DATA SENSE

Facilitating Citizen Sensemaking of Smart Environments through Augmented Urban Experiences

Katie Frohbose

Department of Graphic Design and Industrial Design
College of Design | North Carolina State University

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Deborah Littejohn, PhD | Committee Chair
Associate Professor of Graphic Design

Kermit Bailey | Committee Member
Associate Professor of Graphic Design

Denise Gonzales Crisp | Committee Member
Professor of Graphic Design, Director of Graduate Programs

ABSTRACT

As pervasive, invisible, and ubiquitous computing occupies corners of public and private space in smart cities, it is becoming increasingly important for citizens to be informed and aware of the affordances and agency of data and sensing artifacts. Building awareness into the design of the Internet of Things (IoT) infrastructure can be difficult, due to its inherent invisibility. As such, designers need to consider ways in which new technologies can help bridge the digital–physical divide the IoT transgresses. This investigation uses the Acts of Noticing as the framework to bring a pedestrian into awareness of invisible IoT infrastructure. It explores how various technologies and touch points in digital and physical spaces can provoke pedestrian engagement with IoT sensors and data. It then investigates how embodied and contextual interactions in augmented reality can encourage sense-making of IoT sensors and data in new forms.

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PART 1:

DEFINING THE PROBLEM

INTRODUCTION

To Begin: A story of a mushroom

In “Design for Collaborative Survival: An Inquiry into Human-Fungi Relationships” (Liu et al., 2018), design researchers explore how interactive tools can reshape perspectives of natural systems. The study uses the act of mushroom foraging as a context to question how technology can be leveraged to bring awareness to another species in order to gain deeper insight into their affect and agency. Human–fungi symbiosis is explored through a series of design provocations known as the Acts of Noticing: engagement with the natural environment, attunement with the livelihood of the other species, and expansion or a blurring of the nature/culture divide. Sensing materials, wearables, and walking sticks extend human sensory capacities into the environment, allowing the researchers to notice, attend to, and become struck by the nonhuman (mushroom) life (ibid, 2018).

The fungi is described as a complex bio-indicator that is both food and fungus that simultaneously decomposes and creates, destroys, and rebuilds. It is essential and invisible, powerful yet edible, and ferments in human bodies and spans across desolate landscapes; “the ubiquity of fungi is undeniable” (Liu, et al., 2018, p. 4). I certainly know I had limited fungi knowledge and was grateful to come across such an interesting study, which has become the underlying intention of this research: facilitating Acts of Noticing with pervasive and invisible IoT infrastructure in smart urban environments. Similar to the fungi, these sensors, data, and algorithms that comprise the Internet of Things are at once ubiquitous and invisible, powerful and manipulative, public and private. They occupy all corners of the urban floor and mediate our experiences. They affect and are affected by us. We cohabitate and co-produce the world with them. Yet, how aware is the human of IoT infrastructure when invisibility is built into its design? What are the implications for such invisibility? How can designing for awareness yield a more attuned and empowered citizen?

This investigation delves into speculative interactions with data and sensors and smart cities. It uses the Acts of Noticing as a framework to investigate ways citizens can come into contact with and interact with IoT infrastructure in new ways.

PROBLEM STATEMENT AND JUSTIFICATION

Problem Statement

Smart cities are characterized by ubiquitous sensing technologies that measure, monitor, and respond to human and nonhuman conditions and activity. These sensors are embedded in mobile devices—phones, cars, watches, and in the environmental infrastructure—sidewalks, traffic lights, and crosswalks, among others. A connected crosswalk senses a user's presence and notifies her when it is safe to cross the street. A surveillance traffic camera monitors the street to detect traffic and pedestrian patterns for safety. While IoT's affordances aim to make life easier for its citizens, its pervasiveness, invisibility, and reliance on human data raises issues of transparency and ethics for the future of IoT design.

An inherent attribute of "smartness" is its seamless, magical, and invisible design. Originating in the mid 90's with Weiser's notion of the disappearing computer, the standard for IoT is to not communicate its "presence, purpose, practice and analysis to the wider audience it is monitoring" (Weiser, 1995; Mikusz et al., 2018, p. 1). Rather, it functions as an unobtrusive tool to aid and abet humans in their day to day lives. IoT sensors obscure their hardware (form, location, distribution) and their networked functionality for the more valued effect of seamlessness.

While invisibility does make living in these spaces a little more enchanted, it becomes problematic when humans and their data are deeply enmeshed in their networked infrastructure. Embedded ubiquitous computing renders space and time invisible as it seeks to go anywhere and be everywhere. A consequence is that relations of power and control are rendered invisible as well (Galloway, 2004). In these datafied spaces, a citizen is subject to data collection, capturing, and storing of personal information simply by moving through public space (Sumartojo et al., 2016). A user generates more data than they participate, leaving data trails as metadata for applications and companies to aggregate and use (Andrejevic & Burdon, 2015). Some tangential effects concern user data—privacy, agency, control, ownership, algorithmic influence, and representation (Andrejevic & Burdon, 2014; Panda, et al., 2017). Designers can overlook citizens' right-to-know if they do not consider the unintended effects of invisibility in the design of networked sensors and objects.

Some concerns include humans are becoming increasingly less aware of privacy risks and connected objects surrounding the end-user (Panda, et al., 2017, Mikusz, et al., 2018). Design tends towards top down technocratic determinism, in which human right-to-know becomes sidelined (Gabrys, 2016). Citizens are less equipped to understand the digital fabric of smart ecosystems in which they are embedded, thus reducing their power and agency (Marenko, 2015).

It was predicted that in 2020 there would be 50 billion smart objects in urban cities with trends alluding to even more embeddedness and invisibility by 2030 (Ericsson, 2011). As such, there is a need for digitally attuned citizens who are informed, aware, and kept in the loop in the design of digital environments (Heitlinger et al., 2019).

Justification

Building transparency into smart designs is difficult when embedded sensors, data, and algorithms are hard for non-expert citizens to conceptualize (Lupton, 2017). Information flows in shared public spaces are dynamic and volatile, and data are invisible, abstract, and immaterial (Mikusz, et al., 2018). As user data are fragmented and translated across private, public, digital, and physical realms through various devices and applications, information and data flows are difficult to trace (Mashhadi et al., 2014; Lupton, 2017, 2020). When doing research about IoT sensors and uncovering my own personal data trail, resources generally took the form of outdated websites with disjointed hyperlinks. Due to the complexity of smart ecosystem infrastructure, it is unreasonable to assume citizens would spend time researching sensors and whether or not their personal data are implicated in its use. As such, there is a design potential to create a consolidated platform in which IoT sensors are made evident and accessible.

Facilitating sensemaking and awareness of IoT sensors and data is evident in a number of design provocations, including The Amsterdam Civic Dashboard (Amsterdam, n.d.), Citizen Sense kits (Citizen Sense Kit, n.d.), Sensory Walks and Citizen Science Projects (Gabrys, 2016), Air Quality Measuring Apps (Sensaris. n.d.), IoT Assistant ("New infrastructure will enhance privacy in today's Internet of Things," n.d.), Smart Watch (Shaw et al., 2017), AR IoT, (Jo et al., 2016) and the Sense Egg (The Air Quality Egg Learning System, n.d.). Collectively, these examples advocate for citizen's right-to-know and uniquely address the concept of transparency and smart citizenship through place-based sensing, access to open source data, and active participation (Heitlinger et al., 2019; Gabrys, 2016).

This investigation builds upon those provocations by asking how design can facilitate citizen sensemaking across the physical–digital environments through a range of modalities and interactions. As citizens are immersed within and move through sensory embedded environments, it is essential for designers to explore how new technologies can: 1. Provoke awareness of the invisible IoT infrastructure; and 2. facilitate data sense-making in ways that emphasize its spatial and material qualities. As such, this investigation proposes the use of multimodal interventions in the physical space and immersive embodied interactions in augmented reality as a means to build transparency into the design of IoT systems.

This investigation is an inquiry into possibilities, potentialities, and ethics surrounding sensors and data in sensory-embedded environments. It explores potentials for augmented reality to facilitate awareness of IoT sensors through interactions with them in situ. It uses the framework of the Acts of Noticing to bring citizens into engagement, attunement, and expansion with sensors and data in new ways (Liu et al., 2018).

ASSUMPTIONS AND LIMITATIONS

Assumptions

As the Internet of Things points towards a future of increasingly connected objects, this investigation assumes IoT sensors will be accessible to users, regardless of public or private ownership. As such, it assumes that users will be given public access to data their personal data is safe and secure through the use of this application. Though the prototype is contextualized through a mobile phone, visual studies can be imagined in the context of augmented reality headsets. As studies are situated in the future of smart spaces, it assumes that the software and application are able to efficiently handle the heterogeneity of users, situations, and environments that are required and that geolocated data points can be accessed in real time and space.

Limitations

Studies take a speculative approach. They are meant to provoke and present possibilities that are backed by secondary research into the future of the IoT in smart cities. The examples of sensors and data used in visual studies are not derived from an existing database of local IoT sensors in Raleigh, NC nor from that of a single citizen. Rather, they are chosen from existing research of current technologies and future trends of sensor deployment and use in sensory embedded spaces (Appendix A: IoT Infrastructure). The final prototype is not user tested and aims to simulate the experience rather than function as an existing application. The user group is limited to those who have the cognitive, physical, and perceptual capabilities to interact with future augmented reality technologies in mobile phones and headsets.

ANNOTATED BIBLIOGRAPHY

Relevant literature was found using the NCSU library database through searching for these key words: Smart Cities, the Invisible Computer, Smart Citizenship, Awareness, Data, Data Sense, Augmented Reality, Speculative Design, and More than Human Participatory design.

Smart City & Invisible Computer	
Defining the sensor society	Andrejevic & Burdon, 2015
Cyber–physical–social frameworks for urban big data systems	De et al., 2017
Towards an integrated theory of the cyber–urban	Forlano, 2015
Intimations of everyday life: Ubiquitous computing and the city	Galloway, 2004
Digital urban acupuncture	Iaconesi & Persico, 2016
Deleuze and design	Mereko, 2015
Evolution of social IoT world	Panda et al., 2018

Table 4.1

SMART CITY + INVISIBLE COMPUTER

Literature provides insight into the IoT and the role of design in the context of smart cities. It covers data, sensors, connected objects, artifact agency, and the disappearing interface (Table 4.1).

A smart city is characterized by ubiquitous high-volume information flows among humans and computing that has three components: sensors that measure environmental conditions and movements, algorithms that find patterns and predict future scenarios, and actuators that respond to data in real time (Ratti & Claudel, 2016).

The IoT ecosystem is referred to as the cyber-physical-social system, the cyber-urban, the objectspace, the sensory society, and digital skin. (De et al., 2017; Forlano, 2015; Mereko, 2015; Andrejevic & Burdon, 2015; Rabari & Storper, 2014).

The IoT is a platform that connects heterogeneous and pervasive electronic gadgets such as sensors, actuators, RFID tags, electronic devices, smartphones, among others. These devices continuously generate information about the physical world (Panda, et al., 2018).

These agents influence our behavior and establish complex relations with us (Iaconesi & Persico, 2016).

A major challenge for designing interaction in smart environments concerns the disappearance of the computer as a visible, tangible and distinctable device (Stephanidis et al., 2019).

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The paradigm of dematerialisation is not only highly problematic, but also misleading as it obscures the material reality and complex infrastructure of the digital infoscape (Marenko, 2015).

Smart systems are likely to be more opaque to non-technically educated citizens and users (Rabari & Storper, 2014).

Embedded ubiquitous computing renders space and time invisible as it seeks to go anywhere and be everywhere. A consequence of this is that relations of power and control are rendered invisible as well (Galloway, 2004)

SMART CITIZENSHIP + AWARENESS

The concept of Smart Citizenship is the driving value of this project and serves as the proposed outcome (Table 4.2).

Rather than functioning as a node in a cybernetic city, smart citizens resist technocratic determinism through bottom–up, community–driven, and democratic efforts for facilitating access, participation, and transparency of data in sensory embedded environments (Heitlinger et al., 2019).

Smart Citizenship offers a different vision of a city that is less technologically and optimization-driven and more about empowerment for the people (Ratti & Claudel, 2016)

Inclusion of humans in the loop presents opportunities for user feedback while making data collection more transparent. Humans in the loop necessitates awareness of IoT infrastructure (Mikusz et al., 2018).

Education and training can help eliminate worries of users about data privacy and misuse of information (Mahmood, 2019).

In order to act in the world, people need to know what is going on. It is because of awareness of their environment that people can understand a situation and thus act on the situation (Niemantsverdriet et al., 2019).

Smart Citizenship + Awareness	
Decentering the human in the design of collaborative cities	Forlano, 2016
The right to the sustainable smart city	Heitlinger et al., 2019
Guide to ambient intelligence in the IoT environment	Mahmood, 2019
Human data interaction in IoT: the ownership aspect	Mashhadi et al., 2014
Raising awareness of IoT sensor deployments: living in the internet of things	Mikusz et al., 2018
Designing for awareness in interactions with shared systems	Niemantsverdriet et al., 2019

Table 4.2

Data & Data Sense	
Datafication, dataism and dataveillance	Dijck, 2014
Digital urban acupuncture	Iaconesi & Persico, 2016
Feeling your data: touch and make sense of personal digital data	Lupton, 2017
Data selves: more-than-human perspectives	Lupton, 2020
All data are local: thinking critically in a data-driven society.	Loukissas, 2019
The affective intensities of datafied space	Sumartojo et al., 2016

Table 4.3

A deficiency for IoT design is that users lack awareness of who has accessed their devices due to unintelligible feedback (Mashhadi et al., 2014).

Without a basic understanding of the material constraints under which computing systems operate, the virtual will remain invisible and unaccounted for (Forlano, 2016)

DATA & DATA SENSE

> *Research in this domain frames how data is understood and approached in this investigation (Table 4.3).*

Data are ubiquitous; “they are in the shapes of buildings, in streets, and in urban furniture; in the forms of the paths chosen by city dwellers to traverse spaces and places; in signs, symbols, images, and icons; in colors; in the smells and sound we feel while we are in the city” (Iaconesi & Persico, 2016, p.30).

“Dataveillance can be very difficult to identify, particularly when it involves hidden sensors using software in which the terms and conditions and privacy policies are absent or not well explained; algorithmic decision-making which lacks transparency; or illicit access” (Lupton, 2020 p. 9).

Datafication is the quantification and tracking of human behavior and social media technologies. This phenomenon is the new paradigm of society (Dijck, 2014).

Datafied space presents a way to understand the way we move through the world. It decenters digital data as a fixed, discrete thing and instead locates them as part of a complex entanglement of everyday life (Sumartojo et al., 2016).

Data are insights into local knowledge and have a complex attachment to place. Interfaces re-contextualize them in new settings, thus stripping them from their natural settings (Loukissas, 2019).

Data sensemaking acknowledges the use of the human senses in people's response to data. It involves the entanglements of human senses and digital sensors in the act of sense-making. It is embodied, affective, and material nature of engaging with and learning from data (Lupton, 2017 & 2020).

AUGMENTED REALITY

> *Augmented reality is the primary technology upon which this investigation focuses. Literature aims to highlight its affordances and limitations, as well as provide a conceptual lens of its perceptual, cognitive, and social function (Table 4.4).*

Augmented reality creates interactive spaces through computation (Galloway, 2004).

In this aesthetic paradigm, the physical and digital spaces are combined (Manovich, 2010).

In AR, virtual and real objects are intermeshed through a real-time overlay of digital information that is contextual and dynamic in the physical environment (Lukosch et al., 2015; Manovich, 2010).

Augmented reality is considered one of the ideal interfaces in the IoT (Cozzolino et al., 2018).

Providing an interface that supports AR to represent smart objects allows for better perception by the users of smart environments and its functions. Some affordances of AR: real time visualizations,

Augmented Reality	
Visualizing the internet of things	Aliprantis, et al, 2018
The virtual factory	Cozzolino et al., 2018
Intimations of everyday life: ubiquitous computing and the city	Galloway, 2004
Collaboration in Augmented Reality	Lukosch et al., 2015
The poetics of augmented space	Manovich, 2010

Table 4.4

Design Theory	
Non anthropocentrism and the nonhuman in design	Disalvo & Lukens, 2011
Speculative everything	Dunne & Raby, 2013
Decentering the human in the design of collaborative cities	Forlano, 2016
Healthy urban environments: more than human theories	Maller, 2018

Table 4.5.

mobility, and leveraging the natural interaction between physical objects and users (Aliprantis et al., 2018).

DESIGN THEORY

Speculative and More than Human participatory design provides project insight into the design methods, ethics, and interventions this investigation explores (Table 4.5).

By exploring ideas before they become products or technologies, designers can consider the possible consequences of technologies before they happen. Instead of experimenting with things as they are now—making them better or different—you consider other possibilities altogether (Dunne & Raby, 2013).

An orientation towards dynamic non- humans through exploring how they can be conceptualized, represented, and accounted for can reveal new and insightful directions for understanding, analyzing and potentially intervening in practices for social and environmental change (Maller, 2018).

Perspectives that move us beyond the human as the singular or dominant frame of reference can begin with the consideration of nonhuman expressivities which can be explored through emphasizing their material agency, appropriating nonhuman form, investigating nonhuman senses, and designing for nonhumans (DiSalvo & Lukens 2011).

Experiments, prototypes, and demonstrations in hybridity and liminality that defy existing categories can serve to showcase productive collaborations between human and nonhuman factors that will shape hopeful, alternative futures (Forlano, 2016).

DASS FRAMEWORK
Designing for Awareness in Interactions in Shared Systems (Niemantsverdriet, K., et al, 2019)

Information
Information
Detail & Abstraction
Inference & Explicitness
Privacy & Control

Embodiment
Representation & Placement
Effort & Intentionality
Initiative & Presence
Persistence

Interaction
Anticipation & Revisability
Recoverability & Intervention
Interaction Alternatives

SMART CITIZENSHIP
(Antoniadis et al., 2015; Heitlinger et al., 2019; Mikusz et al. 2018)

Right to the Hybrid City
Citizen Engagement
Participation
Representation
Ownership
Civic IoT
Data Access
Transparency
Literacy
Commoning
Democratic

DATA SENSE
(Lupton, D. 2017, 2020)

Sensemaking
Multisensory
Embodied
Enacted

Data
Material
Contextual
Lively

ACTS OF NOTICING
(Liu et al., 2018)

Engagement:
Sharing the physical space with the non-human collaborator

Attunement:
Sensing the livlihoods of the non-human collaborator

Expansion:
Blurring the nature-culture division

Dimensions for Noticing
Scope: thick – thin
Temporal Trajections: past – present – future
Familiarity: familiar – strange

Table 5.1

Figure 5.1 A synthesis of the frameworks: Multisensory Acts of Noticing (Liu et al., 2018), The DASS framework (Niemantsverdriet et al., 2019), Data Sense (Lupton, 2017 & 2020), Smart, Citizenship help guide this investigation. ***Table 5.1*** lists each framework's inherent attributes.

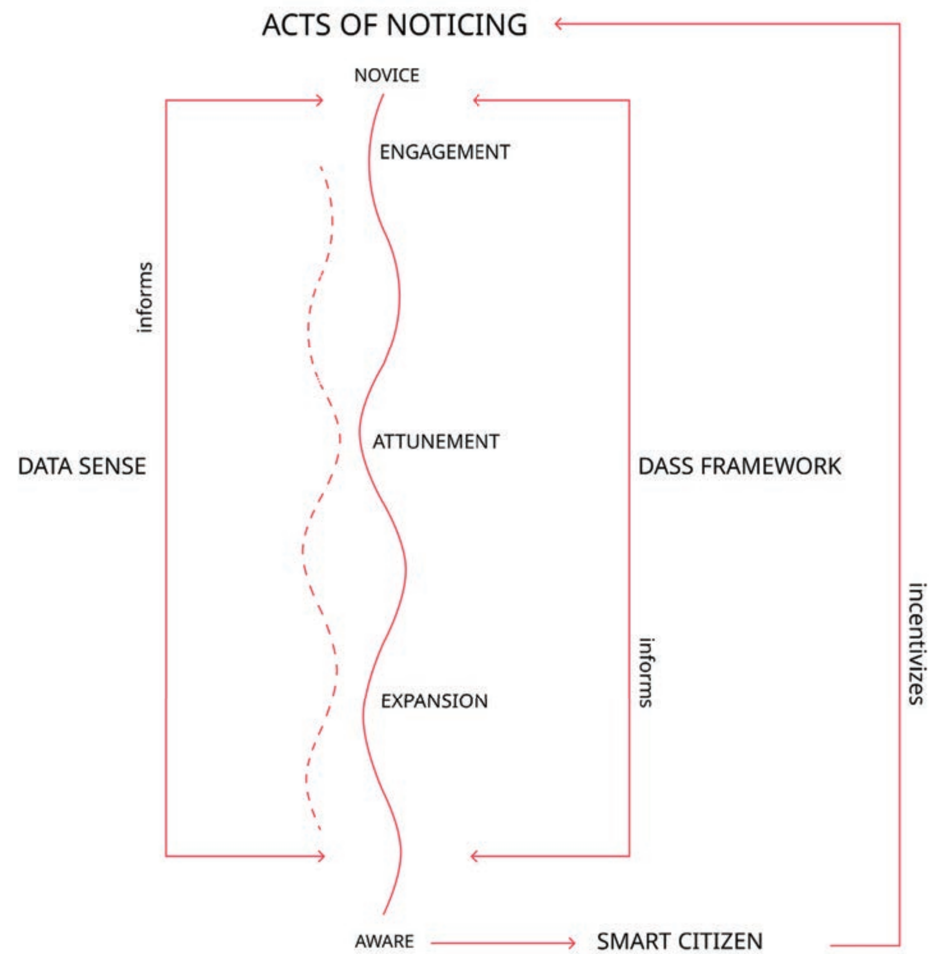


Figure 5.1

CONCEPTUAL FRAMEWORK AND RESEARCH QUESTIONS

Conceptual Framework

Multisensory Acts of Noticing is a framework to help humans shift perspective and gain insight into how systems function outside of our anthropocentric norm. It is derived from a design probe that explores how interactive technologies can bring the human into awareness of another species, the fungi (Liu et al., 2018). Stages of noticing include three tactics: engagement, attunement, and expansion. In the context of the fungi study, engagement is the shared physical experience of the environment. Attunement is the ability to sense the livelihoods of nonhuman collaborators, and expansion blurs the nature-culture division (Liu et al., 2018). Acts of Noticing are broken up further into dimensions that refers to the scope or level of focus (thick – thin), temporal trajectories (future – present – past), and familiarity (familiar – strange), as seen in Figure 5.1.1. Acts of Noticing is the primary framework that guides this investigation. The three sub questions explore the concepts of engagement, attunement, and expansion in sequential order.

The DASS framework gives a structured and holistic view of how designers can implement awareness of information into the design of interactive and shared systems. It defines awareness in the context of design as a product (a state of knowledge) and a process (of maintaining awareness through perception and action) (Niemantsverdriet et al., 2019). It covers three main considerations: the type of information needed for awareness; how awareness can be embodied; and how awareness can be used in interaction. This framework guides the studies that address representation and embodiment of information in the AR application when exploring the design space, analyzing the context, and prototyping.

Data Sense involves the entanglements of human senses with digital sensors in the act of sensemaking. It is supported by embodied forms of sensemaking in which humans learn and act with and through their bodies, and includes their encounters with nonhuman objects, which, in turn, generate sensation and feeling in human bodies (Lupton, 2017). It is multisensory in that it forms data sensemaking that invites "not only viewing but also touching and handling and, in some cases, the senses of hearing, taste and smell" (Lupton, 2017 p. 1600). This investigation is framed from the perspective of data sensemaking. It recognizes materiality of data as a lively thing distributed spatially and contextually in the digital–physical milieu of sensory embedded environment. A part of this investigation's scope is to speculate about the affordances of AR to facilitate acts of data sensemaking.

