of the first author (as the maker of the Desktop Odometer), and our research goals. Sales were generated both organically and through our own personal networks; many people learned about the Desktop Odometer through word of mouth and social media platforms like Instagram and Facebook.

5.1.2 Customer Reviews. Amazon.com also carried the benefit of its status as a platform where people are accustomed to reflecting upon and critiquing artifacts. Customer reviews are a genre of communication that is social, meant to be seen by others, and reactive [9, 28, 39]. It is common for reviewers to use established formats to communicate ideas, such as images of the product in use, unboxing videos, product comparisons, and more. This form of product feedback is thus a useful way to generate discourse around a particular object. While product reviews can be humorous, hyperbolic, or plain incendiary, they are useful communication tools users employ to articulate their experience with a device. Similarly to how Love/Hate letters [24] (a common method in design) rely on the use of emotion and well known modes of expression, we see customer reviews as holding potential to reveal how people experience objects or devices. As a work of Discursive Design, the primary goal of the Desktop Odometer is to prompt discussion and reflection in order to bring awareness about how web infrastructure works. Through the positioning of the Desktop Odometer on the Amazon Marketplace, Amazon becomes the vehicle and customer reviews become the means to create discourse. Initially, we hypothesized that the customer review forum on Amazon could be used to inject design research and discussion about that research into a more public sphere. However, this hypothesis proved problematic, as Amazon Customer Reviews are highly controlled and regulated. We discuss these events, as well as ethical considerations and questions in more detail in the discussion section.

5.1.3 Participants. Desktop Odometers were sold to 46 participants residing in 18 different American states and two countries (U.S., U.K.), over a period of 8 months (Figure 12). As mentioned in section 5.1.1, our choice to use Amazon (a U.S.-based company) meant that our reach was limited mostly to a U.S. audience, and indeed almost all of our participants were located in the U.S. The age of participants ranged from 19 to 68 years old. We reached out to 10 of the 46 participants personally to see if they would be interested in buying the device; 14 of the participants contacted us after seeing information about the device which we had posted to either Facebook, Instagram or Reddit; and 13 of participants purchased their Desktop Odometer after learning about the device from someone other than the first author of this paper. The remaining 10 people who purchased the device found it while shopping on Amazon (Figure 11). Of the 46 participants, 21 left a review of their Desktop Odometer. No reviews came from organic sales. In this project, the only data we collected about participants were their customer reviews. We did not have a way to track behavior change, other than self-reports through customer reviews. Here we are very interested in the discourse that might happen around discovering hidden infrastructure, which is why we rely on self-reporting. In addition to written reviews, some customers posted pictures and videos of the device in their home, one customer even created an unboxing video.

5.1.4 Data / Analysis. We collected the 21 reviews left by customers. We did not collect information other than the reviews themselves, so it is not possible to know how long the device was used, how it changed or did not change behavior, or who the buyers were, except if the reviewers left those details in their reviews. We chose only to focus on the reviews themselves, because we were curious to see what could be learned from this genre of public discourse online. We used open coding to categorize customer reviews into distinct themes related to opaque infrastructures. Once we

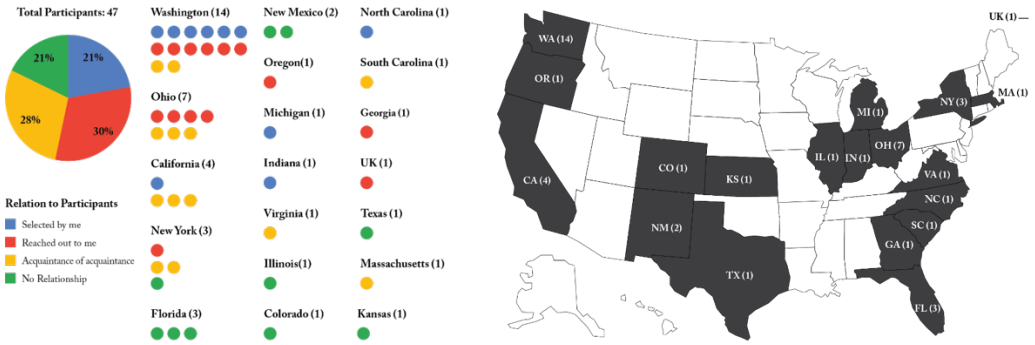

Figure 11-12: Left: Data visualizations depicting the authors relationship to customers. Right: Map showing the state in which the customers reside.

had grouped customer reviews into common themes, we expanded upon and revised these themes [30].

