Living with things

An open-source approach to the exploration of IoT through speculative design and hacking

Nefeli Alushi

Nefeli.alousi@gmail.com

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Supervisor: Anuradha Venugopal Reddy
Abstract

In the field of human-computer interaction, the majority of domestic IoT and smart devices run on proprietary software that possess limited technical properties and predetermined functionalities. As practices of building, modifying, and making IoT applications grow, this thesis follows an open-source approach to IoT to investigate the relationships of humans and things in a domestic setting.

As a result of this material exploration, proprietary frameworks for interactions with smart devices are challenged through speculative scenarios, that include diverse instances of human-things interactions.

Thus, a research through design methodology is suggested to support series of experiments, conducted to explore instances of perceived intelligence of these open-source hardware, without the use of advanced computational systems as proprietary devices entail. The suggested process is the creation of a speculative design artifact that combines hacking practices, to support designers in generating insights and to further iterate on possible open-source IoT interactions.

Keywords: Domestic Internet of Things, Research through design, open-source hardware, Arduino, speculative design, hacking practices
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1 Introduction

1.1 Context

The emergence of automation and computational innovation along with the fourth industrial revolution, has made the term Internet of Things (IoT) widely recognised - shaping the course of human-computer interaction (HCI) and our perspectives of how technology can be ingrained in our daily lives. Automation has integrated in modern homes, optimizing existing appliances, creating new ways for monitoring, and controlling devices by turning them into smart homes. From a user perspective, as these domestic IoT devices are becoming intrinsic within the home setting and everyday living, they consequently have an impact on how humans perceive and interact with them. Particularly, when their computational capabilities and their capacity to simulate human intellect grows respectively.

Over a decade IoT devices have rapidly grown in numbers, however, the logistics behind the technology are still not entirely comprehended by all users (Ammari et al., 2019). Nonetheless, the majority of vendors in the IoT industry have been relying on black-boxed electronics that implement sophisticated computing, built to be used in explicit condoned ways, that prevent any transparency on the artifact’s internal functionalities (Jenkins, 2014). These aforementioned IoT devices commonly operate on proprietary software and prohibit any source code modifications, therefore users are dependent on the companies to decide the manner and constraints of their interaction (Rappaport, 2017). Building on this obscurity, designers should be able to intervene and explore these devices, before thoughtlessly improving their technical capabilities, by upgrading the software with advanced computing that promotes opaque IoT.

On that account, the opacity in proprietary systems highlight the significance of knowledge for open-source systems, particularly open-source hardware (OSH), which is the main design material for this thesis. These open-source systems facilitate freedom for exploration in the arisen relationships between humans and IoT devices and from a social aspect they provide larger welfare compared to proprietary platforms (Mineraud et al., 2016). Furthermore, the growing practices to build, modify and hack IoT devices are already challenging current design choices and are contributing to future IoT applications. The assumption here is that there is no need for these domestic IoT devices to be artificially intelligent as determined by proprietary IoT companies, and instead to allow individuals to create their own instances and interpretations of intelligence by taking the open-source (OS) approach to IoT. How do we experience and interpret domestic data-enabled devices? What intelligent qualities might be attributed to our relationships with IoT through OS?

1.2 Contribution

This thesis is a material exploration of OSH, that aims to contribute knowledge to the field of interaction design and to HCI researchers. A series of experiments with IoT devices placed in a domestic setting are carried out,
to explore diverse experiences of human-thing interactions and how they are perceived from a user-centred standpoint. The methodological approach followed is an autobiographical research through design (RtD), where the design experimentations focus around employing different types of Arduino hardware attached to electric appliances. The goal is to explore if the existing relationships with these devices can be enriched, and if that would be perceived as an augmentation to their intelligence.

Connecting these devices to domestic electric appliances, their interactive capabilities open-up from predetermined affordances and functionalities to any performance the hardware can be programmed to execute. This thesis seeks to explore interactions that contribute to the development of a human-machine subjective relationship, or aid in enhancing existing ones by speculating on possible functionalities that these appliances could be programmed to perform.

The additional technical capacities can enable the devices to simulate intelligence that will aspire to disprove the hypothesis that sophisticated computation and proprietary IoT, are not the only means humans can relate to domestic IoT devices.

In terms of theoretical contribution, speculative design approaches and hacking practices are combined to gain a better understanding of both perspectives in a holistic way. As their starting points and motivations tend to differ, I argue that combined, these two approaches have a common ground and are valuable in early design stages as well as in revealing new insights on the possible future relationship of humans and devices.