Smart citizenship is derived from literature covering aspects of citizen engagement. Smart citizenship does not refer to the cognitive capabilities of citizens; rather, it is a broader concept that encompasses an ethos of citizen agency through grassroots, bottom-up participatory design. It addresses notions of transparency, accessibility, and accountability in the design of sensory embedded environments (Antoniad, et al. 2015; Heitlinger et al., 2019). The smart citizenship domain sets the values for this investigation.

Definition of Terms	
Acts of Noticing	The framework used to bring a user into awareness. It consists of three phases: engagement, attunement, and expansion (Liu et al., 2018).
Engagement	The shared physical experience of an environment (Liu et al., 2018).
Attunement	Attunement is an act of awareness, attentiveness, or responsiveness to something (Merriam-Webster, n.d.).
Expansion	The blurring of the nature/culture division or blurring of the human–technological division (Liu et al., 2018)
Mixed Reality	A technological blend of physical and digital realities (Manovich, 2010)
Embodied Awareness	Stems from embodied sensemaking that relies on multi-sensory ways of understanding experience. (Lupton, 2017)
IoT Internet of Things	The interconnection of computing devices embedded in everyday objects that send and receive data. An example of this infrastructure is a smart city.
Multimodal Technologies	Refers to different modes of interaction: Visual, Auditory, Haptic, taste, orientation. (Gibson 1983).
Augmented Interactions	Interactions in the context of augmented reality which is characterized by virtual, dynamic, and context specific information overlaid on the physical environment (Manovich, 2010).

Table 5.1

Research Questions

MAIN

How can the design of a mixed reality experience facilitate transparency of IoT sensors and data through citizen engagement with its infrastructure?

SUBQUESTIONS

Engagement
How can the design of multimodal interventions present initial touch points for the user to access the IoT infrastructure over time and space?

Attunement
How can the design of contextual layers of information translate the IoT infrastructure's functionality and intent?

Expansion
How can the design of applied interactions facilitate an embodied awareness of information while promoting user agency?

METHODS

Secondary Research:
An extensive literature review of sources applicable to the problem space helped formulate my research question, argument, justification, methods, and findings. Precedent Analysis: Opportunities for exploration emerged in the early phase of the investigation through research, compiling, and analyzing existing design provocations, products, and studies.

Design Ethnography
Observational studies utilizing the AEIOU framework of Hillsborough Street informed the context of the investigation's problem space.

Research through design
Making as a form of research encouraged the collection of evidence along the way to inform design decisions.

Interviews + Survey
Interviews and surveys provided insight to craft a persona. Appendix: C

Scenarios
Scenario-building based on secondary research and observational studies helped contextualize the problem space and identify pain points.

Rapid Ideation
Rapid ideations and "what-if" explorations broadened my scope of possibilities early in the investigation and helped circumvent design fixation.

Workshop
A workshop with the sophomore class at NCSU revealed possibilities for design explorations is subquestion two .

Persona Generating, Storyboards, Stakeholder Maps, Refined Scenarios:
These User Experience design methods provided a contextual space to situate this investigation.

Concept Mapping, Prototyping, Visual Studies, Concept maps and visual studies provided visual confirmation and analysis of concepts. Prototyping brought the project into fruition.

Figure 6.1 Process work.

Methods were derived from Martin and Hanington's ***Universal Methods of Design*** (2019).

PART 2:

EXPLORATIONS

PRECEDENTS

As a part of this investigation, I researched existing design applications, experiences, and frameworks that center around citizen sensing, IoT awareness, and augmented reality. Collectively, these examples advocate for citizen's right-to-know and uniquely address the concept of transparency and smart citizenship through place-based sensing, access to open source data, and active participation.

What I took from these precedents:

- Citizens as sensors—citizens understand sensory environments through participatory acts of sensing (Gabrys, 2018).
- Sensing kits are placed based and require mobility to access. Walking is apart of understanding embedded IoT devices spatial scope.
- Transparency is achieved through the use of open source and open data.
- Data is generated and collected through the willingness and active use by a participant.
- Sensor activity can be made evident through public interactive displays that convey ambient information.
- Mobile devices can inform users of local data collection.
- Users can filter through sensors to decide which ones they want to access.
- ARIoT can be experienced in natural ways that use proximity-based sensing and BLE beacons to notify of the user of a sensor near by.
- Sensing nodes do not always take the form of mobile devices. Some are rendered as eggs and other playful forms.

Walking

Citizens as sensors

Open source data

Ambient notification

Notifying users

Proximity based awareness

Creaturely and cute

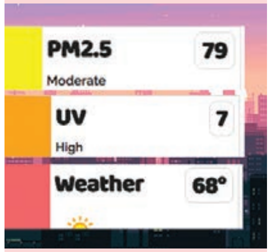


Figure 7.1.1

Figure 7.1.2

Figure 7.1.3

Figure 7.1.4

Figure 7.1.5

Figure 7.1.6

Figure 7.1.7

Figure 7.1.8

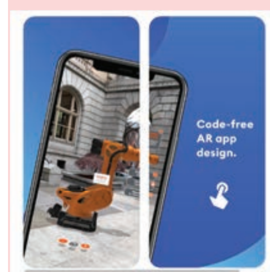


Figure 7.1.9

List of Precedents

Sensaris (Figure 7.1.1) is a mobile sensing technology that measures air quality. This app is for users to manage respiratory related issues. It empowers citizens by giving them access to sensor technologies.

Amsterdam Civic Dashboard (Figure 7.1.4) is a consolidated platform for environmental, traffic, and weather data. The dashboard provides open data, user access to sensing technologies used by city.

Citizen Sense Kits (Figure 7.1.6) are crowd source data kits that give rise to environmental awareness. These kits are examples of design can facilitate citizen participation, mobile sensing to understand sensing technologies.

Smart Citizen Kit is a citizen science kit that allows users to create local maps of noise and air quality. It is used to raise awareness and to find solutions for issues that matter specific communities. The smart citizen kit is an example of open source, crown sensing initiatives to faciliate sensemaking.

Air Quality Egg (Figure 7.1.7) is a design probe that records specified levels of air contaminates. Any data it collects can be uploaded to the cloud and then access through web portals or a mobile app. The egg is provides a sense of playfulness to sensing technologies.

Big Belly Trash (Figure 7.1.8) is a smart trash can that uses solar energy to measure its amount of waste. It then notifies the trash pickup when it is full, thus reducing energy and unnecessary pickup. Big Belly trash is an example of IoT awareness. It has information on its exterior design that tells the user about it's sensor technologies. The trashcan is interesting because it highlights the types of sensors that are typically made evident are those that can affect user behavior by boasting of common good).

IoT Egg (Figure 7.1.2) is an open source, multimodal sensor suite developed by the University of Surrey that presents sensors readings and recommendations to users through a public display network. The egg is part of a design probe that investigates the effects of shared visibility in the design of IoT awareness. It supports ambient notification and glanceable information through unobtrusive and informative displays.

The Privacy Aware Smartwatches (Figure 7.1.3) is a prototype smartwatch that informs users when they are entering into an environment that could compromise their privacy. When a user is about to enter a region, the application notifies the user to accept or decline.

The IoT Assistant App (Figure 7.1.5) provides users with a single interface through which they can discover IoT resources around them and access privacy options made available to them by these resources. The app helps users discover and control what data is being collected by IoT resources around you - who is collecting it, who it is shared with, and for how long it is retained.

ARIoT provides a framework for identifying smart object for users to understand their operation, enable or disable them. The system learns the user's preferences and becomes more personalized in which it visualizes only relevant objects based on the context of use. Proposes personalization, enhancement of natural interactions, and markerless tracking techniques.

Torch AR (Figure 7.1.9) is a prototype testing app that allows users to create their own AR environments. It lets the user upload images, photos, text, objects, photospheres. Torch AR provides precedents for how information can be experienced and interacted with in augmented environments.

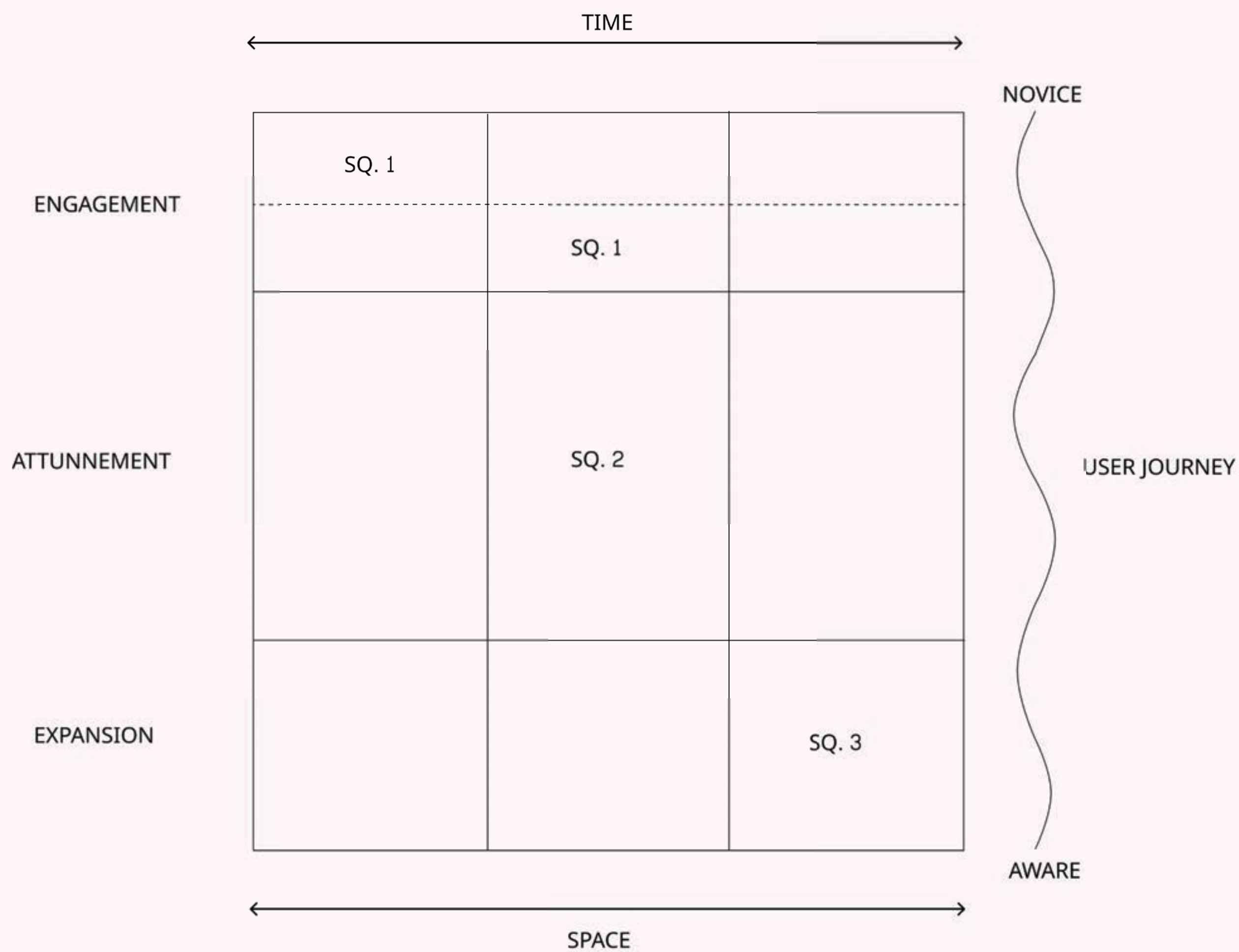

TIME
NOVICE
SQ. 1
ENGAGEMENT
SQ. 1
ATTUNNEMENT
SQ. 2
USER JOURNEY
EXPANSION
SQ. 3
AWARE
SPACE

Figure 7.1.10

STUDIES

This investigation comprises three studies that explore how design can bring a pedestrian into awareness of IoT sensors and data in the context of a smart urban street. Each subquestion addresses a tactic of noticing derived from the primary framework, The Acts of Noticing: engagement, attunement, and expansion. Engagement is the shared physical experience of the environment; attunement is the ability to sense the livelihoods of nonhuman collaborators; and expansion blurs the nature–culture division (Liu et al., 2018).

For the purposes of this investigation, I modified terms to fit the context of this study. Instead of the human–fungi relationship, the focus is on the entanglement between humans, their data, and IoT sensors. As such, engagement is understood as human contact with sensors and IoT data (the environment), while attunement explores information and communication between humans and IoT sensors and data (to sense their livelihood), and expansion explores the blurring of the human–technological division (to achieve expanded awareness). Each subquestion addresses a tactic of Noticing in sequential order (Figure 7.10) and focuses on an aspect of smart citizenship. Subquestion one addresses accessibility and awareness of information; subquestion two addresses transparency of information, and subquestion three explores agency and embodied sensemaking through interactions

Figure 7.10 The investigation framework divides studies into sections of focus that occur over a span of time and space. Subquestion one addresses Engagement and explores multimodal ways to bring the user from a novice into a place of awareness through initial engagement with IoT infrastructure. Sub question two addresses Attunement, and explores how sensors and data can be experienced in the context of AR. Subquestion three occurs once the user is aware of IoT infrastructure and the designed system. This question explores Expansion through an analysis of embodied sensemaking in AR.

Figure 7.1.11

Persona

Studies will follow one persona, Ava, as she commutes to class over the course of time (Figure 7.1.11). Ava is a student who frequently uses social media. As a millennial, she feels comfortable and competent adopting new technologies and recognizes how affected she is by her devices, especially her phone. When asked about the term “smart,” Ava listed her phone, watch, and amazon Alexa, but she was not familiar with the term “smart city” and does not know if she lives in one or not. Ava has grown up with digital and wireless technologies, and rarely thinks about their mechanics. She fears and is convinced that her phone listens to her speak sometimes and wonders how the “cloud” works, but does not obsess over these unknowns. In theory, she considers privacy to be important, but does not really know what that means, nor does she follow through with privacy settings (she finds the process too cumbersome and time–consuming). Ava has a love–hate relationship with technology and sometimes resents her devices as they can be so addictive. Yet, she would not give up what they afford for a life without them. Sometimes she feels seduced by their mysterious capabilities.

Location

Hillsborough Street, Raleigh, NC is typical of a college street in a medium–sized city (Figure 7.1.12; Appendix B: Process Work). It is active and lively, populated with a variety of business, restaurants, coffee shops, bars, and pedestrian activity. On one end of the street is a traffic circle characterized by constant, transient motion. Attention is focused and sustained as cars, pedestrians, and cyclists attempt to negotiate safely through the space. Further down the road is a crosswalk. This area is stop-and-go, characterized by dynamic and ambient buzz. Embedded within this physical landscape are thousands of IoT sensors that are aiding Ava's journey (unbeknownst to her) as she walks to and from class.

Figure 7.1.12

amp	Without looking, describe what a smart city is?	Based on your description, do y you live in one?
/16/2020 17:41:01	A smart city is one that is technologically advanced and uses smart technology to enhance and facilitate the functioning of the city.	Yes
/16/2020 17:59:11	A city that senses and adepts to people's needs as it goes - a connected city - with cameras that can do more than recording - but use different data to triangulate info	No
/16/2020 18:10:52	A city that it's inhabitants can interact with in a progressive way.	Maybe
/16/2020 18:13:32	A city with computer technology incorporated into its infrastructure.	Maybe
/16/2020 18:23:48	Free WiFi throughout city	No
/16/2020 18:50:56	a wired city with components that are responsive to each other and that gather information from citizens	I am not sure

Figure 7.2.1.1

7.2.1 STUDY 1

Engagement

In Design for Collaborative Survival, engagement is defined as the shared physical and the direct sensory experience with the organism of interest in the environment (Liu et al., 2018, p. 2). Engagement is achieved through the act of sensing, which is facilitated with a wearable prototype: a data harvest vest that helps locate the mushroom through nudging the wearer along the way. The authors express the necessity for direct engagement with the environment to bring the wearer's attention to the conditions that communicate something about the specimen of interest. Engagement is the first step of Noticing, as it lays the groundwork for noticing in deeper, richer ways.

This study focuses on eliciting engagement through initial contact with the design system. It takes a step back and asks how potential technological interventions can bring the pedestrian into Awareness engaging more fully with sensors and data recognized in the AR application (explored in subquestion two and three). When paired with smart citizen values, study one explores the idea of citizen right-to-know and accessibility of IoT information. As such, this study investigates a range of possibilities for an unaware pedestrian[1] to gain access to IoT information *in situ*.

1 The concept of "unaware pedestrian" is supported by literature on solitary mobility in the city, the anesthetization of users to digital information when moving through public space, and the ambient commons, (Bull, 2004; McCullough, 2015). Modern pedestrian mobility is oftentimes solitary with user attention directed towards their private worlds. In my observations, many pedestrians were alone with headphones on—heads down looking at content and not at the environment itself. A function of this investigation is to ask how design can snap a pedestrian out of that solitary state into one of awarenesses of the invisible IoT infrastructure.

Sub question 1:

HOW CAN THE DESIGN OF MULTIMODAL INTERVENTIONS PRESENT INITIAL TOUCH POINTS FOR THE USER TO ACCESS IOT INFRASTRUCTURE OVER TIME AND SPACE?

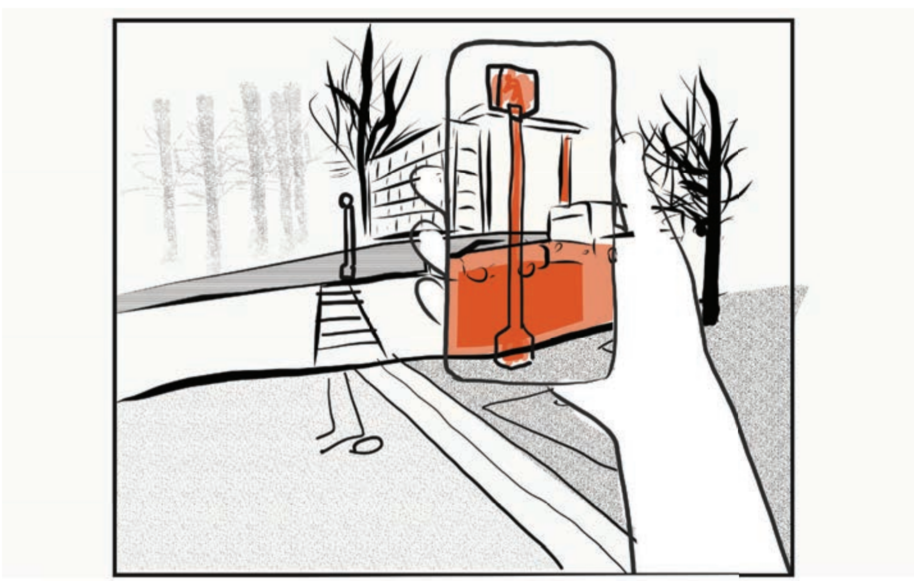


Figure 7.2.1.2

Figure 7.2.1.2 Sketches help illustrate the scenario in the design prompt. In this image, Ava is holding up her phone and scanning for local and active IoT sensors in AR.

Figure 7.2.1.1 A preliminary online survey inquired about citizen's hopes, fears, and level of awareness of IoT devices in smart cities. Some findings reveal mixed feelings towards IoT devices: irritation and resentment, appreciation and fear, confusion and excitement. These findings helped craft Ava's persona.

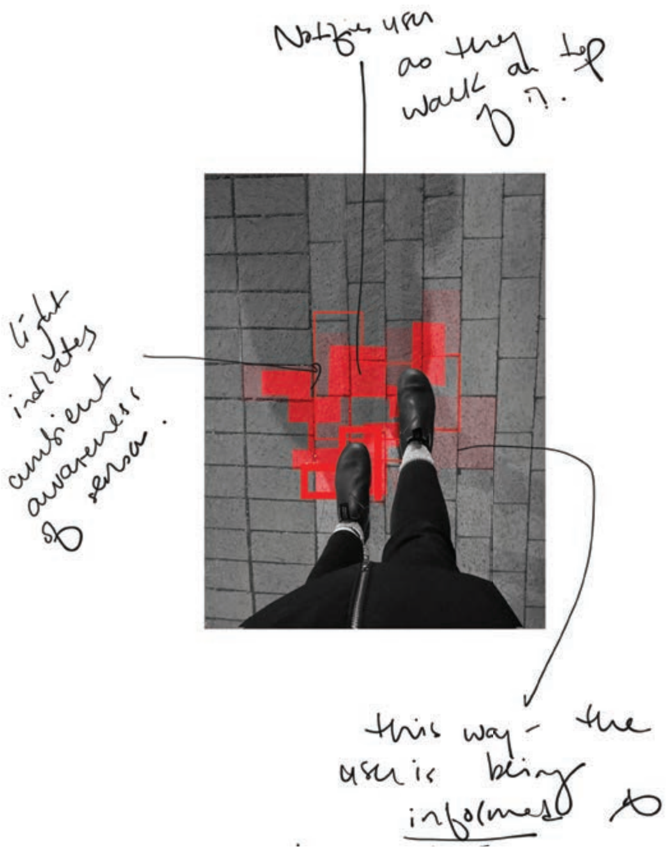


Figure 7.2.1.3

Methods

Secondary research (Figure 7.2.1.5), ethnographic observations (Figure 7.2.1.6 & 7.2.1.7), visual sketches, and concept mapping (Figure 7.2.1.6) guided this study. Technological Interventions are divided into phases both before and after Ava has downloaded the AR application. They are synthesized and codified in a concept map that highlights the affordances, limitations, and potential implementations on Ava's journey.