5.2 Learning from the customer reviews of the Desktop Odometer

The customer reviews were rich, at times hyperbolic and humorous, and very often touched on how the Desktop Odometer changed their perception of the web infrastructure. Below we offer a qualitative analysis in which we explore themes expressed through customer reviews. The participants' names have been changed and we have chosen to refer to all in the gender neutral (they/them) in order to ensure anonymity and respect participants' privacy.

5.2.1 Considering Material Implications. Starosielski writes, "A focus on infrastructure brings to relief the unique materialities of media distribution – the resources, technologies, labor." [34]. A quotation from American designer and artist Maya Lin reads simply, "What we don't see, we pollute." [15]. In these quotations, both Starosielski and Lin center transparency as a necessary condition from which to begin to understand the resources upon which one depends. The desire to more deeply engage with these systems was expressed by Tyler, a customer who was amazed at how far information online must travel. Tyler described their experience using the device, writing, "whaaat this is amazing! It's a very new idea and helpful in an age where we often take information and the Internet for granted. It was eye-opening for me to see which links or pages would cause a huge distance to be added to my total miles." Tyler's review demonstrates how the Desktop Odometer added a spatial dimension to their web browsing, allowing Tyler to consider the distance between different websites and compare the relative distances to their own desktop. For Tyler, thinking spatially helped them to appreciate the internet's infrastructure instead of "taking [it] for granted," and generated new excitement for an otherwise everyday activity. For Tyler and others, the Desktop Odometer's mileage count offered a novel way of experiencing the internet rather than just a series of interchangeable displays on a stationary screen.

Reflecting on the shift to working from home in response to COVID-19, Alex described how using the device made using the internet a more dynamic activity. Alex wrote, "The Desktop Odometer makes the immateriality of the Internet real and brings a small but meaningful feeling of movement back into my life. While I am not walking past the park to my now indefinitely closed office building, I am logging onto my email, thousands of miles away. I move from website to website, traveling at breakneck speeds." Thinking about the device in the context of their own life led Alex to formulate a more dynamic understanding of the web as a proxy for their own body. While during COVID-19 shutdowns, Alex was unable to move very far physically, the internet allowed them to communicate with people "thousands of miles away" and move "at breakneck speeds" between websites. Alex's experience likely resonates with many others in the spring of 2020, finding themselves suddenly stuck in their immediate surroundings, unable to move around as usual. For Alex, the Desktop Odometer's approximation of mobility brought comfort.

Drawing the participants' attention to the immense distance information travels, the Desktop Odometer motivated some to consider the Internet's energy use and its contributions to climate change. One customer, Taylor, wrote "I'm merely sitting, or standing at my desk, yet my actions are reaching great distances. Action at a distance; I feel so powerful. My Desktop Odometer made me feel quite accomplished at first, until I read an article in the New Republic, I learned that the Internet "is the largest coal-fired machine on the entire planet, accounting for 10 percent of global electricity demand." Whoa. Okay, time to unplug my devices and read a book." For Taylor, the Desktop Odometer's mileage counter at first elicited a sense of awe at just how far a click can take a user, making them feel "powerful". This first reaction was countered upon researching the huge carbon footprint behind the global internet, prompting Taylor to consider reducing their time on the internet.

Realizations about the material cost and sustainable challenges of the internet proved compelling enough that they pushed customers to enter in dialogue or even debate. In one exchange, Eliot wrote, "Now that I have the Desktop Odometer I don't feel the need to travel via airplanes as much. It feels great to know I am going so far without burning fossil fuels and destroying the environment. #GoGreen." Another customer, Connie, responded, "you still are burning fossil fuels etc. because all that Internet cloud stuff is actually happening here on earth in city sized servers all over the planet that are using tons of energy (fossil fuels etc.) and helping

with global warming and destroying the environment..." Eliot and Connie's exchange shows how the structure of an online comment forum can facilitate debates. While Eliot's account of the Desktop Odometer highlighted the immaterial facets of the web—how information can "travel" around the world without humans having to move great distances and expend resources— Connie's comment reminded Eliot of the material infrastructure powering their web travels, all of which relies on fossil fuels just like airplanes.