1.3 Delimitations

The design material utilised for the exploration of domestic IoT, were OSH Arduino devices which are targeted for interaction designers with some pre-existing programming knowledge. More specifically this thesis was limited to the use of the following microcontrollers: The MKR WiFi 1010 attached to a MKR IoT Carrier, the Nano 33 IoT board and lastly, the Arduino IoT Cloud platform. In addition, the target group for this thesis is confined to interaction designers and tutorial content producers with some programming experience.

The placement of these IoT devices is the kitchen environment, as these are the appliances that are used almost every day within a domestic environment. More specifically, I chose the kitchen because it's the room where the majority of interactions happen mindfully as the user is most probably present in a more awake state. Rooms such as the living room or bedroom are limited from a user perspective as their IoT devices are likely associated with entertainment or relaxation, therefore their usability is dependent on the user's psychological or emotional state.

Moreover, due to the current Covid-19 pandemic, physical meetings with people are ill-advised, hence the challenge was the inaccessibility of designers, makers and researchers that were able to meet in person. Therefore, the design workshop for receiving critique on the experiments and prototyping activities, was conducted online and was limited to two participants.
1.4 Structure of thesis

This thesis topic was inspired by the sudden increase in the time spent at home in times of social distancing, and consequently my growing usage of electrical appliances and IoT devices. In addition, my entrance to the maker community through my internship which propitiously led into my occupation, enabled me to learn and work more closely with OSH and software. The employment of OSH affected my existing relationship with the domestic devices and allowed me to investigate my prior assumption - that only proprietary and highly complex data-enabled devices can be perceived as intelligent, and can facilitate instances of empathy, emotional connection, or presence in a human-machine interaction.

With this hypothesis in mind, the structure of the thesis is as follows:

Part 2 exemplifies what has previously been done in the HCI and IoT areas, introduces the materials that will be explored, as well as past research examples that have investigated the relationship between people and things in a domestic environment.

Part 3 presents some theoretical background on the topic and the synthesis of existing theories that aided in the design exploration of this thesis and are relevant to the field of HCI.

Part 4 contains the methodological approaches that are applied during the design process and inform the design exploration.

Part 5 demonstrates the actual material exploration, outlines the design process, applies the methodological approaches and presents the main findings.

Parts 6 consists of discussions and critical reflections of the design process and findings, while presenting the challenges faced during research.

Part 7 is a summary of the thesis, including some of the main contributions.

1.5 Research question

*How might we design IoT for the exploration of subjective relationships between humans and things, through speculative and hacking approaches in a domestic setting?*

2 Background

This part introduces some theoretical background for IoT, defines it in terms of this research and presents its current opportunities and limitations. Furthermore, the topic of domestic IoT and the human-thing interaction is discussed, as well as what it means to design for smart things that can explore the relationship between humans and things. This chapter also presents a few projects that inspired the design activities of this study and relate to the exploration of domestic devices in the field of HCI.
2.1 Construing the Internet of Things

Computation and automation technologies in the setting of the home, have been a central area of research in the HCI field, with the IoT technology being right in the centre. A broad semantic definition of the term IoT, is a network of interconnected devices or “things”, ingrained with sensors, actuators and other technologies that exchange data over the internet for the attainment of a beneficial objective (Whitmore et al., 2014) (figure 1). In other words, IoT can be defined as an infrastructure that “allows people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service” (Vermesan et al., 2011, p. 8).

According to Miorandi et al. (2012), “the embedding of electronics into everyday physical objects” will make them ‘smart’, thus “letting them seamlessly integrate within the global resulting cyberphysical infrastructure” (p. 1497). Their prediction that the Internet as an infrastructure will slowly fade into the background stands true, ensuing a level of abstraction to the understanding of how these devices work and raises questions on the nature of interaction with these technologies. Therefore, there is an opportunity for the exploration of new applications that can bridge the obfuscation between the physical and virtual realm of IoT, and further investigation on ways of interaction and co-existence with these devices.