Embedded
Distributed

Smart Parking
Structural Health
Noise Urban Maps
Smartphone Detection
Electromagnetic Field Levels
Traffic Congestion
Smart Lighting
Waste Management
Smart Roads
Air Pollution
Portable Water monitoring
Smart Grid
Tank Level
Photovoltaic Installations

Figure 7.2.1.4

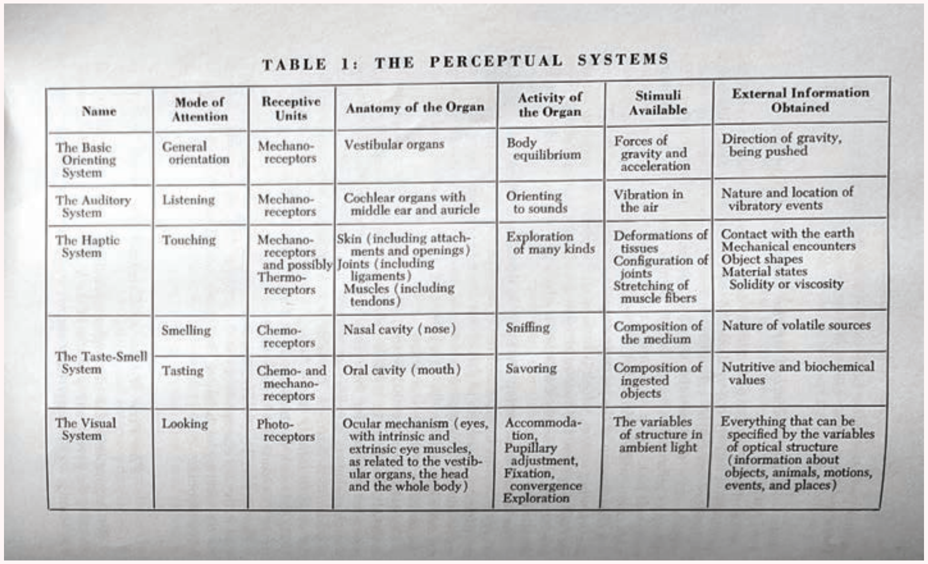


TABLE 1: THE PERCEPTUAL SYSTEMS

Name	Mode of Attention	Receptive Units	Anatomy of the Organ	Activity of the Organ	Stimuli Available	External Information Obtained
The Basic Orienting System	General orientation	Mechano-receptors	Vestibular organs	Body equilibrium	Forces of gravity and acceleration	Direction of gravity, being pushed
The Auditory System	Listening	Mechano-receptors	Cochlear organs with middle ear and auricle	Orienting to sounds	Vibration in the air	Nature and location of vibratory events
The Haptic System	Touching	Mechano-receptors and possibly Thermo-receptors	Skin (including attachments and openings) Joints (including ligaments) Muscles (including tendons)	Exploration of many kinds	Deformations of tissues Configuration of joints Stretching of muscle fibers	Contact with the earth Mechanical encounters Object shapes Material states Solidity or viscosity
The Taste-Smell System	Smelling	Chemo-receptors	Nasal cavity (nose)	Sniffing	Composition of the medium	Nature of volatile sources
	Tasting	Chemo- and mechano-receptors	Oral cavity (mouth)	Savoring	Composition of ingested objects	Nutritive and biochemical values
The Visual System	Looking	Photo-receptors	Ocular mechanism (eyes, with intrinsic and extrinsic eye muscles, as related to the vestibular organs, the head and the whole body)	Accommodation, Pupillary adjustment, Fixation, convergence Exploration	The variables of structure in ambient light	Everything that can be specified by the variables of optical structure (information about objects, animals, motions, events, and places)

Figure 7.2.1.5

Figure 7.2.1.6

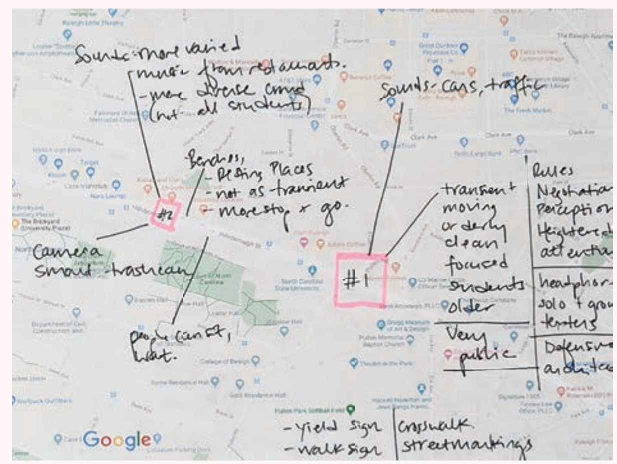


Figure 7.2.1.7

Figure 7.2.1.5 Multi-modality seeks to broaden user access. This investigation focuses primarily on the auditory, visual, and haptic ways of engaging with the system (Gibson, 1983).

Figure 7.2.1.3 The sketch of amplified reality is one of the technological intervention explored in this investigation.

Figure 7.2.1.4 A list of sensors in smart cities helped inform context and understanding of its networked capabilities.

Figure 7.2.1.6 & 7.2.1.7 Observations of Hillsborough Street reveal characteristics typical of a high traffic university strip . Location # 1, the traffic circle is transient and open with constant repetitive motion populated mainly by professors and students deliberately walking to and from class—heads down, and focused. Further down the sidewalk, location # 2, the commute becomes stop and go as pedestrians pass by restaurants, cross walks, and traffic lights. In the context of a smart city, this street is embedded with sensors and actuators that respond to Pedestrian activity.

Figure 7.2.1.8. Big Belly Trash is an example of a public marker. Its design lets the user know it is equipped with an embedded sensor by providing insight into what it does and how it works (See Chapter 5, Precedents).

Figure 7.2.1.8

Figure 7.2.1.9 The prototype privacy notification system is an intervention that informs the user that they are about to enter into a sensory embedded space—allowing them to decide if they would like to enter the space or not.

Figure 7.2.1.9

Table 7.2.1.3. Table 7.2.1.1. lists potential touch points explored in Study One. The chart is organized by design type, its mode of interaction, how close it brings the user to the sensor, whether or not the touchpoint exists in physical or virtual space, the level of interaction it elicits from the user (thick to thin), and its degree of privacy.

Technological Interventions

Technological interventions explore different modes of engagement within a busy college street. The objective is to bring the user, Ava, into contact with the IoT infrastructure in both the physical and augmented space when she is walking to class.

Interventions differ according to their modality; user proximity to local sensors (if the user is on site or accessing information from afar); whether they exist in the physical or digital space; their dimensions of noticing (thick to thin); and their degree of privacy (See Table 7.2.1.1).

Pre-AR interventions draw pedestrian into engagement by disrupting the monotony of a daily commute. Within AR, interventions aim to inform, nudge, or remind the user of IoT sensor activity in near proximity.

Pre AR:
Markers
Amplified Reality
Public Interactive Screen
GPS Mapping

In AR:
GPS tracking
Markerless Tracking: BLE Technology
Image Recognition

Design Type	Example	Mode	User Proximity to sensor (Near to Far)	Space (physical or Virtual)	Scope (thick to thin)	Public/Private
Markers	QR code, Signage	Visual	Near	Physical, Digital	Thin	Public
Amplified Reality	Motion sensors that light up as a user walks past them	Multi-modal	*In situ*	Physical, Digital	Thicker	Public, Semi-private
Interactive Screen	Public touch screen	Visual, Auditory	Ranges	Physical , Digital	Thick	Public
GPS Map	Digital Mapping	Visual	Ranges	Digital	Thick	Private, Public
GPS Tracking	GPS location	Orientation	Near	Digital	Thin	Private
Markerless tracking	BLE technology	Orientation	Near	Digital	Thin	Private
Image Recognition	Object Detection	Orientation	Near	Digital	Thin	Private

Table 7.2.1.10

Technological Touch points pre–AR

The following scenarios explore how local IoT sensor activity can be made evident through a range of strategies and modalities. The scenarios occur when Ava is walking to and from campus over a period of time.

1. *It is another day. Ava is walking to school, watching her feet as she walks. She is listening to her favorite podcast and thinking about her project she needs to complete that day. As she walks, Ava notices a red glow from her periphery. She looks further and sees that the light is responding to her footsteps. Ava keeps on walking and each step makes the crosswalk turn red. She turns around and notices that it is happening to everyone else too. She is intrigued and delighted, but wants to know more.*

Figure 7.2.1.11

Amplified reality (*Figure 7.2.1.11*)is an expression of public, embedded sensors (Falk et al. 1999). In this scenario, the red light and the subtle vibrations provoke ambient awareness of the IoT sensors location and activity in direct proximity to them. It provides a richer sensory experience but with thinner information. Amplified Reality offers multimodal and spatial, ambient, and implicit awareness with a lack of detail and added information.

2. *Ava continues on her way. At the next crosswalk, she stops and waits for the light to turn green. She looks around and notices the cross walk pole has a small red tag with an icon on it—the same read at the glow on the sidewalk. Beneath, the sticker is a QR code. Remembering the red light, she scans the code and goes on her way.*

Figure 7.2.1.12.

Markers (*Figure 7.2.1.12)* can serve as a visual indicator of IoT sensors. They can be as simple as analog informative signs posted on a sensory embedded device such as the solar belly (See Precedents) or they can connect the user to the application through QR codes. Affordances of markers are that they are cheaper and can be easily distributed. Limitations are aesthetics and the difficulty of identifying thousands of heterogeneous sensor types in public space (Jo et al., 2016). Overall, they provide thin interaction with limited potential for relaying embedded sensor information. Markers could prompt exploration.

3. *On her way back from class, Ava is a little more relaxed. She puts on her headphones and crosses the street. Coming the opposite direction is a professor walking towards campus. He is a tech enthusiast and interested in IoT sensors and data. About midway through the sidewalk, both Ava and the professor notice a new public display screen in the street. They both stop and stare at the screen.*

Figure 7.2.1.13

A public interactive display screen (*Figure 7.2.1.13*) provides a holistic view of all of the local, active IoT sensors. Display screens provide ambient information and peripheral awareness but have the capabilities of eliciting thicker interactions for multiple pedestrians to view and interact with at once. It is public, accessible, and can link the user to open source data to provide an real time digital mapping of information.

Technological Touch points in AR

Ava has downloaded the application. She has had it for a while but rarely uses it. She still traverses across sensory embedded environments. How does the application notify her of local sensors—and if they are using her data or not?

4. *Ava now has the AR application. She rarely uses it and forgets that she has it. She is again, walking back from class. Sensors in her phone recognize an embedded sensor in the traffic light that snaps her geo-location data. The app notifies Ava that her data has been accessed. She gets a push notification telling her that a sensor is nearby and using her information.*

Figure 7.2.1.14

Access to sensors through ***GIS capabilities*** (*Figure 7.2.1.14*) can span multiple devices across the public and private realms, providing the widest range of accessibility from a variety of distances from the IoT sensor's location. GIS can enable viewing of heterogeneous sensor types, their location, and past and present information. While GIS can serve as a powerful reflective aid, it lacks the sensory and embodied dimension this investigation seeks to explore (overall). However, it can be an integral component to the system in terms of providing access to sensors and geospatial data.

5. *Having received the notification, Ava opens up the app and scans the environment. Visual indicators appear that mark active IoT sensors nearby.. She sees that there is a hot spot near the top of the traffic light so she pulls her phone out to face the light, which reveals detailed information. Ava learns that the light is equipped with an image surveillance camera that tracks her appearances and movements. She is alarmed so she taps on the light to see if her data specifically has been captured.*

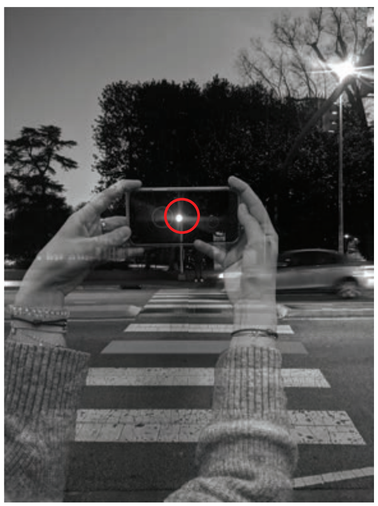


Figure 7.2.1.15

Markerless Tracking: BLE technology *(Figure 7.2.1.15)* Ava's phone, the mobile client, is able to connect with nearby IoT objects through beacon sensors that label and locate sensors based on object ID (Joe & Kim, 2016). A user can select a designated object to which can then transfer information about its tracking and functionality. This enables a direct communication between the user and the sensor in context of where the sensor exists—facilitating awareness of its presence.

Figure 7.2.1.16 (right) synthesizes Ava's journey with interventions along the way. It situates each touchpoint and draws connections among them according to their attributes.

1. Scope: (thin to thick) describes the level of attention the touchpoint could provoke.
2. Far—Near describes the access each touchpoint can give to the user. Do they engage with the system from afar or in near proximity?
3. Mode of Interaction situates the touch points in terms of modality. Most rely primarily on visual modes, while amplified reality, AR can provoke embodied, multisensory awareness.
4. Public vs. Private can facilitate shared experiences or private, customizable experiences.
5. Physical vs. Virtual points to ccessibility—are these touch points evident in the physical space, or do they require access to a connected device to gain awareness?

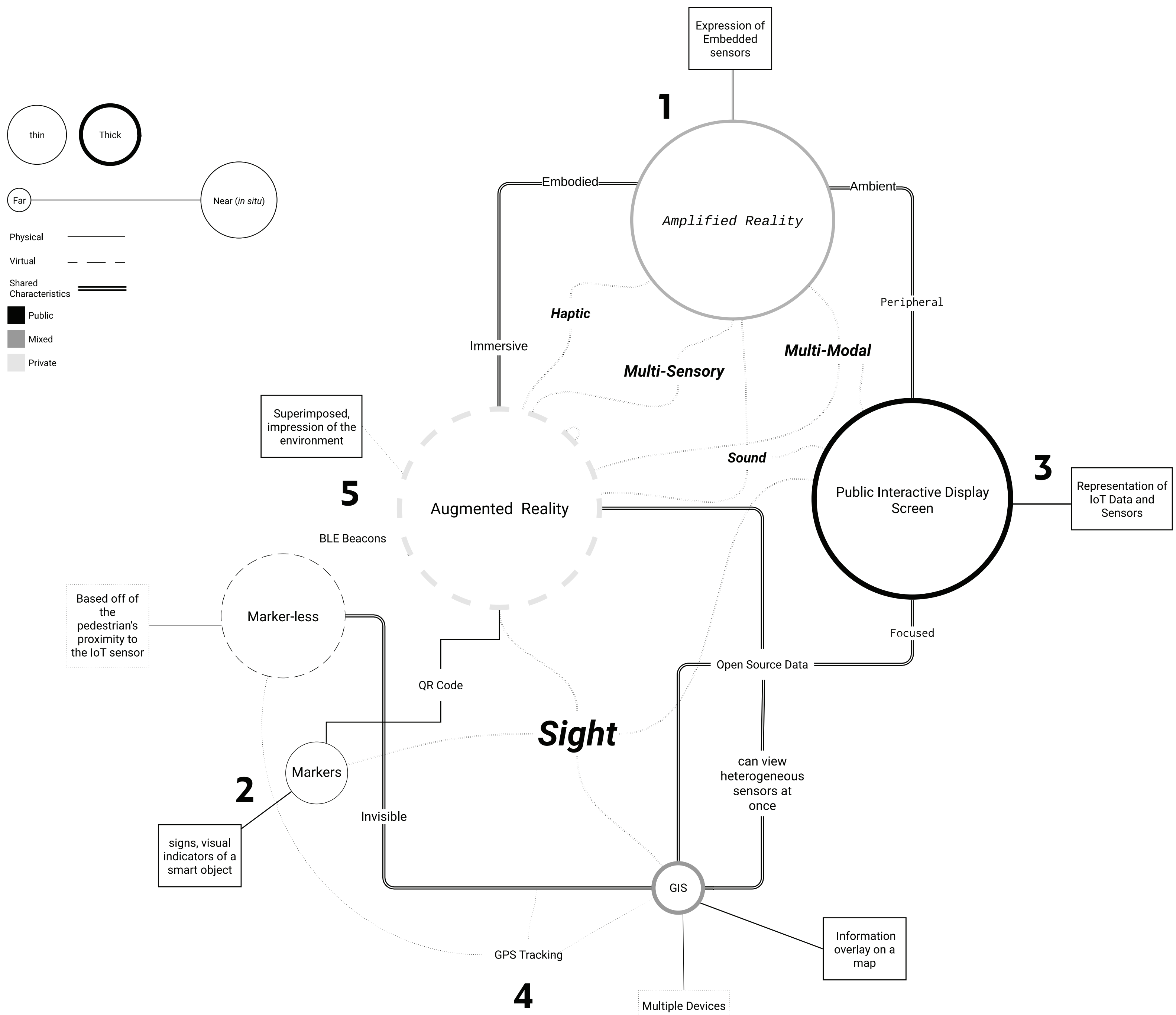


Figure 7.2.1.16

Findings

This study explores how an IoT sensor can be transparent through the design of multimodal, technological touch points in public space. These touch points vary in ***visibility, modality, location, and the type of information they provide.*** The result is a concept map that synthesizes these variables to deduce, where and when, these touch points should intervene.

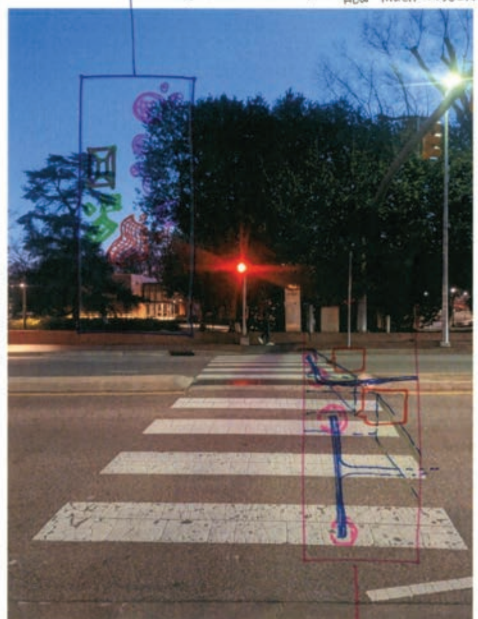
The idea of intervening is a way of creating friction—and can be a tactic to bring unaware pedestrians into contact with invisible systems. These frictions range from evoking ambient, thinner interactions that are successful in provoking a sensory awareness of space (ambient intelligence), to explicit, thicker interactions that enable access to detailed information (public interactive display screen). They explore the effects of facilitating awareness and in direct proximity to an IoT sensor. By gaining access to IoT information from afar (GIS), users can assess if they feel comfortable walking through the space. By engaging with sensors in situ (BLE), users gain awareness of their spatial scope.

From these studies, these questions emerged—***should the design of sensory embedded spaces bring awareness to the user or should the user seek it out?*** Should IoT infrastructure make itself visible through explicit interventions in the physical environment (public display screens and visible markers) or by implicit expressions of itself (amplified reality)? Should IoT infrastructure actively notify a user of its presence through nudges (push notifications and markerless tracking), or remain seamless and invisible? What are the ethics designers should consider when working in sensory embedded spaces?

Lastly, this study shines a light on the fine line between ***receiving too much information versus not enough***. A data collection notification system may provoke interest and action in some and irritation from others. How can we design awareness so it is customizable to users' needs?

WHY IT RELATES:
I CONSIDER MYSELF A
PEDESTRIAN COMMUTER &
I WONDER ABOUT THE PEOPLE
WHO DRIVE & THEIR IMPRINT ON
RALEIGH. I ALWAYS WONDER IF TREES WERE PLANTED OR
JUST GREW FROM POLLEN
THAT BEES SPREAD

WHAT WOULD IT SAY:
WHAT TYPE OF TREE? HOW MANY OF THESE TREES EXIST IN
RALEIGH?
IS IT NATIVE TO NC? HOW MUCH OXYGEN ARE THESE
TREES OUTPUTTING?
WHAT'S THAT
RELATIONSHIP W/
CAR EMISSION?
ARE TREES
PLANTED TO
CANCEL / BALANCE
INCREASED CAR
EMISSIONS?



WHY IT RELATES:
I WALK TO SCHOOL
OFTEN & I WONDER
IF SOMETIMES THE
CROSSWALK SENSES
ME B/C THE SIGN
TURNS ON WHEN
I'M CLOSE ~~OR~~

WHAT'S THE
INFRASTRUCTURE
LOOK LIKE?

IS IT USING M.L TO TURN ON
CROSSWALK SIGN BASED ON PATTERNS?

WHAT WOULD IT SAY?
HOW MANY SENSORS ARE EMBEDDED INTO
THE FLOOR?
DOES IT FEEL MY WEIGHT?
DOES IT COLLECT DATA ON HOW MANY
CARS PASS? ON HOW MANY PEOPLE
CROSS?
WHO HAS ACCESS TO THIS DATA?
CAN IT TELL ME WHEN THE MOST AMOUNT
OF PEOPLE CROSS? (WHAT TIME)

On a scale from 1 - 10 from least to most—how aware are you about smart technologies?	What is of most importance to you concerning smart technologies?
4	Information
8	Affordability - to avoid exclusion. also Transparency.
8	Control
4	Transparency
8	Privacy

Figure 7.2.2.1.

7.2.2 STUDY 2

Attunement

Attunement is an act of awareness, attentiveness, or responsiveness to something (Merriam-Webster, n.d.). In Design for Collaborative Survival, it is in the "ability to sense the livelihood of the nonhuman other" (Liu et al., 2018). Attunement focuses on how design strategies can translate IoT sensor and data functionality and intent according to these factors:

Their functionality: How they measure, monitor, collect, or trace data. Functionality is interpreted as how the IoT device works in the operational sense (where are the sensors located, what do they do and how they communicate and with whom or what).

Their intent: What data they measure, monitor, collect, or trace and why. Intent explores that type of information collected, its level of sensitivity, and how it should be presented to the user.

Subquestion Two:

HOW CAN THE DESIGN OF CONTEXTUAL LAYERS OF INFORMATION TRANSLATE IOT INFRASTRUCTURE'S FUNCTIONALITY AND INTENT?

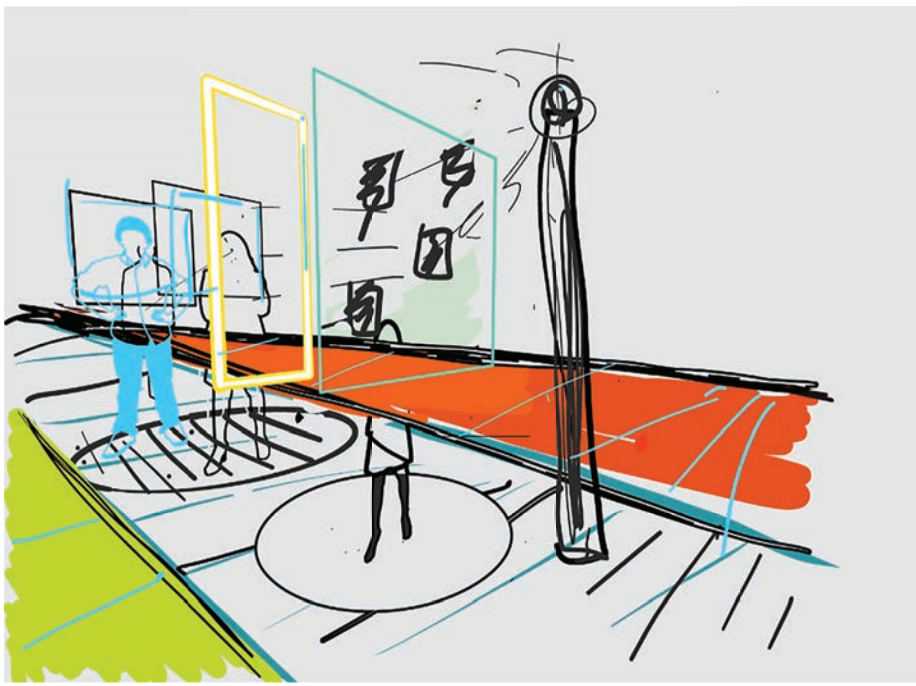


Figure 7.2.2.2

Figure 7.2.2.2. A sketch of Ava viewing sensor activity through the lens of AR.

Figure 7.2.1.1. A preliminary online survey inquired about citizen's hopes, fears, and level of awareness of IoT devices in smart cities. This question asks "what is the most important to you concerning smart technologies?"

Early Investigations: Setting the Stage

Early studies (Figure 7.2.2.3.) approached translation from the lens of expressivity. I applied the metaphor of biological sensing in an effort to align IoT sensor functionality with that of human sensing. As such, representational strategies look animistic, organic, and creaturely. Thus, the concept of co-sensing with the city sensors emerged. This idea was derived from research into participatory citizen sensing projects through the lens of sense-making and served as the backbone for the remaining design provocations (Gabrys, 2016).

Figure 7.2.2.3.

Sensors

Later visual studies identify levels of information needed to bring awareness to an IoT sensor: level one provides awareness to its location and identification of the sensor. Level two provides information to the sensor's mechanics, and information it collects.

Level 1:
Provides awareness to the sensor's location and identification.

- Highlighting, blocking, marking, and sound uses ambient awareness as a means to inform the user of the sensor's location and activity, providing insight into contextual and thin operational information (whether it is on or off).
- Metaphor and symbols use representational strategies to identify the sensor in space, providing insight into contextual and labeling information.
- Textual overlay uses explicit information to label, identify, and describe all aspects of the sensor.