As illustrated by the examples above, many customers were able to engage with the hidden infrastructure of the web through considering the material implications of their web travels. For some, this meant grappling with the fact that the internet uses an enormous amount of energy, mostly by burning fossil fuels. For others, the Desktop Odometer generated new excitement about web browsing by showing the physical distance that a web search may travel, and for others, the mileage counter served as a proxy for physical travel, providing a sense of normalcy during the COVID-19 pandemic.

5.2.2 Purposeful Attention to the Web. In their reviews, many customers described how using the device led them to focus their attention on facets of the web that often go ignored. This lends support to Starosielski's argument that, "Capitalist societies generally educate people to appreciate the "conveniences" and "choices" of modern consumer technologies, but to remain blind to the infrastructures that support them. As a result, infrastructural changes often occur quickly and without notice, short-circuiting citizens-users' ability to participate in systems development." [34]. Sam's review hinted at this idea: "The Odometer is an interesting thought experiment, one that recenters your focus from the content that you consume every day to the backend mechanisms that make your browsing experiences possible." Sam's review highlights how the Desktop Odometer was a useful product for thinking about the Internet's inner workings and relating knowledge of that infrastructure back to the everyday experience of surfing the web. Using the Desktop Odometer, Sam was prompted to think more deeply and critically of the web, beyond the "choices" and "conveniences" that obscure its infrastructure.

Similarly, the Desktop Odometer helped some participants understand abstract concepts such as data within the context of their own life. Jordan wrote, "this little object from the future makes tangible, what was previously invisible and unknown to me. The odometer is a daily, delightful reminder to me that data really might be the most valuable resource of our time, and it need not feel like an episode of Black Mirror." Jordan's review describes how using the device led them to think about the value of user data—not in the context of a dystopian future—but situated within the world in which they currently live. By recontextualizing information which at times may seem sci-fi or futuristic, users may begin to see how information is already embedded within everyday life. This may be important for building better understandings of internet infrastructures.

5.2.3 Conceptualizing Web Traffic. Using the device left some customers with a more accurate picture of how information travels. For example, participant Jen wrote, "Often I tend to think of the "Internet world" as existing on almost a different plane than the "real world". This product showed me, in a way, the physicality of the Internet, and that things don't actually just magically appear on my screen." In their review, Jen provided a sketch of a map depicting their understanding of how information moves throughout the web, before and after using the device (Figure 13). Jen's drawing illustrates how using the device led to a more accurate conception of how information travels.

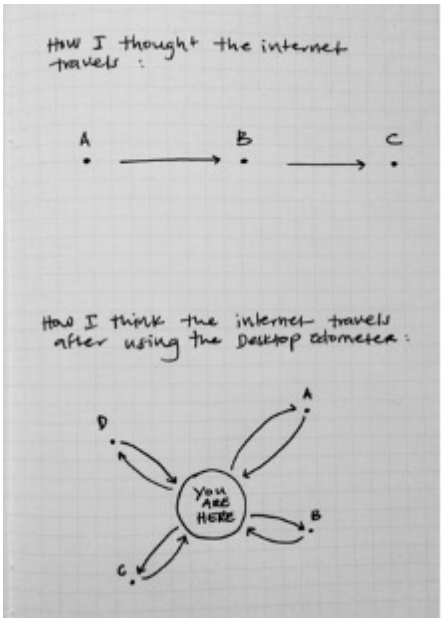

Figure 13: Image posted by customer, Jen

In addition to enabling new understandings of opaque infrastructures, the Desktop Odometer prompted users to ask a variety of interesting questions. Frankie wrote, "I am curious if bigger tubes translate to faster Internet? When the Internet is slow or tubes are overworked what does that look like? How does the system decide which request has priority when there is a lot of traffic?" Frankie's question demonstrates how the device became an experiential gateway to thinking about how web traffic is controlled, and how the system might prioritize certain traffic over others. Questions like Frankie's may be important first steps for starting to consider agency and control regarding access to information.