As IoT processes function in the background, the interfaces of appliances and devices also gravitate towards simplistic and minimal designs that limit the user’s ability to manipulate them or understand how they work. Janlert and Stolterman claim that the development of new technologies and solutions that have “no distinct surface to turn to, users may feel as if they are communicating with everything or nothing instead of addressing a particular locatable entity” (Janlert & Stolterman, 2014, p. 529). The argument applies to the perspective of proprietary and complex IoT systems found in “smart-homes”, where the human-computer interaction is mostly limited to their interfaces while the artifacts continue to function covertly. Nicenboim (2015) points out that from the user’s perspective, this can result in unconscious or almost instinctive interactions where participation is presumed. Although from an economic perspective, in the industrial markets this blurred interaction and technocratic approach is considered a successful and effortless design, from a social aspect further analysis and research on how current and future IoT can impact us, is needed (Leopold et al., 2014; Nicenboim, 2015).
Even though there is not one single correct definition for IoT as it can be interpreted differently depending on the context and perspective, the term carries a connotation of ambient intelligence due to the enhanced functionalities of these data-enabled “things” (Whitmore et al., 2014). Nansen et al. (2014) suggest that IoT technologies enable the communication between things while supporting human/user needs and render them as social objects that can mediate human social relationships, thus perceiving them as smart. The word smart here is not understood as a device being able to possess human sentience, but to “recognize that they do have an existence and agency that might be supported through IoT designs” (Nansen et al., 2014, p. 87).

Moreover, further research has been done from the perspective of things being intelligent, borrowing theories from different fields such as psychology and philosophy. One example explores the concept of animism as a research method for understanding how we experience relationships with smart things and what role they play in our lives (Marenko, 2014). Marenko uses a speculative paradigm of animated things, to argue that the boundaries between users and objects are ‘fluid’ and through this perspective the established notions of user-centered design are challenged (2014, p. 223).

Although a post-humanistic approach has been the basis of various research, such as the work of Cila et al. (2017), the efficacy of this approach can be disputed. Cila et al. (2017) discuss modern products and how they “are active agents in shaping the network of relationships they are in together with other human and nonhuman actors” and argue that design-based inquiries tend to overlook the societal impacts of IoT devices (p. 456). As argued by Leonardi et. al (2012), it would be incorrect to claim that “technology “caused” a particular change when ample evidence shows that people decide how they will let the technology influence their work” (p. 33). Things viewed as closely relating to humans to the point where the distinctions are blurred, regardless of their artificial intelligence, is problematic as long as humans are at the heart of design.

2.2 The shift of proprietary domestic IoT

Only a decade ago home automation and IoT appliances were a luxury that exclusive offices and opulent homes possessed, however smart devices are becoming intrinsic within common domestic settings and everyday living, now more than ever. In relation to the home as a setting, IoT technology attributes a level of intelligence to the meaning of home, shifting the roles of these appliances within the user’s environment, as well as transforming them into smart homes (Mennicken & Huang, 2012). The embedded intelligence in devices provided by sensors can make domestic electric appliances smart, enabling them to collect real-time data and communicate with users and each other (Vongsingthong & Smanchat, 2014). In other words, appliances and devices that exist in the home are upgraded from their previous limited functionalities, to interconnected devices that can have an impact on how humans perceive them through their ability to communicate beyond their functional purposes.

In their research, Taylor et al. (2007) claim that intelligence in homes is found in the interactions with the objects within domestic settings, therefore data-
enabled devices are “understood less as something to be designed as intelligent and more as a resource for intelligence” (p. 383). Furthermore, their assumption is that “smartness” is ascribed to homes by people based on how they behave in the environment, which tools and artifacts they use and their decision on their placement within the domestic ecology (2007, p.384). Existing home appliances and objects already have a functional purpose but through living and interacting with these devices on a daily basis, a sense of familiarity is formed, which combined with IoT technology it enhances their perceived intelligence.

Most interfaces of domestic electronic devices along with technological artifacts in general, follow existing design guides that most users are already accustomed to. There is a preconceived notion on the nature of interactions, as well as sense of familiarity with electronic products that follow familiar motifs, as they are allusions of what users are already accustomed to (Dunne, 2005). Additionally, as humans tend to project their own inherent qualities to things, the anthropomorphism of automated and smart objects are amplified (Darling, 2016). Consequently, the addition of complex models and intelligent systems to domestic IoT devices can enhance the user’s perception of things being social and can mimic sentience.

According to Vermesan et al. (2009), IoT facilitates a symbiotic interaction between physical and virtual realms respectively, where things “become context aware and they can sense, communicate, interact, exchange data, information and knowledge” (p. 8). The extended intelligence on data-enabled things makes them appear in complete control of their operation while users count on them to perform accurately every time. In a sense, there is an assumption of expectancy on their constant efficacy that can make users take them for granted, which can lead to them having a dependent relationship to IoT things.