Level 2:
Provides information to the sensor's mechanics and information it collects.

- Hologram: (Mirroring or showing) uses simulation as a means to inform the user of the sensor's mechanics explicitly, providing insight into how it works.
- Textual overlay explicitly labels or describes the sensor, providing richer detail for the user to explore further.
- Linking: Gives access to relevant information that may be related or tangential to the sensor.
- Infographic: provides richer detail of sensor information or user data in context.

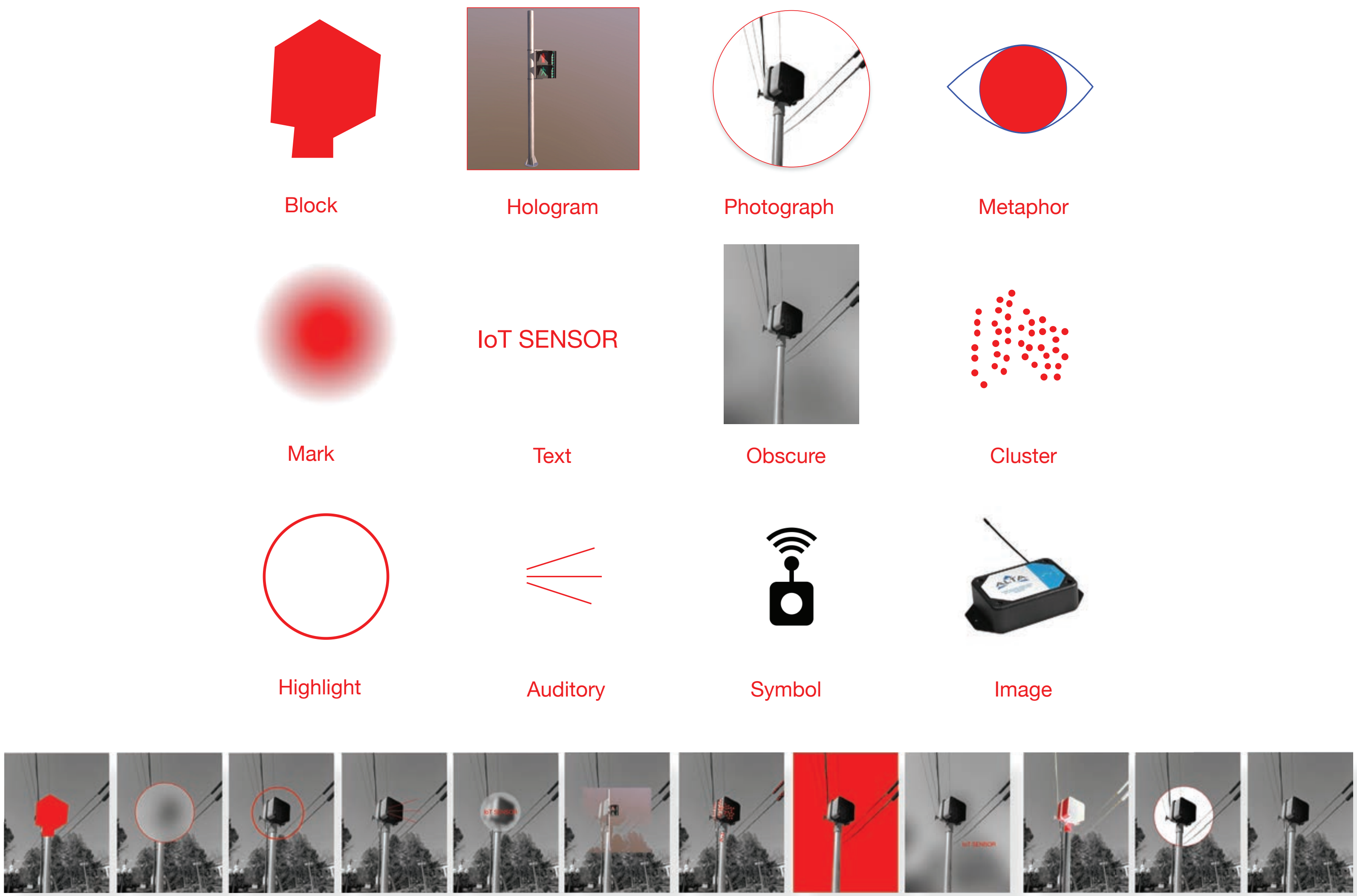


Figure 7.2.2.4.

Figure 7.2.2.4. Strategies show potentials across different modalities according to level one awareness that range from detailed to abstract, implicit to explicit, metaphorical to descriptive, symbolic to textual, and visual to auditory. These tactics serve as identifiers of the sensor (labeling) and identifiers of its location, and type of activity.

Figure 7.2.2.5. (Left page) The three figures illustrate level one of information that brings awareness to the sensors location and type through highlighting and textual overlays.

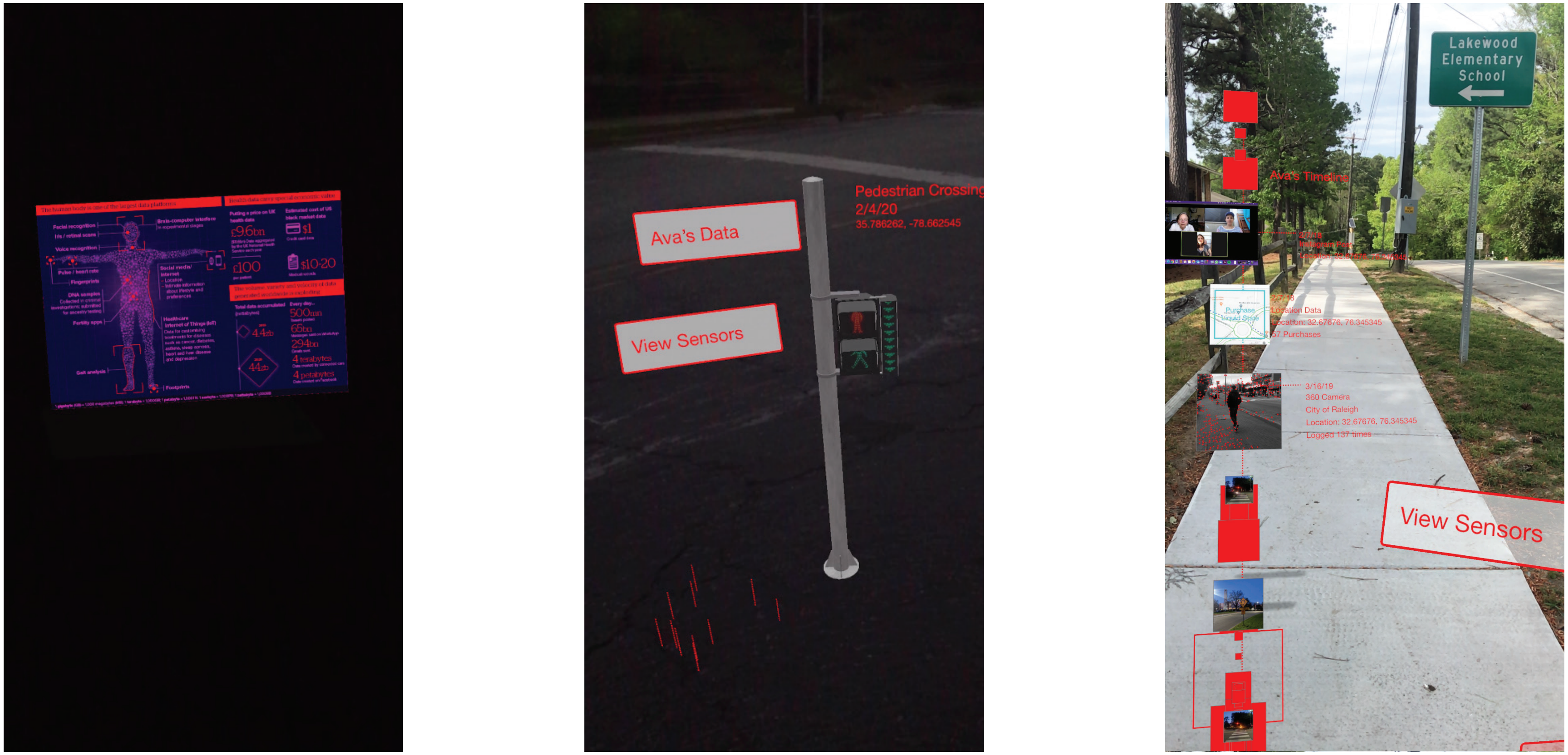


Figure 7.2.2.6. (Right Page). The three figures illustrate level two of information types that provide access into richer, more detailed information about the user or the sensors through use of text, holographic simulation, or mirroring its data collection.

Figure 7.2.2.7

Type of information	What does this say about the environment, the person, the sensor, the interactions to gain awareness.	
Detail and Abstraction	What is the highest level of abstraction that still results in meaningful information	Do people have access to direct information?
Inference and Explicitness	Is there risk for mis-interpretation?	Could the information allow for deception?

Table 7.2.2.1

Contextualizing Studies

To move further with this study, I added context: observational studies of Hillsborough Street and a detailed analysis of the IoT infrastructure (Figure 7.2.2.11.) informed sensor and data potentials that Ava could interact with. I chose a 360 surveillance camera, Ava's personal data, and a crosswalk and applied the DASS framework and level of sensitivity framework to guide representation strategies

The 360 surveillance camera (Figure 7.2.2.8.) continuously monitors and records wide areas. It provides a 360 view and is equipped with a fish eye lens. It has capabilities of infrared vision to detect moving objects and smart surveillance to detect any unusual actions. On the utopian end of the surveillance camera, it monitors the street for safety. On the dystopian end, it can collect biometric data in the form of facial recognition. A surveillance camera is public and infrastructured, therefore it collects sensitive content. It is ubiquitous, always on, and a pervasive form of information collection. The surveillance camera investigates information type and levels of privacy. These studies bring awareness to explicit data capturing that could be highly sensitive.

Personal digital data (Figure 7.2.2.9.) are heterogeneous and dynamic assemblages that describe human actions and traits (Lupton, 2020). They are generated through mobility in sensory embedded spaces and actively through inputting data into a networked system. These data can describe a user's appearances, movements, location, tagged media, purchases, among others. They are distributed among various devices and technologies in the infrastructured space. Personal data studies explore materializations of data with an emphasis on their attributes and context. These studies tell the user about themselves in relation to the environment—explicit data capturing that could be highly sensitive.

The crosswalk (Figure 7.2.2.10.) investigates heterogeneous sensors and data in context. These studies explore how these sensors and data can be differentiated from each other through representation, motion, and applied interactions. This study focuses on what the application can tell the user about the environment. They explore the use of a hologram to simulate sensor mechanics in context. This sensor detects motion or weight and thus, collects anonymous information and would not be considered highly sensitive to the user.

Figure 7.2.2.8.

Figure 7.2.2.9.

Figure 7.2.2.10.

Figure 7.2.2.7. is an analysis of a 360 surveillance camera using the DASS framework, ***Table 7.2.2.1.*** The DASS framework gives a structured and holistic view of how designers can implement awareness of information into the design of interactive and shared systems (Niemantsverdriet et al., 2019).

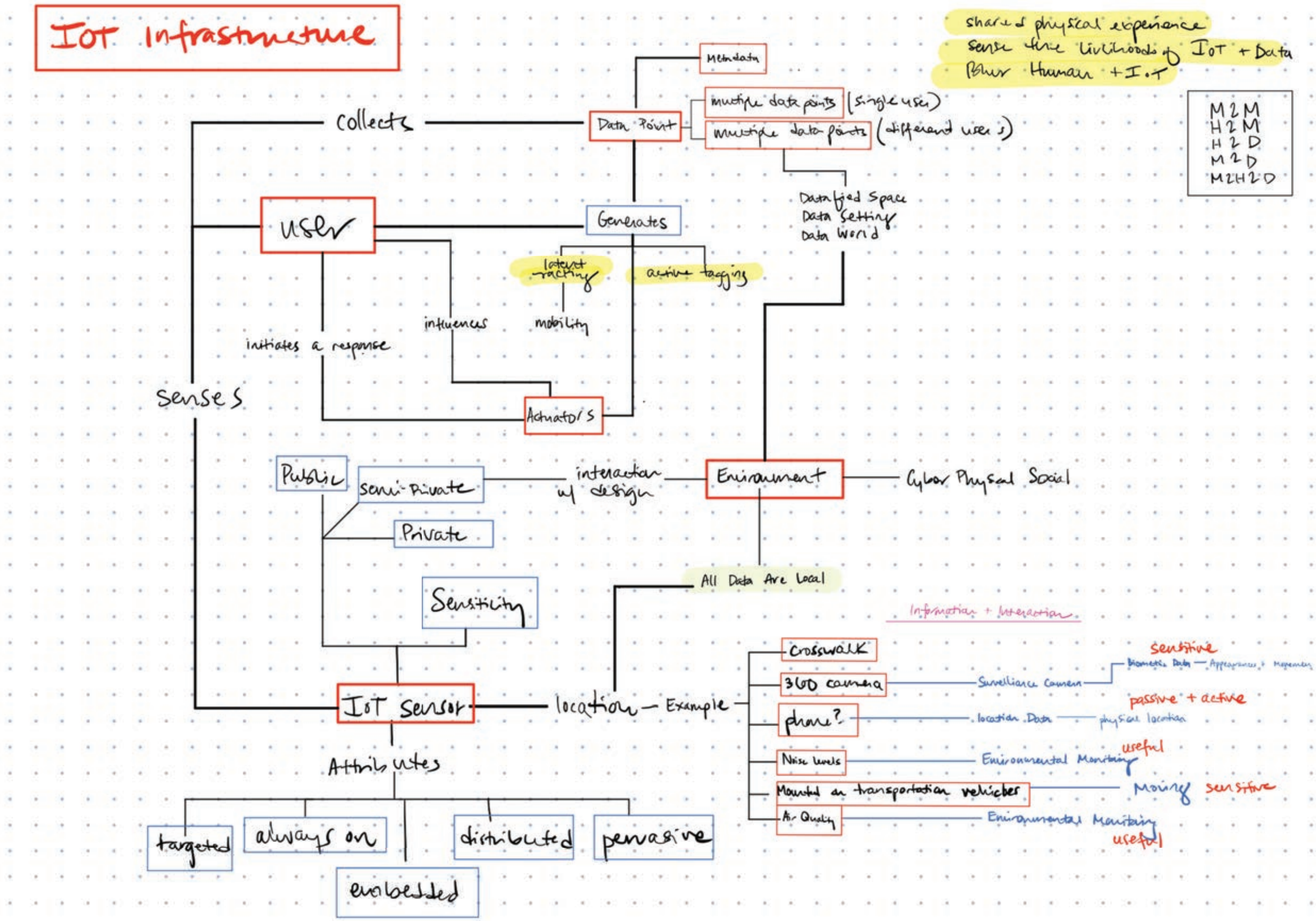


Figure 7.2.2.11.

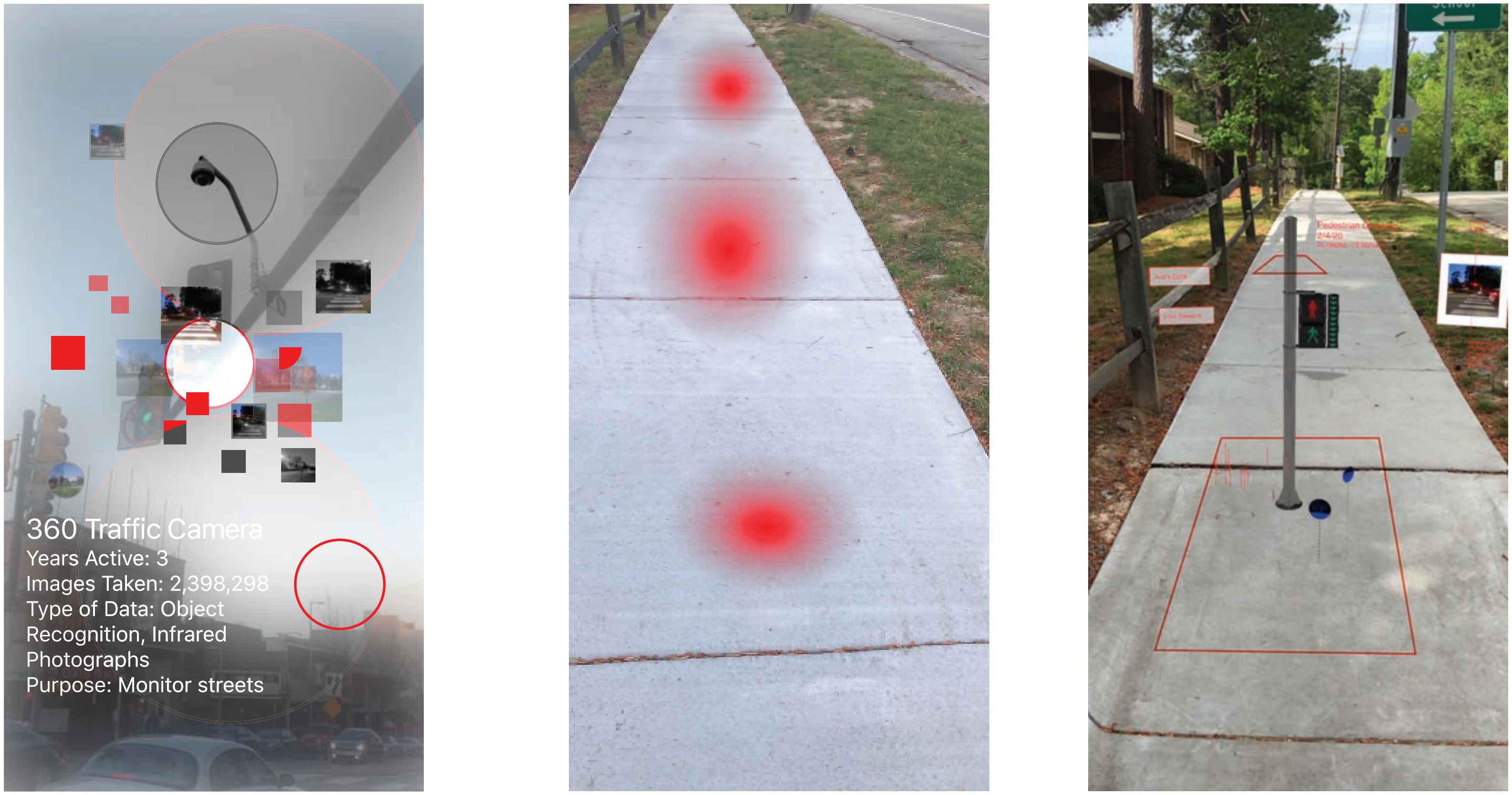


Figure 7.2.2.12.

Figure 7.2.2.11. The IoT infrastructure comprises a triangulation of generation and translation of data among humans and their technological devices, and sensors embedded in the environment. This analysis informed a contextual understanding of IoT infrastructure.

Figure 7.2.2.12. illustrates three different ways to emphasize information in AR. Each sensor differs due to its visibility, intent, and level of sensitivity to collected information. The surveillance camera, a visible sensor that collects sensitive information, emphasizes its content (photos and video footage) over its mechanics (how the camera works). The embedded crosswalk sensor obscures its content and provides ambient awareness to its presence and activity. The crosswalk hologram brings awareness to how it works through a simulation of its operational mechanics accompanied by textual information.

Findings

Each sensor's functionality, sensitivity of collected information, and physical visibility may differ, which can affect how it is represented in AR. Sensors that collect sensitive data should emphasize the information; whereas, sensors that collect anonymous data that is less of a user's concern could emphasize ambient awareness of its location. Sensors whose mechanics are more obscured—how it works and what it does, could benefit from simulating that phenomenon as a hologram. Information privacy also needs to be considered, either by blocking out others or only revealing data points that are related to the user.

Figure 7.2.2.13. Data visualizations

Figure 7.2.2.14. Data Point Visualization

Figure 7.2.2.15. Tagged Metadata

Data

In addition to sensors, I experimented with form and representation of data.[1] These data are generated through the triangulation of people with their digital devices, apps, sensors, and online platforms. Details can include interactions online, use of mobile and wearable devices, and movements through sensory embedded space. These actions tell stories about peoples personal habits, preferences, bodily functions and movements; and about people's attributes: their age, gender, birth date, email, address, sexual identify, geo-location, purchasing habits, ethnicity (Lupton, 2020).

Renderings of data in Figure 7.2.2.20 illustrate data points and their attributes in context. I explored abstract, organic, geometric forms that incorporate textual components, multimedia, and imagery. Initial data points were creaturely and organic. These explorations show how symbolic, textual, geometric representations can house data information.

1 Exploration are informed by Vital Materialist and More-than-human theories that consider data to be deeply entangled with human action (Lupton 2017, 2020). Terms like data double, data traces, data trails, the social life of data, data materializations, data physiciation are applied. These concepts imply a sense of human ownernship to data—they are extensions, by products of human action that are then ciruclated through the digital economy to bought and sold and used beyond their intended uses (ibid., 2017, 2020).

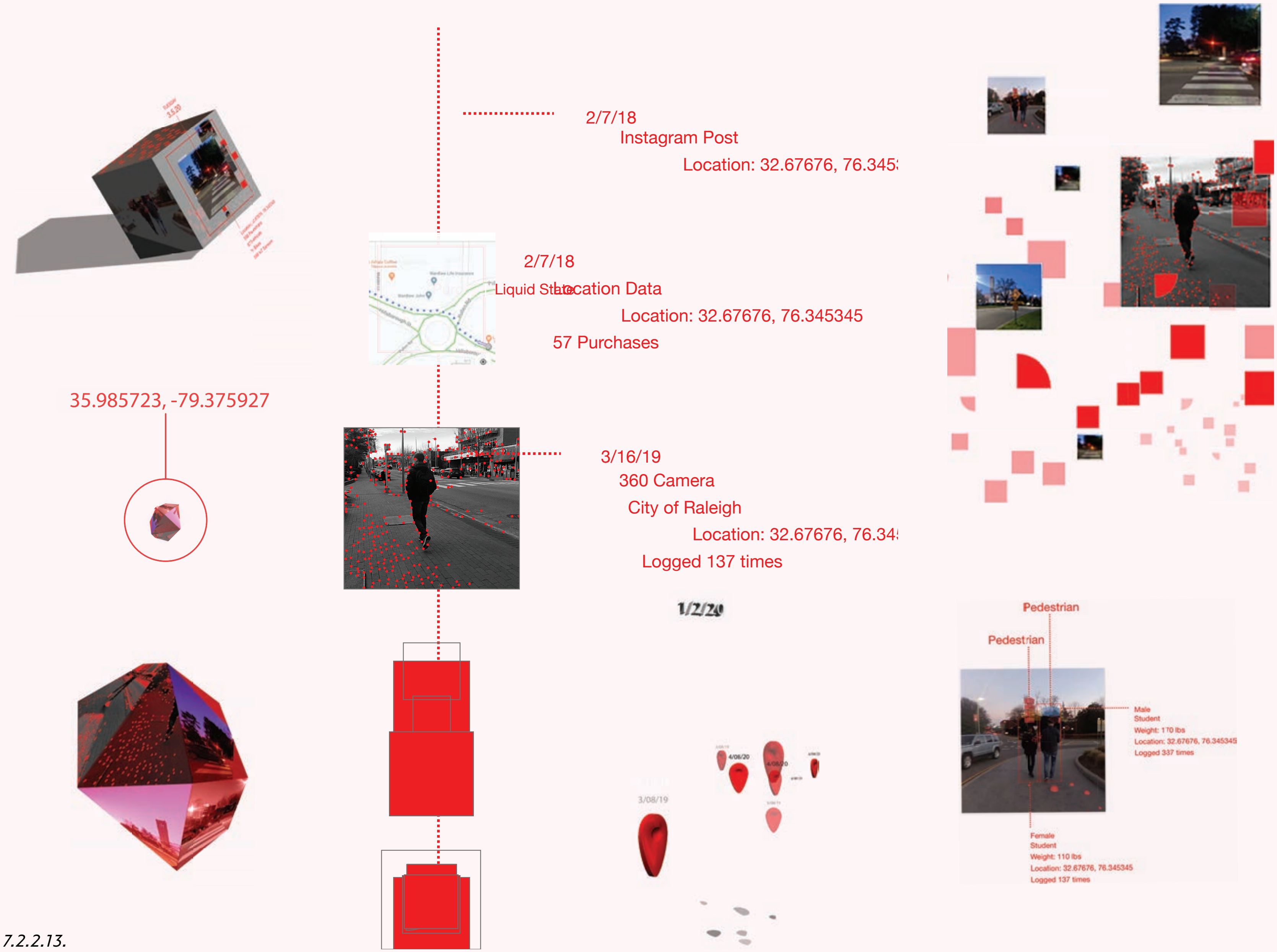


Figure 7.2.2.13.