6 DISCUSSION

In this paper, we have presented the Desktop Odometer, a product created to investigate the everyday user's relationship to and understanding of the internet's infrastructures. We see this project as a modest step toward making these infrastructures transparent for a wider set of everyday internet users outside of the small circle of experts in the field or technology researchers. Below, we discuss approaches to addressing opaque infrastructures through design and HCI in the future, and we critically reflect on Amazon as a site to position research artifacts and hold discussion about those artifacts.

6.1 On Bringing Attention to Opaque Infrastructures

The Desktop Odometer brings to light the distances traveled when surfing the web. As we showed in our findings, this seemingly simple act of displaying these distances in real time has the potential for opening up everything from curiosity to deep reflections about the web and its impact on the planet Earth. Of course, viewing the distance traveled over the course of a web search can only give us a tiny glimpse into the complex and interconnected processes that make up 'the Internet'. We see a fertile ground for further Discursive Design work to continue to create openings to reflect on the web. As we discussed in section 4.1, our experiences in researching and building the Desktop Odometer led us to consider different ways we could visualize web-based infrastructure. For example, what if we designed a device that not only showed distance in terms of a numerical sum, but also traced the trajectory on a map, showing the routes (the most used, and potentially less commonly used) information travels through? What kind of reaction would that generate for people? What if, instead of showing where information travels, we put more emphasis on where data are stored? Could we virtually visit data centers or the spaces around them? Another particularly opaque side of the web is the invisible human labor powering it. Is it possible to create an artifact or an experience to encounter the workers who are training machine learning algorithms that run the web [20]? There are almost infinite aspects of the web that could serve as starting points for discourse around the ubiquity and opacity of the web. By prompting people to think more deeply about internet infrastructures and processes and their relationship to one's everyday life, we have hypothesized that people may develop a better understanding of those infrastructures. However, the question remains, can these design artifacts prompt anything beyond a passive awareness? And, as designers choose what parts of the web to make visible, what are they leaving unconsidered? How should one choose where to 'start' revealing the infrastructures of the web? Since these types of speculations are meant to be public, what are the implications of choosing certain dimensions over others? We reflect more on the method itself below in 6.2, but first turn to the ways in which our inquiry tangled with multiple levels of infrastructure.

In addition to opening a space for more discursive artifacts to reveal and render interactable the opaque infrastructures of the web, we see in this work a starting point from which to chip away at the hidden infrastructures of major platforms within the internet. We saw first-hand how impenetrability is interwoven throughout many aspects of the web: for instance, in trying to publish a browser extension, which we discuss in Section 4.2. This work has also shown that opacity is not siloed within any one level of infrastructure, but that in fact, transparency is even more compromised when standing at the intersection of multiple infrastructures.

6.2 Positioning Research on Amazon: A Critical Reflection on Our Methodological Approach

We sold our product on Amazon to encourage public discussion about the Desktop Odometer. By choosing an online marketplace visible to a broad customer base and embedded in American consumer culture, we open a space with a particularly low barrier to entry, inviting many to engage with the work. That we sold 46 Desktop Odometers and received 21 reviews demonstrates that even with a small batch, we were able to get people to engage with our research through the Amazon marketplace. This responds to recent calls in Critical Design and Futures Studies to become more participatory and more embedded within everyday life. Placing the Desktop Odometer on Amazon.com went one step beyond the classic fake advertisement or catalogues often used in Design Fiction [3, 10, 12, 23, 26], which allowed people to physically engage with the odometer in their own homes.