One example of an IoT device that users presume it will respond to their needs, and function accordingly, is the smartphone; the constant exposure and usability of this technological artifact is taken for granted. Smartphones are constantly aware of their surroundings through the embedded sensors that “listen” for any signs/inputs of interaction with their user interface. Marenko (2014) argues for the notion that smartphones become an extension of us and so “because of this animated and responsive presence, we often end up treating our smartphone as if it is alive” (p. 221). Their instant response builds a sense of trust in their process and accuracy, and consequently users form a personal bond.

As domestic devices gain more control over their functionalities and become automated, our perception of their abilities to be smart grows as well. For example, the Conversations with my washing machine study, explores how everyday appliances augmented by additional digital technologies such as the laundry machine, can improve the use of self-generated energy in families shifting energy consumption activities (Bourgeois et al., 2014) (figure 2). Their work consists of a tablet in conjunction with an application used to hack domestic washing machines, for the purposes of gathering participatory data of energy use. The study offers insights on smart and energy-aware washing machines and how they can form life at home, as well as how individuals communicate with their appliances. While most proprietary devices focus on
data collection for different processes, this research disregards the practical functionalities of domestic IoT and instead focuses on the relations of humans and things.

Figure 2: Conversations with my Washing Machine: An in-the-wild Study of Demand Shifting with Self-generated Energy (Bourgeois et al., 2014).

2.3 IoT hardware infrastructure - sensors and actuators

As previously discussed, IoT can be found in various forms and definitions, but from a software perspective almost all industrial products function on proprietary systems, especially domestic appliances. However, these obstructed devices prohibit any experimentation with their operating system, thus keeping non-tech-savvy users in the dark. As this research aims to explore the potential arisen relationships of IoT devices and users, OSH will facilitate all the design experiments to address the initial hypothesis. More specifically, embedded sensors and actuators will be the main focus of the IoT enabled hardware. The reason for this choice is the openness for intervention and hacking, that these devices offer for the purposes of creating new instances of interactions. Therefore, inspired by some of the definitions of what makes things smart that were briefly presented in the previous section, the usage of OSH in this thesis as a medium for intelligence will be the tool that will facilitate the interactive design experiments.

Looking at the infrastructure of IoT most hardware is built upon existing communication protocols that include RFID (radio frequency identification), MQTT (MQ Telemetry Transport), NFC (near-field communication) and Sensor Networks amongst other (Whitmore et al., 2014). The focus here will be the infrastructure of sensors and actuators that can retrieve and store real-time data. Sensors are an important part of IoT, they are devices that extract live data, monitor changes in the environment such as temperature, humidity or motion and allow information to constantly flow between the physical world and cyberspace (Whitmore et al., 2014). Actuators on the other hand, perform actions that signal and affect the environment around them with various methods such as visual, auditory or kinaesthetic outputs. For instance, one device that includes both sensors and actuators, is a fire alarm which includes a sensor to detect smoke and an actuator that emits an alarm to signal the possible detection of fire.

2.4 Challenges of proprietary IoT

In Hertzian Tales, Dunne (2005) discusses the combination of matter and information as he predicts the emergence of new means of communication
between people and “an increasingly intelligent artificial environment of objects” but argues for their unavailability for design experimentation (pp. 9-11). Dunne claims that most smart materials are either under development, too expensive or consume large amounts of energy, and although his book originally dates back to 1999, the notion of exclusivity and inaccessibility of cutting-edge technology is still relevant, perhaps more so now than ever.

In the industrialized world, sensors, actuators and other machinery components are present, essentially ubiquitously in our daily environments, always running in the background. However, most of these embedded components tend to be overlooked when they are lacking an overt interface where users can directly interact with, or are able to observe any feedback on their functionalities. In particular within a domestic setting, most electronic appliances such as a fridge, a washing machine, or a microwave, comprise such components, yet there is little to no thought on how these sensors are present and "listen" for our interference or input, which interrupts their passive flow and initializes an action. Additionally, the interaction is then rendered limited due to the concealed operation of these black-boxed devices which share a similar initiative and business ethos to closed-source technology.

Accordingly, a distance is formed between the human-machine interaction, where the material's functionalities are not only taken for granted, but also completely disregard to inform or allow the user to alter components of their devices. Nevertheless, one could counter argue that some appliances simply work, and they don't require a deeper knowledge of their mechanisms or a functional transparency since they are operative. Nowadays a car for instance, generally requires that the operator knows how to drive it, rather than having an engineer or mechanics degree to understand how it technically works. Although this argument is valid in the case of a car, the line of transparency and accessibility of appliances when devices are transforming into "smart" appliances, are becoming blurry. A fridge from the 1950’s is not merely the same as a modern smart fridge that constantly gathers personal data from our environment. Nevertheless, it's vital that as designers we should never disregard the ethical considerations behind design choices and the importance of data privacy.