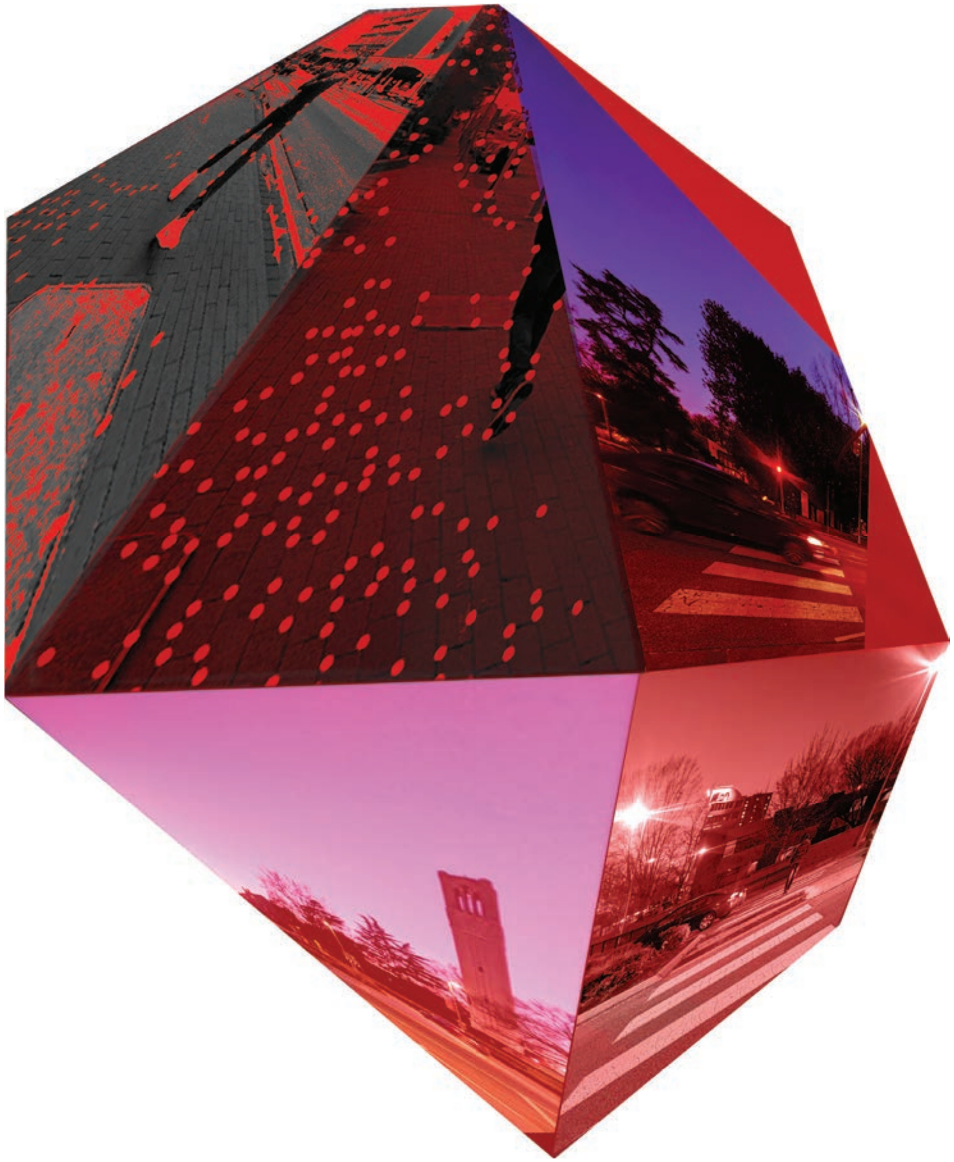


Figure 7.2.2.14

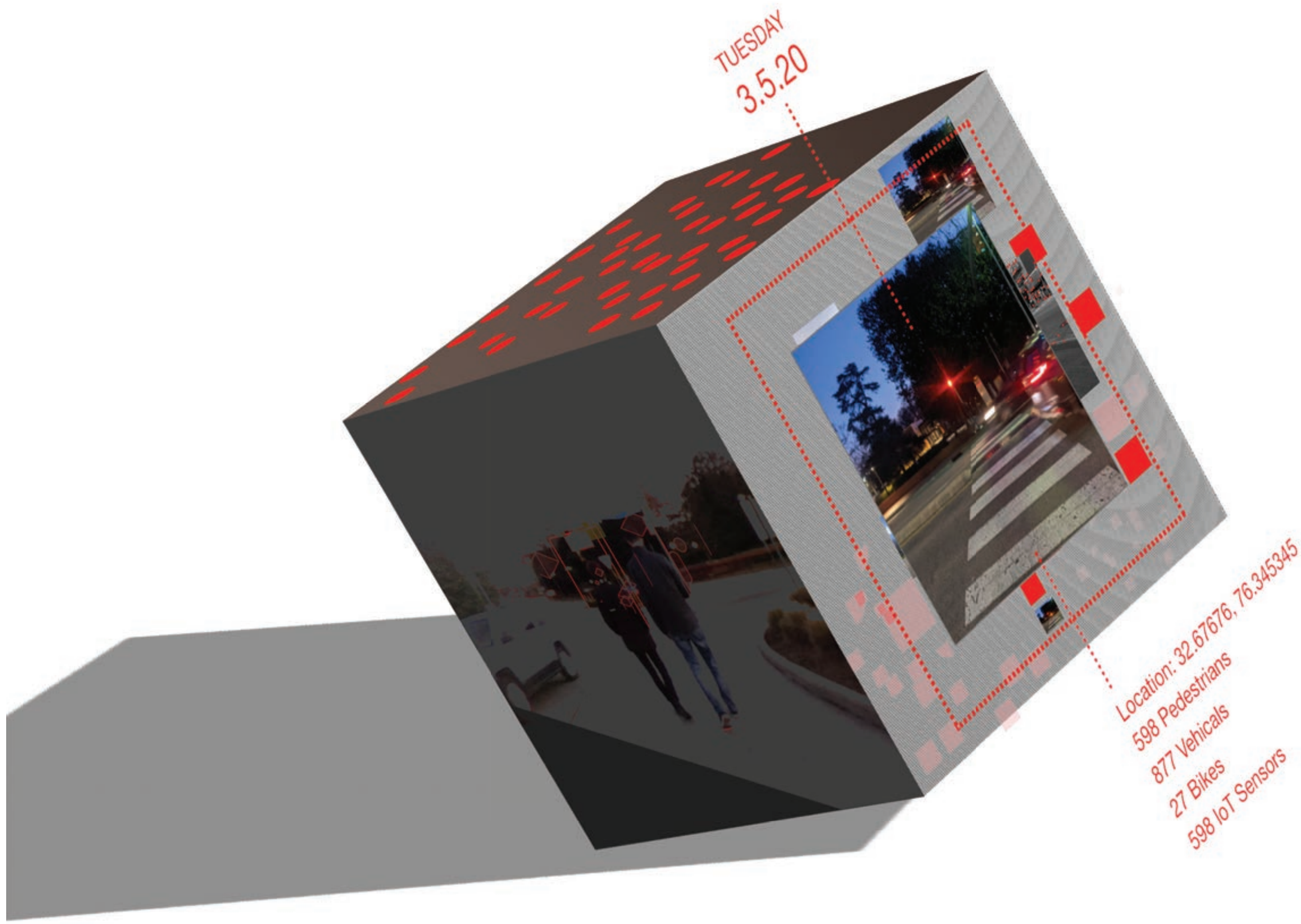


Figure 7.2.2.15

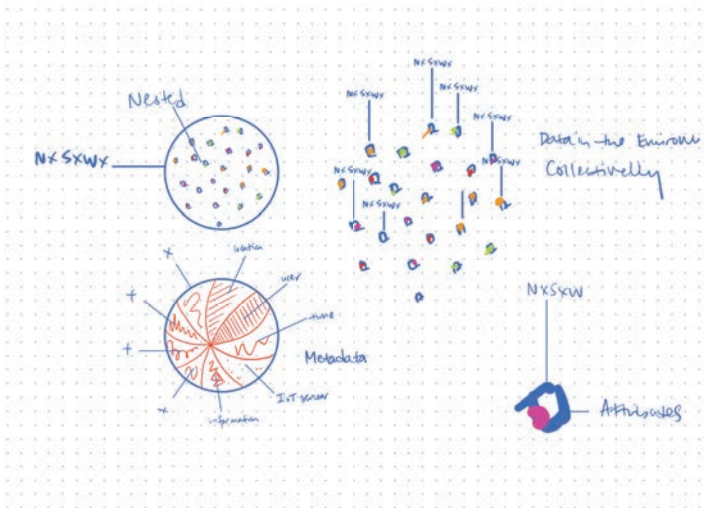


Figure 7.2.2.16 (Above)Illustrates how metadata can be represented on or within a single data point. Are metadata divided on the surface? Or are they represented as individual fragments as a part of a larger data set. Could they be nested within a data point and provoke tapping or entering into a data point, data world, or data set? Or is metadata tagged onto the surface of the data point?

DATA-DIMENSIONALITY

To break down the components of data, I created sketches (Figure 7.2.2.16.) that explore what a data point, data set, data setting, data world, datafied space, and metadata could look like (Lupton, 2020; Loukissas, 2019; Sumartojo et al., 2016). Metadata are descriptive components of a single data point such as its name, location, time, color, shape, and size. When data are grouped together and analyzed they then become meaningful information (Redstrom & Wiltse, 2019).

Figure 7.2.2.17 (Above) The series of images illustrate data dimensionality. From the left to right, the images explore tiny fragmented heterogeneous data points; enlarge polygonal forms that indicate volume; added attributes on data's exterior, nested data, tagged and annotated data, and geo-located data.

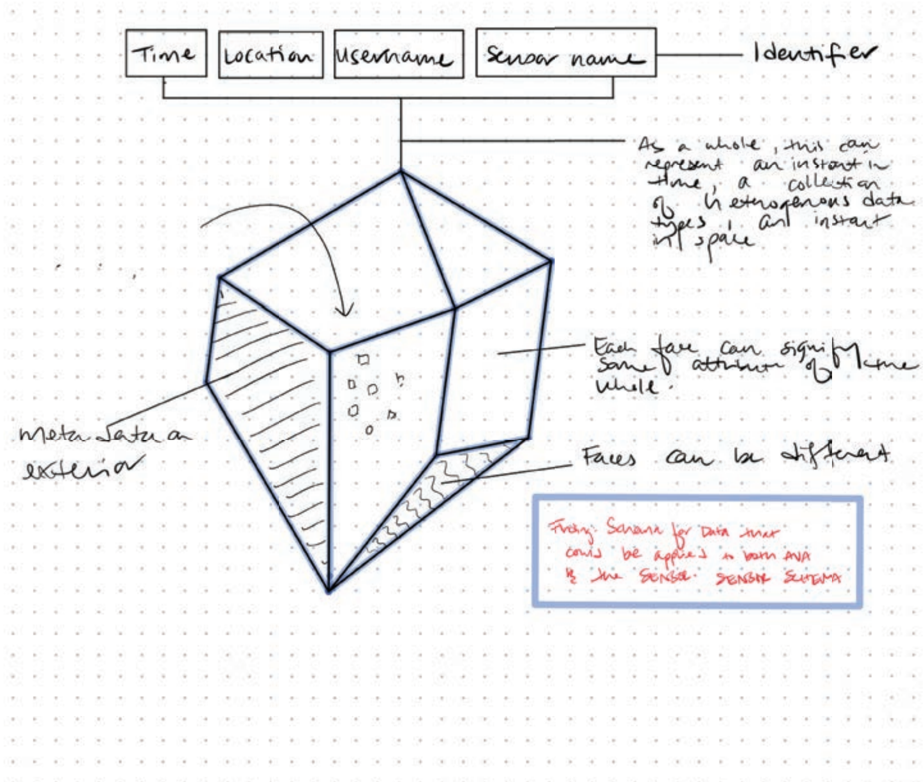


Figure 7.2.2.18.

METADATA SCHEMA

From these explorations emerged an idea of an overarching metadata schema: a modular system that enables heterogeneous information types to be housed in one data point. This system takes into consideration data's components: such as location, time, content, and media, and enables them to shift in hierarchy depending on the users preferences (or the location's and sensor's needs). With this schema, the same form (Figure 7.2.2.189) can represent a single user's data set or a grouping of heterogeneous data points by different users or sensors, and so forth.

DATA ASSEMBLAGE

Ava's (@AVABRnt09) data assemblage (Figure 7.2.2.19.) shows the relationship of her data with specific actions, time, location, and capturing device. It is an abstract representation that depicts the types of relationships the data schema can show when applied in the application. Each polygon consists of an attribute that describe some action that generated data—an Instagram post, a walk past a surveillance camera, and her recent purchases. The assemblage also shows how she is connected to other users depending on location, time, and type of device. For example—at 12:45 pm the surveillance camera took a photo of both Ava and the anonymous user (@weui56).

This assemblage also depicts how data can be identified initially in AR—either by location, time, or username and the type of information that can be nested within each point. For context (Figure 7.2.2.20)

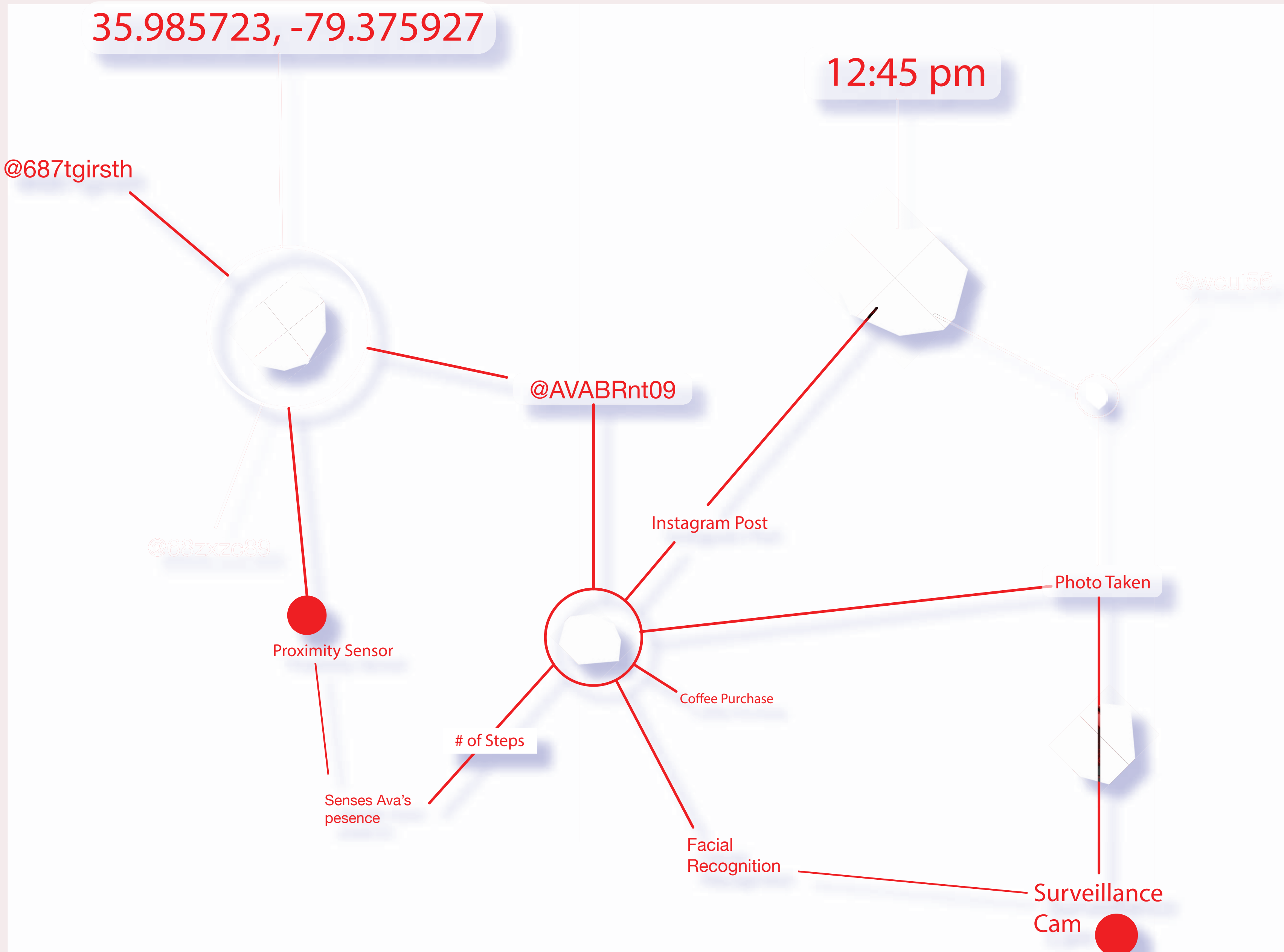


Figure 7.2.2.19.

Figure 2.2.2.20 (Left page) Schema applied in context.

Figure 2.2.2.21. (Right page) Detail example of Ava's data according to time: At 12: 45 pm, Ava uploaded three tweets, tagged a photograph, and had her photograph taken by a nearby surveillance camera. All of this information is nested within a polygon data point.

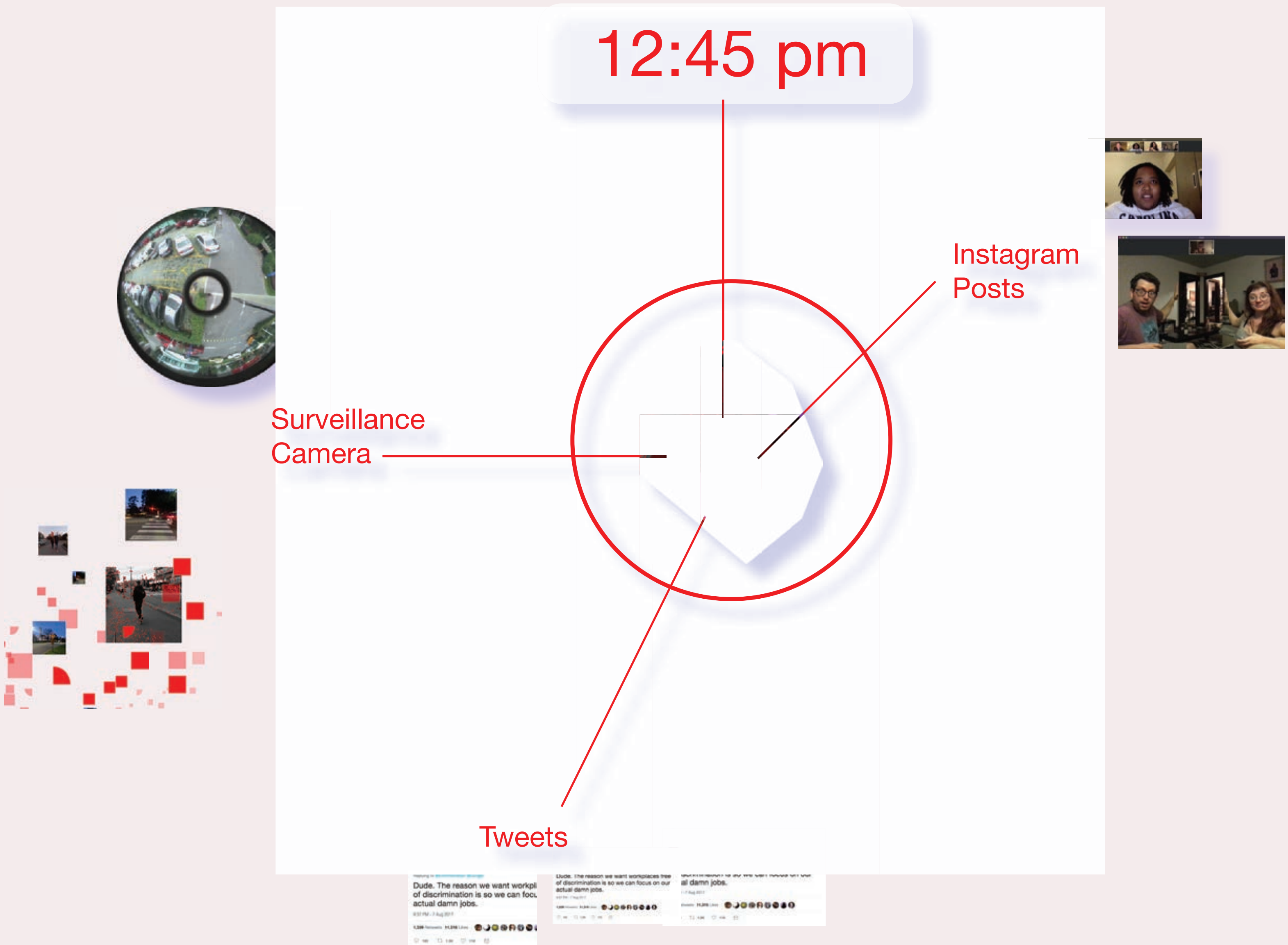
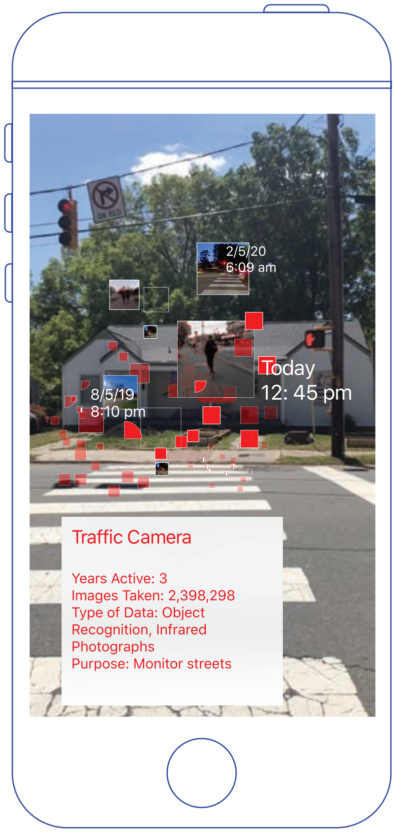
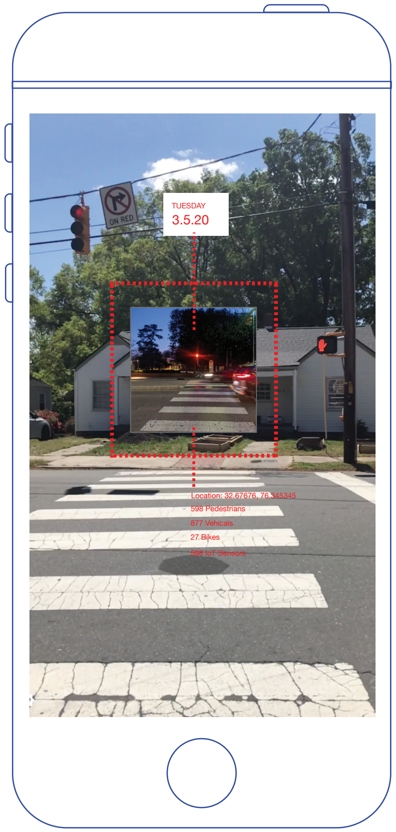
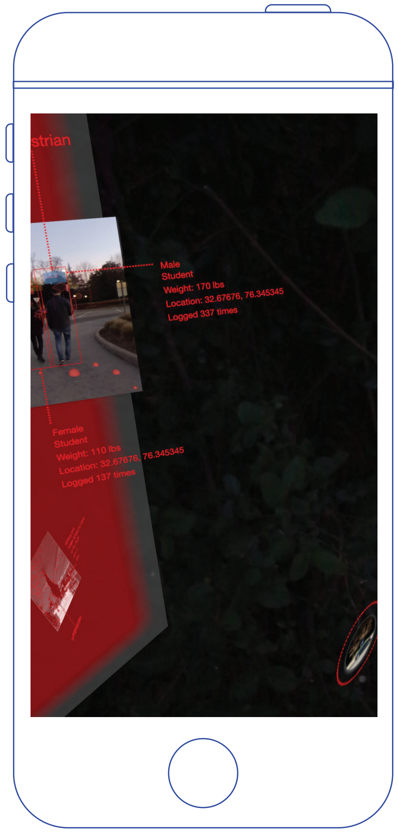

12:45 pm
Instagram Posts
Surveillance Camera
Tweets

Figure 7.2.2.22. Applying the Data Schema: This visual illustrates the move from seeing multiple, heterogeneous data points from afar to specific metadata details.