As we mentioned above (Section 5.1.2), customer reviews are deeply ingrained in consumer culture, so much so that there are well-established sub-genres of reviews (review parodies, for example). As a reminder, Reagle states how many consumers are comfortable using customer reviews as a medium to express their experience of a given object and, on the reader's side, to understand products based on what other people have said in their reviews [28]. In our findings, we saw how this familiarity with the 'formula' of reviews served as the backbone for casual yet meaningful feedback. For example, reviewing the Desktop Odometer, Taylor used a narrative structure: they described at first feeling "powerful" before learning about the internet's energy use prompted them to "unplug and go read a book". Another reviewer, Flynn speculated that the Desktop Odometer's "real" intelligence might be more than it lets on, and personified the Desktop Odometer as their "new expressionless robot friend". The most hyperbolic review came from John, who claimed the Desktop odometer saved their marriage: "Ever since the Desktop odometer, my wife talks to me, goes on walks with me, and even calls me sweet cheeks again like we're back in our 20's when we first met!!" While John's account of the Desktop Odometer single-handedly saving their marriage seems hyperbolic to say the least, perhaps the couple did bond over counting the miles they traveled, as they claim.

We speculate that the casual, familiar setting of a product review left room for reviewers to be creative in their feedback, which enriched their accounts to the benefit of our research. Some reviewers opted to make unboxing videos, some anthropomorphized their devices, some described their experiences in detailed narratives. One reviewer photoshopped the Desktop Odometer's LED screen onto a Furby doll (Figure 14) to demonstrate the need for a more attractive housing for the device. We also observed reviewers responding to one another's comments, as in the exchange between Eliot and Connie, described in our findings (Section 5.2.1). Exchanges like this one highlight the social as well as the discursive possibilities of using online forums such as customer reviews as a site to conduct participatory experimentations. On an online forum such as Amazon.com, speculation and discursive design can be an asynchronous dialogue that evolves and grows over time. It can be a conversation held and seen by many, not simply the designer and user. All of these different approaches provided a wealth of surprising and meaningful feedback about the different ways that consumers understand the internet, and the extent to which our device may have changed or augmented that understanding.

However, using Amazon to disseminate our device and generate reviews proved to be somewhat problematic in ways which ran

Figure 14: Image posted by customer, Max, used to illustrate how different objects could be used to house the device.

somewhat parallel to our difficulties with Google Play. A few weeks into our research, we discovered that eight customer reviews had been taken down with no prior notice or explanation. After much effort trying to contact Amazon Seller Support, we learned that the reviews were taken down because Amazon 'discovered' that we had been in contact with the customers, which violates their Customer Review Policy. The challenge is that for design research, prior contact with participants is not 'fraudulent', but may be part of an approach to conduct research. In our case, contact with potential customers was often necessary to field questions about the research and to troubleshoot the device and its browser extension. Amazon's seller support infrastructure proved to be, fittingly, quite opaque, and we were unable to get any of the lost reviews back. This incident shows that Amazon.com, while advantageous to our research for its position of ubiquity in consumer culture, carries specific challenges to communication with participants—any future work on this platform would have to structure the research in such a way as to communicate with participants without triggering Amazon's 'fraudulent review' policy. Furthermore, we reflect on the fact that while we organically sold products on Amazon.com, the reviews came from participants who had heard about the product in the context of the research project. This further complicates the ideal of having an open, public and inviting space for speculation: how to reach people on the platform in the first place.

7 CONCLUSION

There is no one 'best' approach to investigating infrastructure. Infrastructure is the topic of study in a variety of disciplines. We have focused on using products, a common medium for designers, as an experiential tool to investigate opaque infrastructures.

By making, selling, and receiving reviews about the Desktop Odometer, we not only opened up new ways to understand the web, but we also created new windows in other opaque infrastructures along the way (the Google Extension store and the Amazon marketplace).

The researcher and sociologist Susan Leigh Star describes infrastructure as "both relational and ecological–it means different things to different groups and it is part of the balance of action, tools, and the built environment, inseparable from them" [33]. The infrastructures we have discussed in this work are so totally embedded in everyday life that any notion of choice—choosing whether or not to engage with these systems—is simply an illusion. The fact that there is little or no choice only highlights the need to investigate opaque infrastructures. Through these investigations we can begin to examine how opaque infrastructures align with the values and aspirations of the people who use them, how opaque infrastructures shape the futures of the people who will be affected by them, and whose voices are and are not being considered in the shaping of them.

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