2/5/20
6:09 am
Today
12: 45 pm
8/5/19
8:10 pm
Traffic Camera
Years Active: 3
Images Taken: 2,398,298
Type of Data: Object Recognition, Infrared Photographs
Purpose: Monitor streets


TUESDAY
3.5.20
Location: 32.67676, 76.345345
598 Pedestrians
877 Vehicals
27 Bikes
598 IoT Sensors

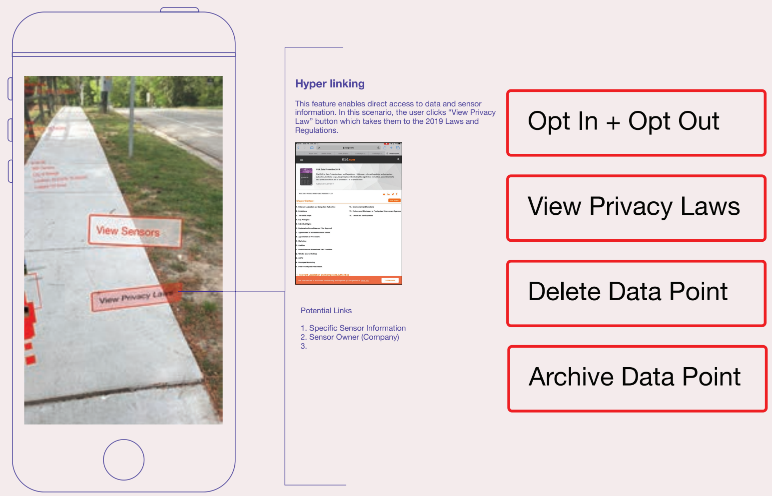

strian
Male
Student
Weight: 170 lbs
Location: 32.67676, 76.345345
Logged 337 times
Female
Student
Weight: 110 lbs
Location: 32.67676, 76.345345
Logged 137 times

Information

The second part of this study focuses on the information that can be relayed (see Level two information). It became clear that specific prompts would be different depending on the sensor and data the user was interacting with. These investigations explores the use of text, infographics, and hyperlinks to provide richer interactions with sensor material. While the scope of this study focuses more on developing a strategy for representing the information, development can be had to further typographic elements, User Interface (UI) components of the application, and information possibilities. These explorations illustrate the following:

- Hyperlinking to direct the user to more detailed information online. (Figure 7.2.2.23)
- Interactions that encourage user privacy and control over their data (Figure 7.2.2.23)
- The ability to change scenes in the environment to view sensors, local and personal data in the same location (Figure 7.2.2.26)
- Holograms to simulate sensor functionality (Figure 7.2.2.27).
- Contextual information rich with text for the user to read, archive, or save for later (Figure 7.2.2.25).
- Information that takes the form of its media as in (Figure 7.2.2.24).

These examples provide only a fraction of possibilities for information to be accessed in the app. They do highlight the need for linking the object to detailed information on site, opportunities for opting in and out if they do not want their data represented in the app, filtering options so they can choose what they want to see in the environment.



7.2.2.23

Figure 7.2.2.24

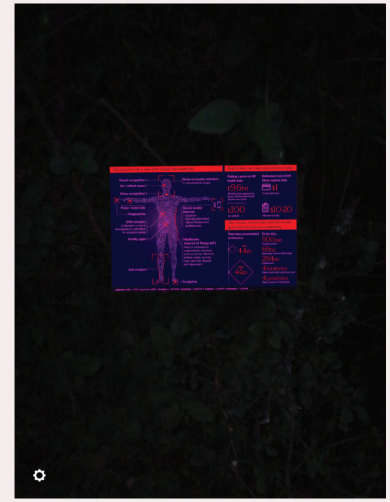


Figure 7.2.2.25

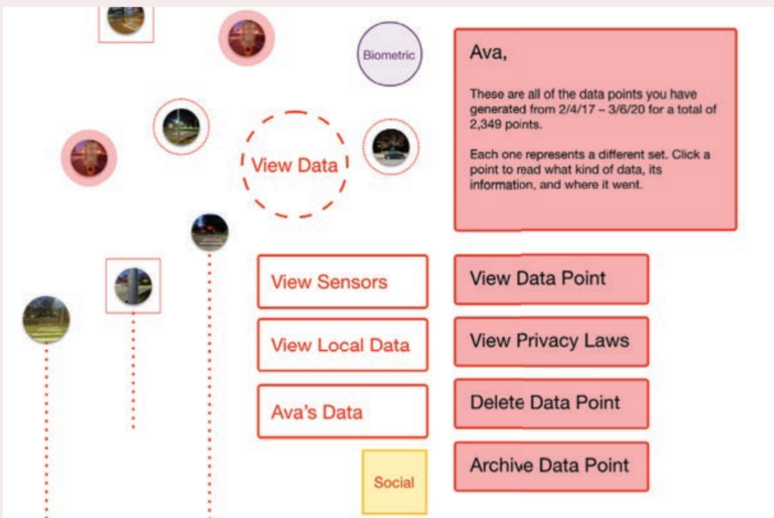


Figure 7.2.2.26

Figure 7.2.2.27

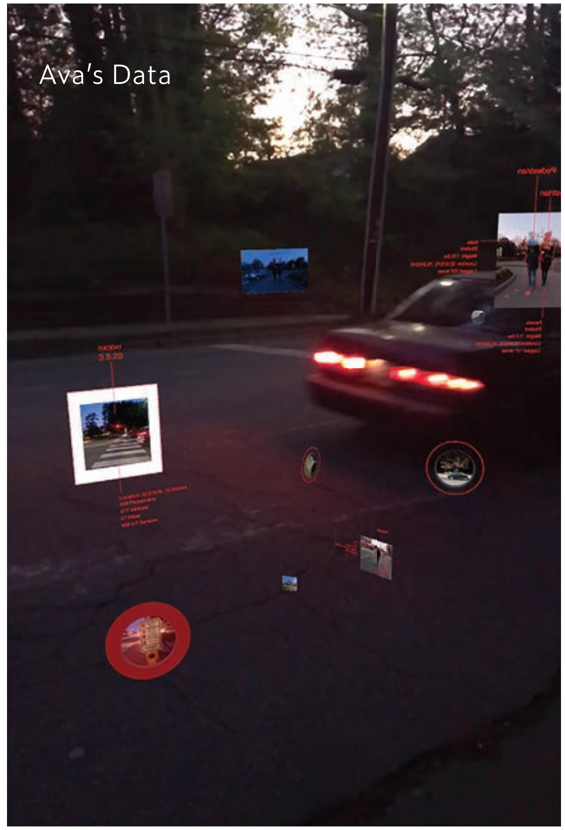
Explorations

The following images combine all of the elements discussed in this study. They were created with the assets in (Figure 7.2.2.26). that were put into torch AR in which interactions were applied to simulate the User experiencing viewing sensors, interacting with data, and gathering information *in situ.*

Note how the data schema applies—how sensors are represented in space, and how different buttons provide a range of interactions and access to information. These visualizations show the material, physical nature of data represented in space—a primary focus of this study.

Figure 7.2.2.28 These series of images are prototyped images used in Torch AR.


Lakewood
Elementary
School
View Sensors


Ava's Data

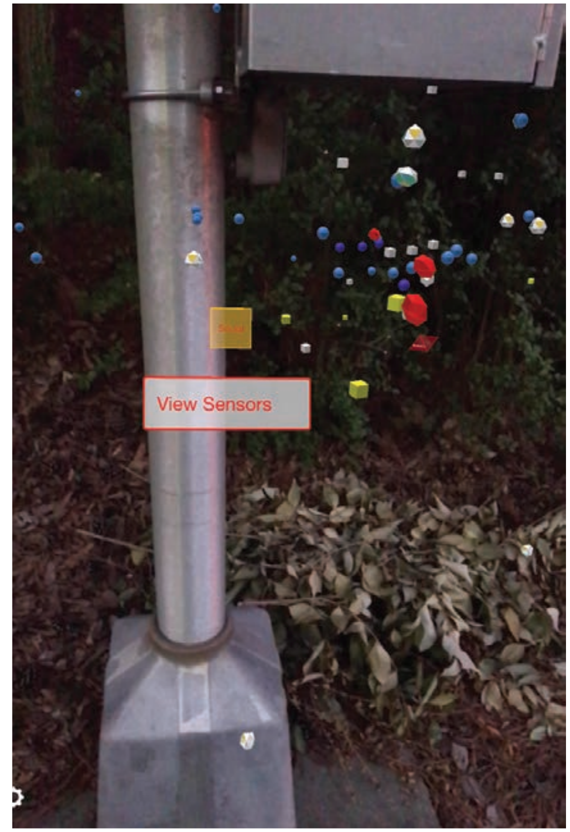
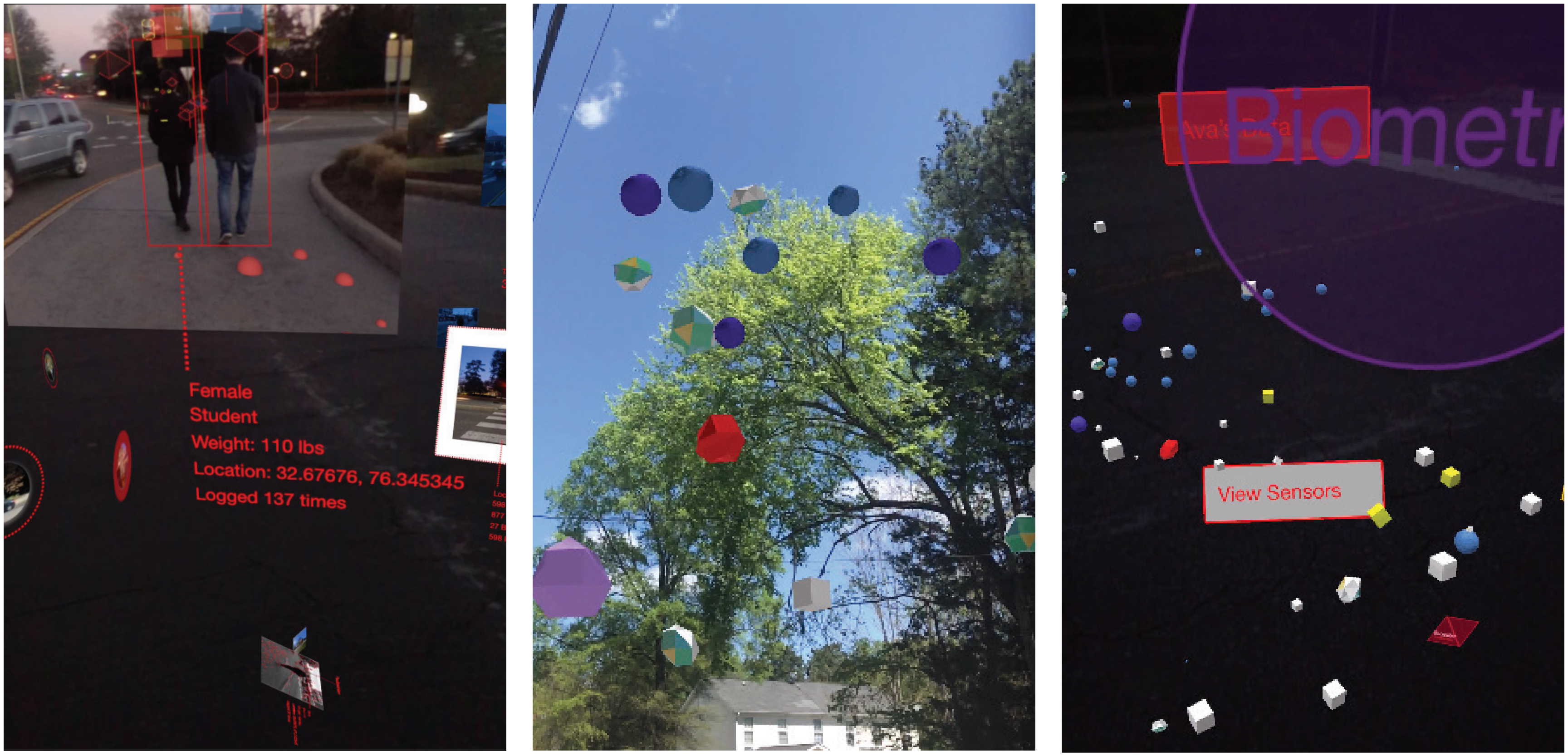

View Sensors

Figure 7.2.2.28 These series of images are prototyped images used in Torch AR.


Female
Student
Weight: 110 lbs
Location: 32.67676, 76.345345
Logged 137 times
Biometr
View Sensors

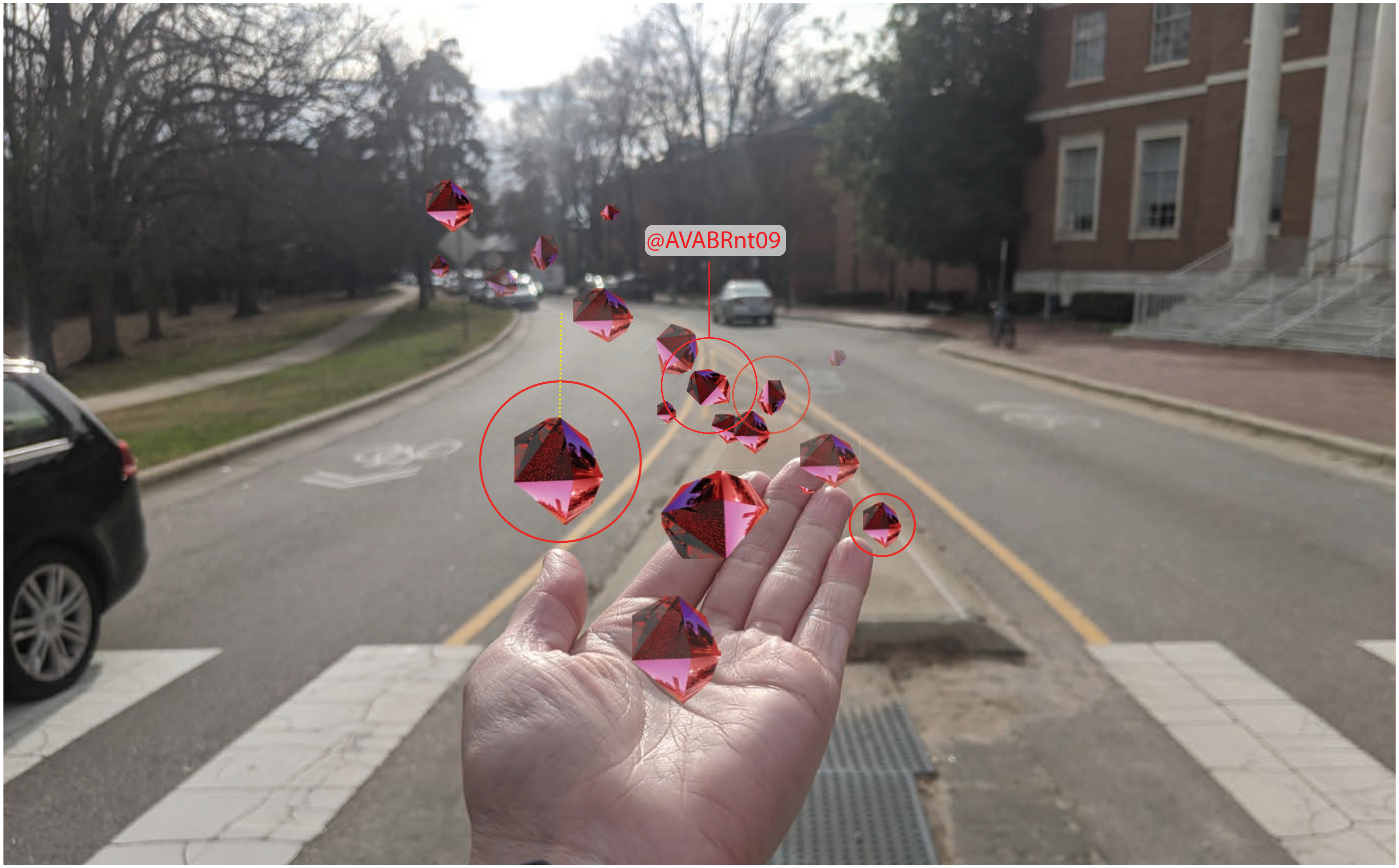
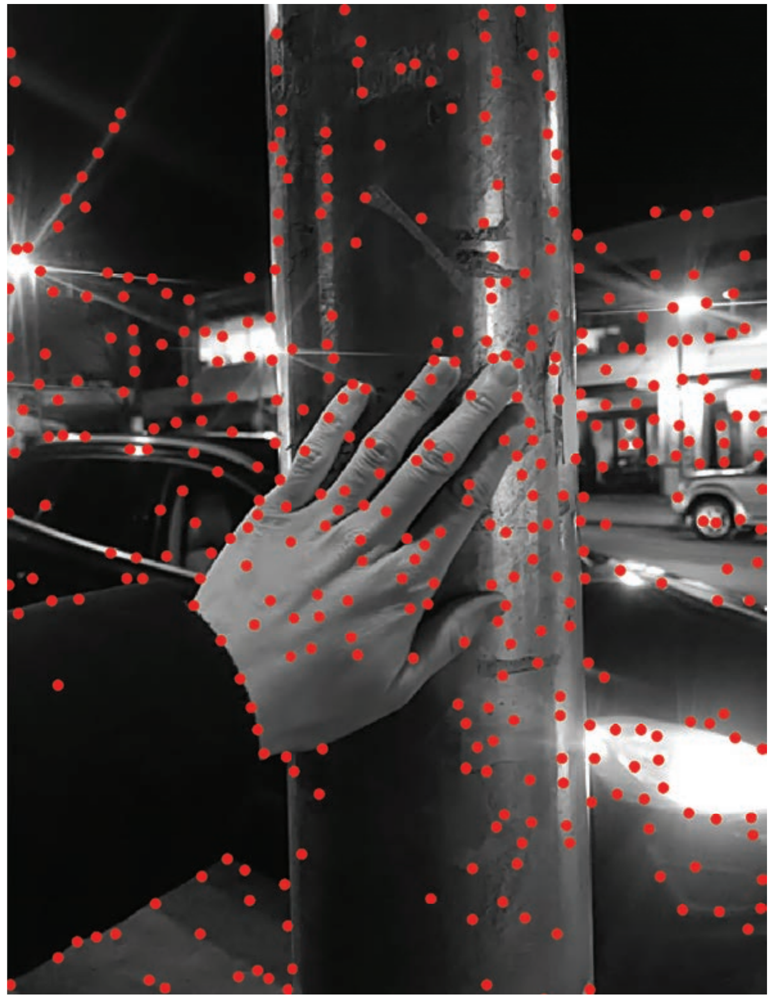


Figure 7.2.2.29 Ava holding her data.

Findings

This study explores contextual and expressive awareness of sensors and IoT data. It details how they can bring awareness to themselves in the environment through tactics that highlight, locate, describe, or simulate their mechanics and intent. It then explores the format in which the information can be given: overlaid text, hyperlinking to websites, providing detailed infographics. It also questions how sensors and data can be differentiated from each other and convey information that is aligned with their purpose—what they do, how they do it, how sensitive a sensor may be to a user. This study proposes a data schema that can be applied in the design of data (and sensors). Metadata can be represented by tagging, nesting, or overlaying information on some form—this information can shift in hierarchy according to the user's preferences. It explores how added motion can help translate data and sensors to the user and proposes that motion should be applied to sensors to show that they are "active" and "collecting data" and only to the data points when they are being interacted with. The study suggests that the format in which information is presented should be related to its context (hyperlinking vs. infographic)—where would the user want to read thick information and where would they want to access it later. Lastly, it proposes that designers should consider how to privilege certain information types when designing for sensors that collect sensitive or anonymous information.



What is one fear you have about the potential for smart technologies 5 years from now?	On a scale from 1 - 10 from least to most—How would you rate your level of interest in smart technologies?
that technology will just be even more addicting and have bad mental and health effects on the next generation from the amount of use.	4
Being forced to use them to be part of society groups/ or at work	7
They will control or watch over things that are inappropriate	9
The current trend will intensify in a more permanent manner. Before we incorporate tech into our bodies semi-permanently I'd love culture to have a healthier relationship with devices.	7
All information is bought and sold	6
that they are so reliant on functioning electricity	9

Figure 7.2.3.1 Smart City Survey

7.2.3 STUDY 3

Expansion

Expansion is the blurring of the nature–culture division. It is the result of engaging with the environment and becoming more attuned to its experience (Liu et al, 2018). This investigation seeks to provoke an expanded awareness of data and IoT sensors by engaging with its materiality through embodied interactions.

Subquestion Three:

HOW CAN THE DESIGN OF APPLIED INTERACTIONS FACILITATE AN EMBODIED AWARENESS OF INFORMATION WHILE PROMOTING USER AGENCY?

Figure 7.2.2.2 Sketch of Ava in Augmented Space

Figure 7.2.3.3 This study consists of a series of walks down Hillsborough Street in Raleigh, NC using a machine vision app that detects object recognition, corners, blobs, angles, lines, and so forth. These images are overlaid with hundreds of tiny dots that represent the algorithmic understanding of space and resemble a thick, data-fied atmosphere.

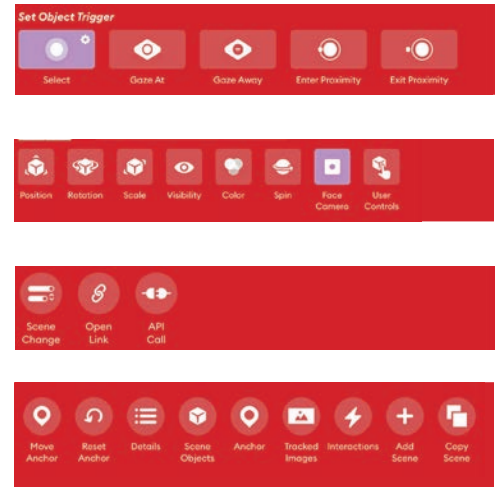
Embodiment

Expansion covers interactions that are synonymous with embodiment in the context of AR. Embodied Awareness unfolds through the experience of walking, locating, accessing, and interacting with sensors and data in augmented space. It is a multisensory, physical experience that can be facilitated in design through interventions that initiate movement (such as leaving traces for a user to follow), provoking first person perspective—the user is the enactor rather than the observer—and through blending in with the environment (Hummels & Dijk, 2015). Through the lens of DASS, expansion can be initiated by considering where information is represented (e.g., highlighted in the environment or viewed through an interface); by observation of the surrounding environment (time of day and ambient use of space), and by assessing effort and intentionality needed to effectively transfer information (Niemantsverdriet et al., 2019).

Interactions

In Torch AR, applied Interactions are what enable the user to sift through different levels of information. By tapping on a sensor, the user can shift to a scene which houses the sensor and data information. By tapping or gazing at a data point, the user can view metadata. The information accessed through interactions tells a story about the environment, the sensor, and the user (Figure 7.2.3.4):

However, when data points and information are floating and spinning from a distance and in unreachable locations, the effects and requirements of the body to achieve interactions need to be factored into their design. If not considered, the experience can be diminished by cognitive and perceptual hindrances such as distortion and resolution, viewpoint mismatching, and illegible displays of information (Olshannikova et al., 2015). Yet, when the goal is to facilitate spatial sense-making of sensors and data through interacting with them in place, interactions must encourage mobility, enmeshment, differences in scale and variable orientation. As such, there is a fine line between requiring too much effort to interact, which would hinder the user experience, and too little effort, which would sacrifice the novelty of experiencing IoT infrastructure in this way.



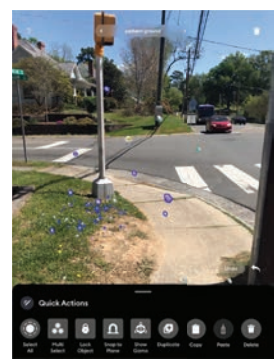


Figure 7.2.3.4 I assigned a tapping, gaze and proximity based interactions to adjust color, pinning, scale, and orientation of the assets. I found the gaze based interaction and tapping to be the most intuitive and the face camera interaction to be the most essential for legibility. The Proximity based interactions failed to work effectively as I would have liked. Gazed based scale interaction worked well to indicate sensor activity and to draw peripheral awareness.

Prototyping

To investigate the relation between interactions and embodiment, I prototyped for both cognitive and embodied interactions, and then reflected on the experience.[1] What follows are my insights and takeaways

.

The data points were scattered and varied—A part of the goal was to find data points and make them interact (spin, change color, enlarge). I found myself trying to make each shape interact—they were gazed-based so I had to walk up to them and orient my device in just the right way.

Assets with applied gaze based interactions require user orientation and mobility to access them.

I did not find this issue to be irritating, but more of a game. What resulted from the incentive to make data points interactive was moving through, among, and toward them. Watching them go from static to moving felt magical.

Small interactions can provoke enchantment and incentivize the user to engage with the system.

Finding the data points was disorienting at first—I wanted to touch them with my hand and had a weird sense of depth. I found myself face down with my device close to the sidewalk trying to catch a data point. Some of them were out in the street—I had to wait for cars to pass by. One side of the street was busier than the other which got in the way of my prototyping so I did the rest of the studies on the edge so I could do more uninterrupted explorations.

Position of assets is important to consider user safety.

My body was moving all around: head up, arms up facing the sky—back tilted, neck bent trying to see all that was around me. I bent down close to the ground, iPad almost touching the curb. I moved in circles, left and right. I was immersed in these forms and had to be flexible and re-orient myself continuously to find them all. A key feature of the app that is important for legibility I found is the "face camera interaction."

Face Camera Interaction is important for legibility and orientation.

I reflected on data points from a distance— How the tiny fragments looked static but almost floating as a whole. I walked towards them and detail emerged. The distance of digital sensors to the physical environment is not 1 to 1. I felt like I was trying to catch them. Sometimes they would move for what seemed like no reason.

There is not a 1 to 1 translation of AR to physical which can create deception of depth.

Prototyping and experiencing the sensors in mid day was very different from dusk. The assets were harder to see—the sunlight hindered my experience. The screen was shiny and reflective. I felt like I could get a much richer visual of the experience with my screen recordings. Prototyping at dusk, however, was lovely. The colors are illuminated—they glow. Even when the environment is black, the assets are still visible. So data and sensors can still be accessible at night.

Time of day drastically alters visibility and the experience.

Figure 7.2.3.5
Woman immersed in data points.

Figure 7.2.3.6 Playful Data Points

Findings

This study proposes that interactions are synonymous with embodied sensemaking in AR. As such, designers should prototype for embodied experiences as well as cognitive ones. Embodied experiences can facilitate a spatial and material understanding of IoT infrastructure through the placement of assets and applied interactions. A cluster of assets surrounding the user can provoke a sense of immersion, while distant and unreachable assets can initiate mobility and re-orientation. It discusses the downsides of embodied interactions such as cognitive and perceptual hindrances caused by distortion and resolution, viewpoint mismatching, and illegible displays of information (Olshannikova et al., 2015). It offers suggestions for improvement: by applying the face-camera interaction to assets that require legibility and orientation or designing variable assets to correspond with the time of day for visibility concerns. It suggests that assets must be able to come to the user in unsafe or crowded environments. It incorporates a reflection-in-and-on-action method to analyze my personal experience with prototyping interactions. Findings suggest that gazed based and tapping interactions are more intuitive and can provide direct awareness of information. While proximity based interactions can affect peripheral sensemaking. There is a fine line between requiring too much effort to interact, which would hinder the user experience, and too little effort, which would sacrifice the novelty of experiencing IoT infrastructure in this way. Lastly, enchanted interactions in augmented space can serve to incentivize the user to engage with the system.

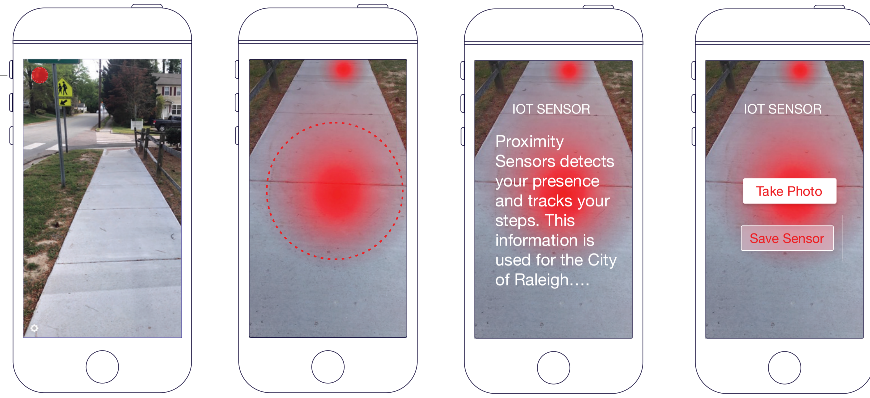
Scenario Map

The following spread (Figure 7.2.4.1.) illustrates how the application can be used over time. In Scenario One, Ava receives a push notification that informs her of local and activated IoT sensors. In Scenario Two, Ava scans the environment for sensors and finds one in near proximity. In Scenario Three, Ava views sensors from afar on a map to decide if she feels comfortable walking down a particular street. In Scenario Four, Ava uses the app to explore in a broad and open-ended way. She stumbles upon IoT sensors in proximity and views her own data.

SCENARIO MAP

SCENARIO 1: PUSH NOTIFICATION

Ava is walking to class. She recently downloaded the app but is unfamiliar with how it works and does not use it as much.

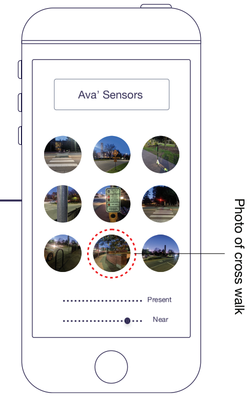


Ava get's a push notification which tells her data is being collected.

She opens the AR app and scans the environment and notices pulsing gradients on the sidewalk.

She taps the gradient and information about the sensor appears on her phone.

She is prompted to take a photo of the area and save the information

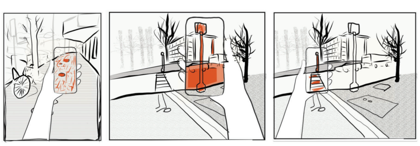


Ava responds to the prompts and the sensor and location is then saved in her catalogue for to access and view later.

SCENARIO 2: SCAN

Ava is walking downtown Raleigh. She has had the app for a month and is familiar with how it works. She pulls open the app and scans then environment to see if there are any sensors in the area.

She identifies the sensors and is curious to see if any are collecting her data.



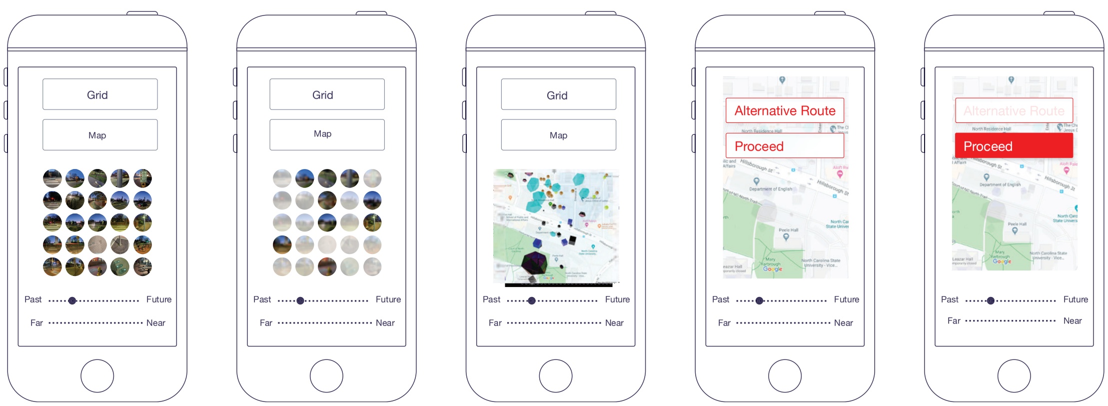
Ava scanning the environment

A sensor being detected. It provides its information type.

She is prompted to take a photo of the area and save the information

SCENARIO 3: FIND

Ava is in a new city. Before she heads out she checks the map to see what sensors are in the area and what data they are collecting



Ava pulls open the app and filters through a grid of sensors in the area.

She selects the ones that are of concern to her.

Sensors appear on a map.

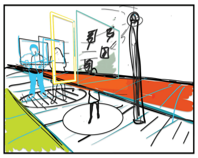
Ava is given the option to proceed or search for an alternative route.

The sensors listed are not collecting data that is sensitive to Ava, so she proceeds with the current route.

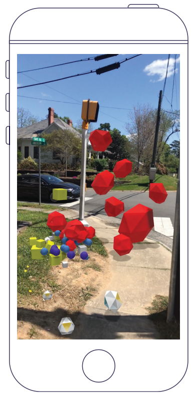
Figure 7.2.4.1.

SCENARIO 4: EXPLORE

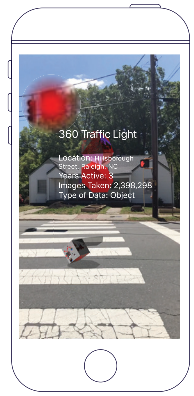
Ava has had the app for a month. She is familiar with how it works and opens it up quite often. She is on her lunch break and is walking back to class. She pulls open the app.



Ava sees a cluster of data points from afar.



She walks up closer to them to see what they are.

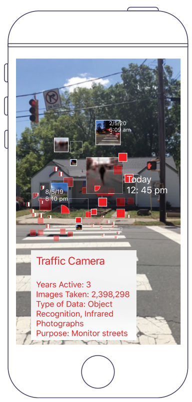


Ava turns to the cross walk and sees activated sensors by the traffic lights. She reads about them.

She deactivates the text feature and searches for data.

She walks up to a data point in the middle of the crosswalk.

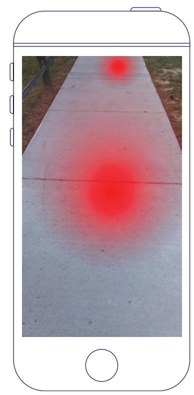
As she nears, applied interactions make the point change color and information becomes visible.



Nested within that data point is all information related to the 360 traffic camera.

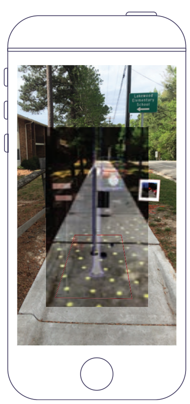
Ava clicks on the point and text appears that describes the location, sensor, and data collected.

She zooms in for further detail.



Further down the sidewalk, Ava get's a push notification telling her there is an activated IoT sensor nearby. She opens her phone and scans the crosswalk.

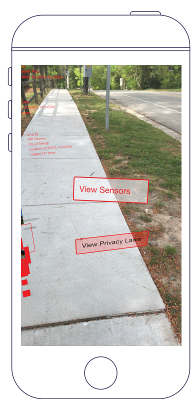
She clicks on the sensor and a hologram appears of the cross walk sign. Surrounding it is information about the sensor and a simulation of how it works.



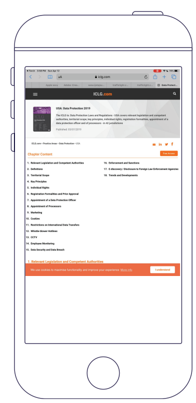
The hologram simulates how the sensor works by highlighting its functional scope.

Ava clicks on “View Sensors” to see all of the activated IoT sensors in near proximity.

She then clicks on “View Ava’s Data” which displays all of the data she has generated and the information embedded sensors have collected on her that day: instagram posts, photographs, movements.



Ava is curious about the IoT sensor and is prompted to read more about it. She selects “View Privacy Laws” which takes her links her to Data Protection laws and Regulations website so she can become more informed.

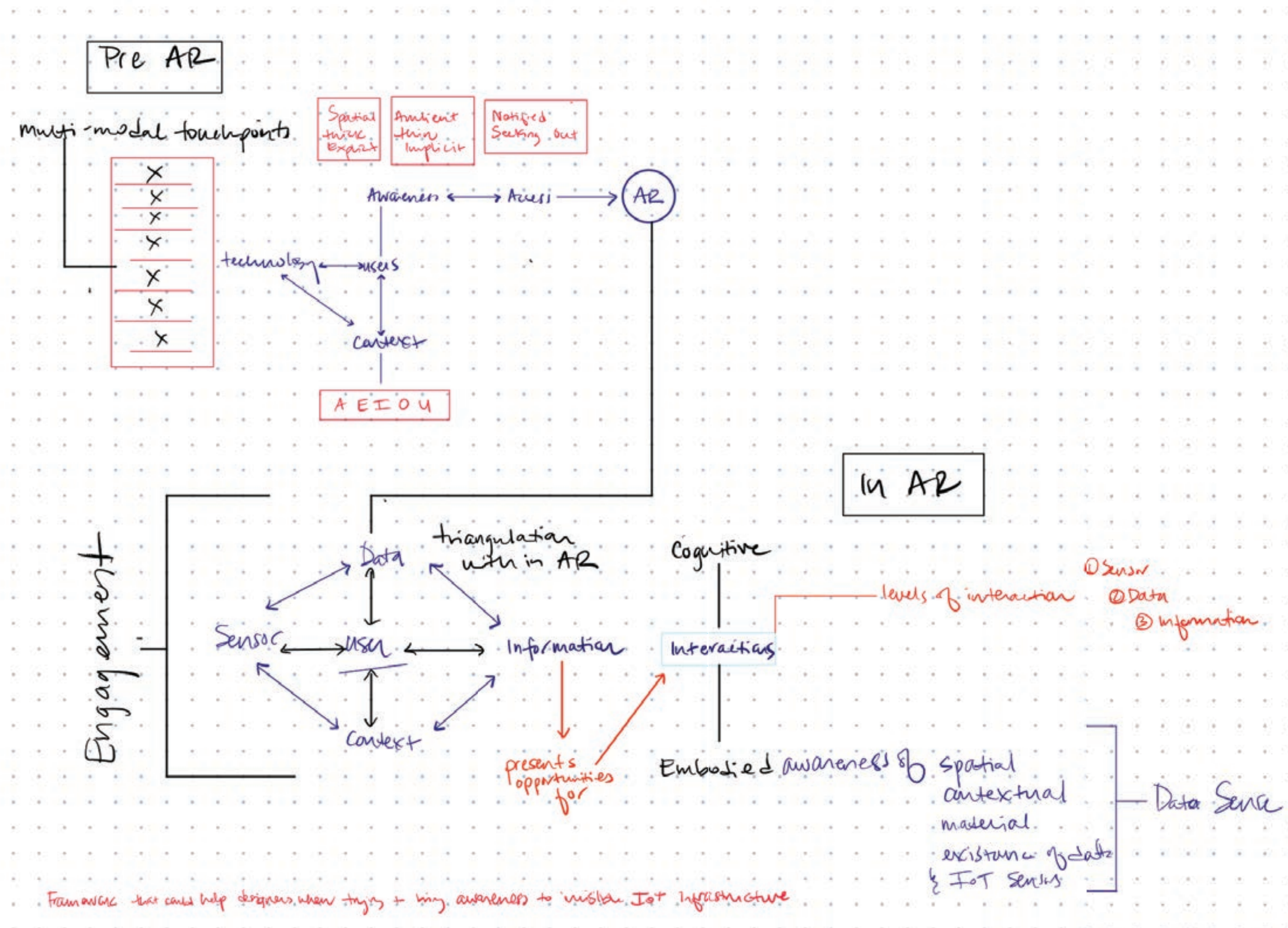


Hyper-linking is a feature enabled in this application. It gives the user access to more detailed information about local sensors.

She gets a call from her mother and has to go. So she puts away the app.

PART 3:

DISCUSSION



Pre AR
multi-modal touchpoints
Spatial
Ambient
Notified
Seeking out
Awareness
AR
technology
users
context
A E I O U
In AR
Engagement
Data
triangulation within AR
Sensor
User
Information
Context
Cognitive
Interactions
levels of interaction
① Sensor
② Data
③ Information
presents opportunities for
Embodied awareness of spatial
contextual
material
existence of data
& IoT Sensors
Data Sense

Figure 8.1.1.

DISCUSSION

Design Principles

These investigations explore a range of tactics that facilitate awareness of invisible IoT infrastructure. They begin in the physical environment, and ask how technological touch points can enable transparency through citizen engagement. These tactics range from open source, public digital displays that elicit thick interaction to thinner ambient nudges that contextualize sensors. They then bring the user into deeper, immersive, and embodied interactions in augmented reality. They explore how sensors and data can be represented in order to translate their mechanics and intent and investigate how embodied interactions can provide a spatial understanding of sensors and IoT data. Findings from these studies suggest principles that could potentially be used in designing for awareness or in the data and IoT domain.

Embodied Sensemaking of Digital Information: Rendering digital information as material, spatial, and contextual acknowledges its existence as a networked thing that humans are embedded within. Rather than resorting to decontextualized and discrete forms of representation, design needs to facilitate ways in which users can draw connections between things that traverse the physical and digital environment (Lupton, 2020). By considering the medium in which the information is experienced, using boundary objects as mediators (Iaconesi & Persico, 2016), framing design problems through the lens of embodied sensemaking (Lupton, 2017, 2020), or facilitating interactions in situ, design can acknowledge the IoT's networked and embedded existence. The same concept can be applied to memories, histories, narratives, and other digital information.

Figure 8.1.1. The sketch synthesizes the proposed framework explored in this design provocation for facilitating Acts of Noticing of invisible IoT infrastructure.

In the Pre-AR stage, before the user has the app, the system requires multi-modal touch points dispersed throughout the environment in order to bring the user into initial engagement with IoT infrastructure . These touch points provoke different types of awareness that range from spatial, thick, explicit, ambient, to implicit and differ in terms of the user being notified of IoT sensors or the user having to seek them out. This triangulation provides access to IoT information and potential use of the app.

Once the user is in AR, they begin to engage with IoT infrastructure in embodied and multi-sensory ways. The triangulation is now among sensors, data, context, and the user, all of which affect the type of information displayed. These interactions result in a cognitive and embodied awareness of sensors and data's functionality and intent. Cognitive awareness reveals levels of information related to the sensor and data. Embodied awareness elicits a spatial, contextual, material understanding of IoT infrastructure.

Designing for friction: The idea of intervening as a way of creating friction can be a tactic to bring users into contact with invisible systems. When designing for awareness, levels of interruption need to be considered: does the user explicitly have to seek out information or are they interrupted and made aware of it in peripheral or demanding ways (Markopoulos, 2009). These frictions range from evoking ambient, thinner notifications that provoke a sensory awareness of space to explicit thicker interactions that enable access to information.

Multi-modality and multi- accessibility: Because user experiences, technologies, and information are distributed across the physical-digital, designers need to translate problem spaces across a range of modalities. In doing so, strategies can be assessed depending on context and the type of information necessary to entice a wide range of users.

Sensitivity to ambient and tacit information versus explicit and direct: Making the invisible visible is a process of bringing awareness to something in the periphery, from afar, into proximity to eventually full engagement. It is important to consider when can information be too in your face, too loud, and when can it be too quiet; thus, proving ineffective. Designers need to adopt appropriate awareness tactics that consider context, users, and sensitivity of information in order to insure transfer.

Personalization and Privacy: When designing for awareness of IoT infrastructure, interfaces need to consider how information is displayed due to its sensitivity level and preferences of the user. Strategies should render information anonymously and allow for user visibility at their own will.

Representation of IoT Infrastructure: Representation should take into account the type of information it collects, how it affects the user, and where the information goes. Designers should consider how to privilege certain information types when designing for sensors that collect sensitive or anonymous information.

Leveraging IoT infrastructure agency through metaphor and enchantment: It is clear from substantial research that embedded sensors and data have a degree of agency and influence on human lives. By remaining invisible, discrete, and abstract, there will continue to be an imbalance of power between users and technological artifacts. Metaphor and enchantment can facilitate an understanding of IoT infrastructure in more agential ways (Lupton, 2017, 2020). These tactics are not synonymous with anthropomorphism or humans personifying objects, which can be deceiving as sensors, data, and algorithms are agents in their own right. Designers should consider these strategies in the design of IoT sense-making tools.

Incorporating Post-Humanist theories as guiding frameworks. By leveraging agencies of non-humans in the design of complex systems, designers can broaden solution possibilities that attend to systems holistically. By adopting a More than Human and Vital Materialist framework, this project renders IoT infrastructure in ways beyond our anthropocentric norm (Liu et al., 2018). Findings can then be filtered through user and human centered methods to make them more viable and usable—after, the weirdness is investigated.

Future Work

Despite limitations in scope, this project covers a lot of ground. As such, a number of possibilities emerged that can be explored in further detail.

Work with an existing data set: The scope of this investigation is speculative. Studies emphasize representing data as a vital and lively thing. Applying an existing data-set can contextualize the studies further to see how the numerical quality of data would influence its scale and form of representation.

Expanding upon multi-modality in the physical and augmented space: Though the outcome of this investigation is primarily visual, it has laid a framework for multi-modal ways in which sensors and data can be experienced. There is opportunity for future work to expand upon different modes such as haptic and auditory in both the physical and augmented space in order to make the application more accessible.

Agency and Reciprocity: This investigation could benefit from a deep dive into the concept of agency and reciprocity of information in this application. These explorations touched on how different types of information and interactions can facilitate agency, but examples are limited. What other ways can users input, tag, remove, or edit information in the system? How can users feel safe and in control and not monitored?

Building out the application from a user-centered perspective: This investigation focused primarily on developing a framework by which designers could address different modes, technologies, and embodied interactions. Further work could be done on the User Interface components, fleshing out interactions, usability testing, and prototyping to make the application viable and usable.

Conclusion

In Design for Collaborative Survival, researchers question how new technologies can make humans aware of how they might situate themselves in multi-species webs; specifically the web between the human and fungi (Liu et al., 2018). This investigation addresses their call to “re-imagine, reevaluate, and reconfigure our understanding of human–technology–environment relationships” by focusing on the entanglement among humans and the IoT infrastructure (ibid., p. 3). Studies guided by Acts of Noticing (Liu et al., 2018), DASS (Niemantsverdriet et al., 2019), and Data Sense (Lupton, 2017; 2020) explore a range of modalities in physical and virtual space to make IoT sensors and data transparent by facilitating engagement with its infrastructure.

Findings propose that awareness can be elicited through engagement with sensors and data in situ: from tacit, ambient notifications and explicit technological interventions in the physical environment to immersive , embodied interactions in augmented reality. Collectively, they explore how design facilitates citizen participation and engagement with IoT infrastructure in material, lively ways as a means to subvert the passive user generation of data evident in sensory embedded spaces (Andrejevic, Burdon, 2014). Further, findings emphasize enchantment and data-sensemaking as a tactic to help bridge the digital–physical divide (Lupton, 2020).

While the scope of this project is largely speculative, its content is of ethical concern for the future of IoT design. Should IoT infrastructure remain seamlessly invisible, or provoke awareness through added friction? Does citizen right–to–know mean that users must seek out information themselves or that transparency is made evident through design? Maybe this issue will not be as pressing to the next generation of digital natives who are so embedded in digital infrastructure their cares and concerns are different from ours. But, I'd argue that it should be regarded as essential as usability testing in the design of IoT spaces. Citizens should have the choice to engage, care, or delete. Designing for awareness can facilitate just that.

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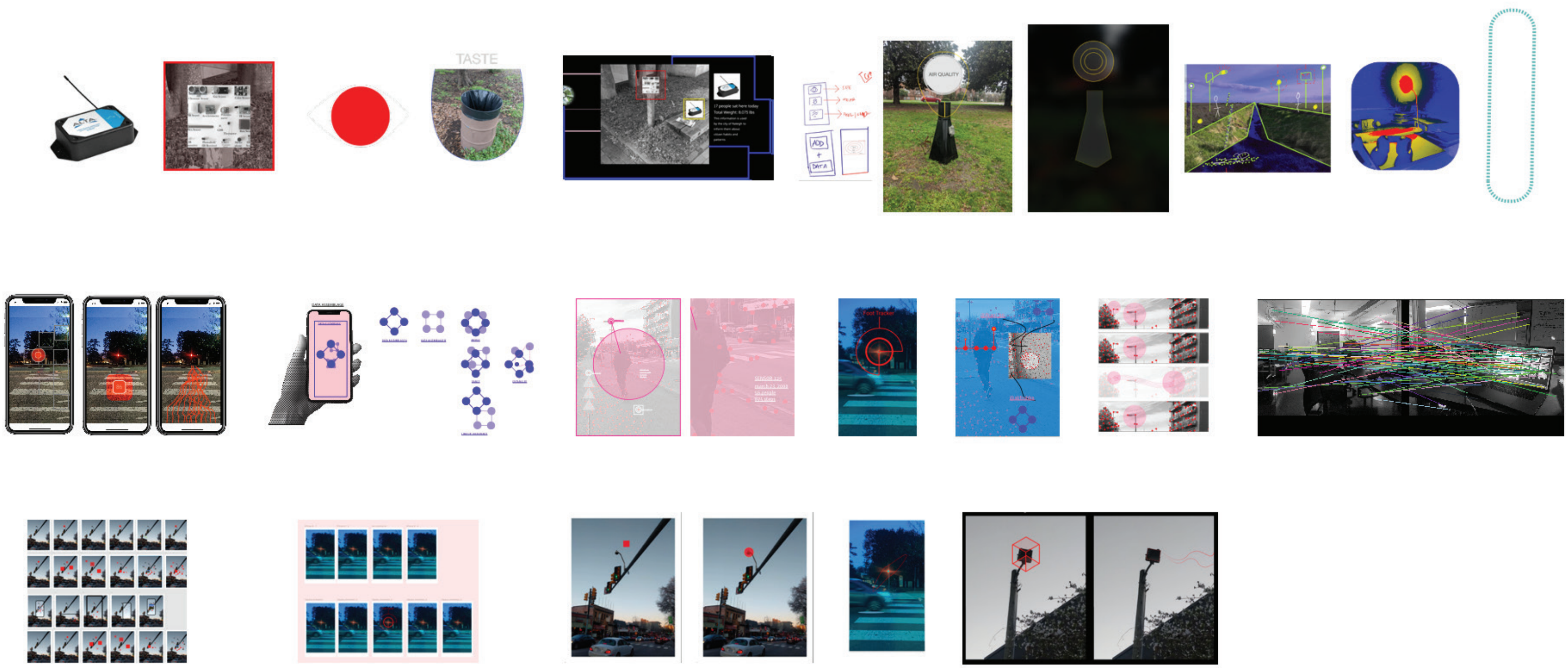
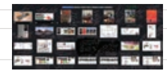
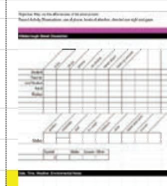
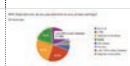
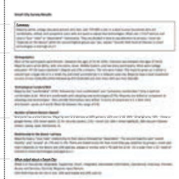
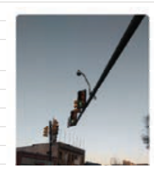
1	CATEGORY	TYPE	SENSOR	DATA	LOCATION	INFO	USER ACTIVITY
Frameworks		**Cyber-Physical-Social**					
Frameworks		**Cyber Urban**	Forlano <3				
Frameworks		**Digital Skin**					
Frameworks		**Sensor Society**	(Andrejvic, Burdon)				
Source # 1		**Cyber-Physical-Social**					
Source # 2		**Digital Skin**					
Source # 3		https://www.monnit.com/applications#Co	https://www.datamation.com/mobile-wireless/75-top-iot-devices-1.html				
Source # 4		https://www.quora.com/How-many-differe	https://www.mistralsolutions.com/articles/building-wireless-sensor-network-using-smartphones/				
Sensor Definition		**Collects and relays data about how it is used. These data can be used to infer informatiom about the user and or the user's environment (Andrejvic, Burdon)**					
Characteristics 01	Andrevjic, Burdon	Embedded	Passive	Always on	Ubiquitous	pervasive passive form of information collection	
Characteristics 02	Andrevjic, Burdon	Distributed	Active	Targeted	Purposeful	User generates more than they participate	
Examples of Smartness (Digital Skin)		*Streetlamp signals say they no longer work*	*Curbs tell the city who parks where, at what times, at what frequency*	*continuous temperature information is fed back from various parts of the build urban environment*	*pedestrian patterns or park use are mapped and analyzed*	*crime, traffic accidents, and other incidents are mapped and analyzed*	
				INFO	EG	EG	
	Fixed Sensor Networks		**WSN (Wireless Sensor Networks)**	*Environmental Monitoring*	Smart Home Installations	Air Quality Monitoring	
	Mobile Sensing		**Mounted on public transportation vehicles**				
	Mobile Sensing		**Smart Phone**	*Localized information*	Noise Levels	traffic conditions	
	Mobile Sensing		**Social Networks**	*Sharing information*	traffic incidents	earthquakes	
1	***CATEGORY***	***LOCATION***	***SENSOR***	***DATA***	***LOCATION***	***INFO***	***USER ACTIVITY***
Quantified Self	User Interests	Mobile Sensor (Wireless?)	Google Search	*Google History*		Interests + Preoccupations	Browsing
Quantified Self	Social Information	Social Networks	Social Media Sites	*Status Updates*		Recent Activities, social encou	Uploads
Quantified Self	Geo-location	Mobile Sensor	**Geo-located Sensor**	*Physical Location*		Physical Location	Movement
Quantified Self	User Interests	Mobile Sensor	Netflix + Spotify	*Viewing + Listening Content*		Viewing and Listening Prefere	Watching
Quantified Self	E-Health	Mobile Sensor	E-Health Records	*Doctors, medicnes, therapies*		Health "status"	tracking, uploading
Quantified Self	Biometric Data	Fixed Sensor	**Surveillance Camera**	*Appearances + Movements*		Appearances + Movement	Movement
Quantified Self	Biometric Data	Mobile Sensor	**Facial Recognition**	*Appearances + Movements*		Appearances + Movement	Movement
Quantified Self	Social Information	Mobile Sensor	Dating Apps	*Private + Sexual prefences*		Private and sexual preference:	Dating
Quantified Self	Activity + Interests	IoT Device	E-Reader	*pages read + skipped*		Book preferences, habits	Reading
Quantified Self	Biometric Data	Mobile Sensor	Google Wellbeing	*Heart Rate*		Health Status, wellbeing	Movement
Quantified Self	Biometric Data	Mobile Sensor	**E-Health Apps**	*Physical Activity*		Health Status, wellbeing	Excercise
Quantified Self	Biometric Data	Mobile Sensor	Mobile App	*Moods*		Health Status, wellbeing	Uploading, Updating
Quantified Self	Biometric Data	Wearable	Wearables	*Reproductive cycles*		Health Status, wellbeing	Uploading, Updating
Quantified Self	Biometric Data	Wearable	Wearables	*Sleep Patterns*		Health Status, wellbeing	Sleeping
Smart City	Traffic	Fixed Sensor	**Smart Parking**	*Available Parking Spots*			
Smart City	Architectural Health	Fixed Sensor	**Structural Health**	*Vibrations and material conditions in buildings, bridges, and historical monuments*			
Smart City	Urban Data	Fixed Sensor	**Noise Urban Maps**	*Sound in bar areas and centric zones in real time*			
Smart City	Urban Data	Fixed Sensor	**Spartphone Detection**	*Detects devices with Wifi or Bluetooth interfaces*			

1	CATEGORY	TYPE	SENSOR	DATA	LOCATION	INFO	USER ACTIVITY
Smart City	Energy	Fixed Sensor	Electromagnetic Field Levels	*Energy radiated by cell stations and Wifi routers*			
Smart City	Traffic	Fixed Sensor	**Traffic Congestion**	*Vehicles and pedestrian levels*			
Smart City	Electricity	Fixed Sensor	**Smart Lighting**	*Intelligent and weather adaptive lighting*			
Smart City	Urban Data	Fixed Sensor	**Waste Management**	*Trash Levels*			
Smart City	Traffic	Fixed Sensor	**Smart Roads**	*Intellient Highways with warning messages and diversions according to climate conditions and unexpected events like accid*			
Smart City	Environmental Data	Fixed Sensor	**Air Pollution**	*Control of C02 emissions of factories, pollution emmitted by cars and toxic gases generated in farms*			
Smart City	Environmental Data	Fixed Sensor	Portable Water monitoring	*Monitor the quality of tap water in cities*			
Smart City	Energy	Fixed Sensor	Smart Grid	*Energy consumption monitoring and mangement*			
Smart City	Energy	Fixed Sensor	**Photovaltaic Installations**	*Monitoring and optimization of performance in solar energy plants*			
Smart Phone	Measurement	Mobile Sensor	3-Axis Gyroscope	*Rotation in space—roll, pitch, yaw*			
Smart Phone	Measurement	Mobile Sensor	3-Axis Magnetometer	*Location Direction (compass)*			
Smart Phone	Measurement	Mobile Sensor	Accelerometer	*Acceleration, Gravity, Speed*			
Smart Phone	Environmental Data	Mobile Sensor	Ambient light	*Illuminance*			
Smart Phone	Media	Mobile Sensor	**Camera**	*images, video*			
Smart Phone	Geo-location	Mobile Sensor	**GPS**	*Location Direction (compass)*			
Smart Phone	Environmental Data	Mobile Sensor	Humidity	*Humidity*			
Smart Phone	Media	Mobile Sensor	**Microphone**	*Audio*			
Smart Phone	Environmental Data	Mobile Sensor	Pressure	*Pressure (used to determine altitude)*			
Smart Phone	Environmental Data	Mobile Sensor	**Proximity**	*Nearby objects without any physical contact*			
Smart Phone	Environmental Data	Mobile Sensor	Temperature	*Termperature of the device*			
Smart Phone	Environmental Data	Mobile Sensor	Biochemical	*Biochemical agents*			
Quantified Self	Quantified Self	Mobile Sensor	**Facial Recognition**	*Appearance*			
Smart Phone	Environmental Data	Mobile Sensor	Barometer	*Air Pressure*			
Quantified Self	Biometric Data	Mobile Sensor	**Heart Rate Monitor**	*Heart Rate*			
Quantified Self	Biometric Data	Mobile Sensor	Fingerprint Scanner	*Scan finger prints*			
Quantified Self	Biometric Data	Mobile Sensor	Iris Scanner	*Retina Identifier*			
Smart Phone	Measurement	Mobile Sensor	Digital Compass/Magnetomet	*Orientation, Direction*			
Quantified Self	Biometric Data	Mobile Sensor	**Pedometer**	*Step Counter*			
Quantified Self	Biometric Data	Mobile Sensor	**Pulse Oxymeter**	*Pulse*			
Smart Phone	Environmental Data	Mobile Sensor	**Geiger Counter**	*Harmful Radiation level detector*			
Smart Phone	Measurement	Mobile Sensor	**Laser**	*Auto Focus, distance Measurement*			
	Quantified Self		Sociometers (MIT)	*amount of face to face interaction, conversational time, physical proximity to people, physical activity levels.*			
IoT Sensor		Iot Device	**Seat Occupancy Sensor**	Pressure		Seat Occupancy	
		Iot Device	**Infared Motion Sensor**	Movement			
		Iot Device	Water Detect Sensors	Water Levels			
		Iot Device	**Activity Detection Sensors**	Sudden Movement			
		Iot Device	Magnent Detection Sensors	Magnetic Source			
	Environmental Data	Iot Device	**Temperature Sensors**	Temperatures of Roads	Utility and Light Poles with probes running down the pole and into the asphault, just below tl		
	Environmental Data	Iot Device	**Pollution Alert Application**		Sensors deployed in an urban environment to collect data abiout air quality, detect high con		



Appendix B

Study	***1, 2, & 3***	***1, 2, & 3***	***1, 2, & 3***	***study 2***	***1, 2, & 3***	***1, 2, & 3***	***1, 2, & 3***	***study 1***	***study 3***
	I WISH + WHAT IF	***INTERVIEW***	***SURVEY***	***WORKSHOP: WWWYS***	***ANNOTATED PORTFOLIO (1)***	***Uu***	***A DAY IN THE LIFE OF A SENSOR***	***OBSERVATION OF H-B STREET***	***DATA TRAIL***
Made	☑	☑	☑	☑	☑	☑	☐	☑	☑
Completed	☑	☑	☑	☑	☑	☑	☐	☑	☐
Analyzed	☑	☑	☑	☐	☑	☑	☐	☑	☐
Purposes of understanding	Generative ideation	Users Knowldege, Hopes + Fears	Users Knowldege, Hopes + Fears	User wishes	Common themes	Contextual Understanding	Contextual Understanding	Environmental Understanding	Contextual Understanding
Category	Speculative, Ideate		Qualitative	Speculative, Ideate		Informational	Speculative, Ideate, Qualitative	Qualitative	Observation, Quantiative
Study			Results:						
Findings		Main issue: Trust, transparency, full disclosure							
		Data generated: Lifestyle data, anatomical data, personal habits + data				There are fixed, mobile, and wireless sensors. Humans generate data through our activity.			
		Usually does not track, but notices data from lock screen							
		The smaller the device, the more intimate it is			Overall Themes				
		Finds data to be innaccurate			Symbiosis between H + M			Activity	I personally have been tracked for the past 3 years (without knowing).
		Worries about data legitimacy						Constant, repeditive, motion, transient	I can look and see my location history, types of movement (walk, rive a car) the distance and everything. I can see images I took—and when.
		Problems with judging himself when he sees data			Data as vital & Material:			Mostly deliberate walking. Little meandering. Mostly singe—heads down, focused, just walking.	Pros: I can remember the past more easily—like "oh yeah! I remember that day!"
		Smart City means cameras, environmental sensors, air purity monitor			surreal			Serious tone with some frustration.	Cons: WTF. all of my stuff is tracked. Permanantly. I cannot delete this stuff. It has already been used in ways I do not know.
			Irritation + Resentment, Appreciation, Fear, Seduction, Confusion, & Excitement.		floating			Negotiation among cars, pedestrians, cyclists	I literally did not know this was happening. It is probably the default setting on a google app.
					3D			Environment	I recorded a 15 minute video of it and analyzed how this breaks down.
				How can enchantment to users in?	blobs, bodily, alive, mutating			Open and public—no privacy	
Findings					Symbolic Representation			Clean, orderly	
					Neo-Animistic Organic			rules, costumes, social norms to abide by	
					Symbolic Representation			Brick, asphalt, trees, sound of engines, sound of cars moving, pauses and pulses.	
								Interactions	
					Actors: Moving, walking			Negotiations, perception, heightened attention	
					Environment: Speaking			Stakes are high—vulnerable if you are a walking body.	
					Affordances of ENVR offering, showing, speaking to, giving meaning to the user			Objects	
					How does data change when moving			Backpacks, purses, phones, headphones, cars music, texting	
					Recontextualize information: changing background: does that change the meaning of data			street markings, signs, defensive architecture	
								Users	
					Things: Envr.			Students, professors, graduate students, a bit older.	
					Envr. data, human data, sensors			Sensor Identifier:	
								Trashcan (evident)	
					Actions			Camera (evident) if you looked	
					Annotating, tagging, finding, tracing data in space			Mystery otherwise	
					Interface for collecting data			surveillance	
					Documenting				
					Customizing: Making it personal				
					Connecting, matching, entanging: symbiosis				
					Mapping: multimedia				
					Immerson in Data Space				
					Data Selves: Creaturing Data				
					Data World, Space, Environment				

Process Work

Smart City Survey Results

Summary
Majority are skilled, competent users who are quick to adopt new technologies. Most own 1-3 IoT devices and have a "love—hate" or "dependent" relationship. They are divided in how to pay attention to privacy—most say "depends on the device" while the second highest group says "yes, always." Overall, their level of interest in smart technologies is mid-high at a 7.

Demographics:
Most of the participants were female—between the ages of 25-34 (50%). Everyone was between the ages of 18-65. with one Latinx, Asian, Middle Eastern, and two black participants. Most were college educated—47.2% have a bachelor's degree and 23% a masters. The rest were mixed. The majority grew up in either a suburb near a large city or in a small city and most currently live in a medium sized city. Majority have a dual household income of over $100,000 (33%) followed by $75-$100,000 and then from 26% less than $34,000.

Technological Comfort/Skill.
Majority feel "comfortable" (37%) followed by "very comfortable" and "somewhat comfortable." Only 1 said not comfortable at all. Most are comfortable with adopting new technologies (37%). Majority are skilled or competent at adopting new technologies—few consider themselves very skilled. In terms of awareness it is a little more distributed—peaks at 4 and 8. Most fall between the range of 4-8.

Number of Smart Devices Owned:
Everyone has a smart device. Majority own 1-3 devices at 55% percent. 11% own 5-10 96%= Smartphone, 43% = Alexa or google Home, 32% Smart watch, 22 %= Security System, 11% = Smart Car, 18% = Smart lightbulb, 18% Vacuum Cleaner. Others: laptop, ipad, thermostat, tv.

Relationship to the device + privacy
Majority have a "love–hate" relationship to their device followed by "dependent." The second majority said "overall healthy" and "neutral" at 17% and 11.3%. There are mixed results for how much they pay attention to privacy—most said that it depends on the device and 20% said yes, always or mostly, only 5.7% said not at all. On a scale from 1-10—level of interest in smart technologies averaged at a 7.

When asked about a Smart City:
What is it? Key words: Adaptable, Supportive, Smart, Integrated, Automated, Informative, Operational, Improves, Provides Access and Services, Controls, Requires Input Devices.
50% think they do not live in one. 20% said maybe and 20% said no.

When asked about what it can do for them that a non smart city cannot:
Many said "don't know" others said give resources, make life easier, provide access, free wifi, online resources, monitor high traffic areas, free payment options, sensors, tech capabilities, mass transportation, access to online, light rail, lots of services, public transit, convenience

Relationship to Smart Technologies:
Affected by: High: 30% at 8
Reliance: Very high 35.8% at 10.
Safety: Majority: Comfortable (37%). 32 % (Very comfortable) 26 % Somewhat comfortable. Only 1 said not comfortable.
Type of care: 67% say practical, 26.4% say enthusiastic, 20% say grateful, 15% say worrisome, small amount say apathetic, fearful, and insecure.
Awareness: A little more distributed. Peaks at 4 and 8. four = 17% and 8 = 22.6 % Most fall in the midrange between 4-8.

About Personal IoT device:
Delight: access to information, connects me to others, can track healthy data, hands free list making, enchantment, learn how to communicate with you, makes my life easier, answers questions, track health, things, fears, allows me to communicate with others, provides pleasure: music, access to internet.

Fear: It is listening, what is being recorded, privacy, tracking, addiction, how it collects, hackers, human dependency, it breaking down in inopportune moments (smart car camera breaking). Listening and tracking.

Confusion: How hotspots work, how to personalize it, how it listens when it says its not (Alexa), How the cloud works, Why it is so addicting, why it can't be customizable, How reliable is the information, How is it listening and what does it look like, privacy settings, I am not interested so I don't know, Which of my actions get recorded.

Of Importance: Privacy is the most important 37%, 17%= Knowledge, followed by transparency (13) and Information (11).. Ease is at 9.4, and small slivers are awareness, control,and affordability.

If it ceased to function: 31% would be very upset at a 10 (the rest were scattered) and when asked if it would drastically change their life, 50% said yes, 31% said a little, and 16% said no.

Adjectives:
- Warm: comforting
- Negative: burden, suspicious, distraction, stubborn, necessary evil, consuming, obligatory, annoying, confusing
- Intelligent: genius, reliable, nuanced
- Practical: helpful, time saver, versatile, handy, reliable, convenient, useful, utile
- Aesthetic: sleek, material
- Enthusiastic: amazing, divine

Technology 5 years from now:
Hopes: transparency, less addicting, healthier, more humane, more private, environmentally friendly, decentralized data, accessible, anticipatory, = less work, better at communicating with us.

Fears: Privacy issues, we become too reliant on it, lack of control, loss of human touch, data as commodity, surveillance, so smart we cannot comprehend it, is is manipulative, bias, mental health issues, loss of ownership, it tracks us, humans become lazy, black box.

Speculative Walking through Smart Environment: *(Order from most to least)*
Excited, Anticipatory, Safe - - - - > Ambivalent, Afraid are equals. The least amount are powerful, uncomfortable, vulnerable, and awe.

Reflections:

Positives: I received 53 responses. They were detailed and provided interesting trends and insights into people's relationship, feelings towards, understanding of, and hopes and fears for the future of smart technologies.

Negatives: My sample population is small. Majority of the participants were white, college educated women that make over $100,000 a year in a dual income household per year. This survey is not representative of most people who occupy smart city streets—only a small sample size. If I had time to do another survey, I would try to reach out to another population to see if the results matched or added up. As a result, my findings are representative of a narrow subset of people.

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