### 2.5 Summary

The presented empirical works are examples of previous research in HCI where IoT technology was utilised as a tool for research through design (RtD) practices. Overall, there are different approaches to design activities, some are more thing-oriented and less user-centered, that draw from thing-perspective theories such as object-oriented ontology or post-phenomenology. Others rely heavily on data retrieval, for instance data-enabled design, rather than the nature of their interactivity to gather insights. However, almost all HCI projects share a mutual factor – expanding our knowledge on the relationships between things and us. This thesis has drawn insights from prior work and the methodological approach is situated as an empirical RtD on material-centered interactions of OSH, with a focus on their properties.
3 Theory

This chapter presents a different method for approaching IoT, through the theoretical approaches of speculative design and hacking practices that have been previously applied separately in the field of IoT and are relevant for the thesis. These are introduced and combined to form a new approach in exploring IoT enabled OSH through critical making, which helped unpack and enriched the understanding of the topic.

3.1 Critical and speculative design approaches

The term critical design was coined by designers and independent researchers, Antony Dunne and Fiona Raby during the mid-1990s and was first mentioned in Dunne’s book *Hertzian Tales* (Dunne, 2005). Initially their definition for critical design was the use of “speculative design proposals to challenge narrow assumptions, preconceptions, and givens about the role products play in everyday life” and was a part of conceptual design (Dunne & Raby, 2013, p. 34). They viewed the term essentially as a form of critique towards affirmative design and the notion that technology isn’t always something positive, during a period when design innovations were not critically challenged enough (Dunne, 2005).

Nevertheless, the definition of the term has vaguely changed over the years as it has been adopted in various areas of design, resulting in different interpretations that have compromised the term being viewed as a label instead of an approach. Malpass (2016) examines critical and speculative design through the developed concepts of “para-functionality, post-optimal design and the aesthetics of use”, to convey how the practice operates and how it is recognized as a design research that aims to generate debate (p. 473). Furthermore, Gaver and Martin (2000) refer to speculative design to discuss the conceptual design proposals that they developed and presented in a workbook, in order to “open a conversation with the group about the values that might characterise everyday technologies — values seldom reflected in existing products” (p. 209).

In *Speculative Everything: Design, Fiction and Social Dreaming* (2013), Dunne and Raby address this issue and carry on re-defining the term by offering an updated view on its meaning today and present their A/B manifesto (p. vii) (figure 3). The manifesto comprises two lists where the “A” side refers to how the authors view affirmative design, while the “B” side consists of the correspondents of the other. According to them, speculative and critical design does not necessarily reflect a negative viewpoint of affirmative design, but rather it’s an additional lens or “dimension” for comparison and facilitation of discussion that explores current scientific and technological implications (2013, p. vi). Moreover, Auger (2013) argues that speculative design does not only reinforce reflections on technological futures but it “can also provide a system for analysing, critiquing and re-thinking contemporary technology” (p. 2).
Although problem solving is a core aspect of design, when faced with challenges, designers should look inwards and reflect on their values, beliefs, attitudes and behaviour before rushing to fix a problem (Dunne & Raby, 2013, p. 2). Through speculation and imaginary scenarios, it’s possible to create new spaces for design and gain new perspectives on current societal topics, in order to start discussions on possible problematic design instances, look beyond what is, and ideate on what could be (Dunne & Raby, 2013, p. 3). 

Through speculative approaches designers are encouraged to ask questions of “what if” on societal issues that could prove alarming, and critically reflect on technological applications along with current design trends that might not be thoroughly investigated. For a successful speculative design project, it is also important to draw some limitations for speculation to avoid presenting potential futures that appear implausible and too abstract that the audience would find unrelatable (Auger, 2013). Furthermore, the focus of designing applications should shift towards designing implications through the construction of fictional products and services that “situate these new developments within everyday material culture” (Dunne & Raby, 2013, p. 49).

One relevant project is the Morse Things, a set of ceramic mugs and bowls that are networked to independently communicate with each other via Morse Code and over Twitter, through IoT (Wakkary et al., 2017) (figure 4). The project is a thing-centered, material speculation approach that investigates the relationship, or more so, the gap between things and us. Although Morse Things explore the nature of living with IoT things through a thing-perspective

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**Figure 3: A/B manifesto (Dunne & Raby, 2013).**
and their design draws from concepts from post-phenomenology, their findings inform the field of HCI and domestic IoT, nonetheless.

More specifically, their findings showed that participants projected human qualities to the artifacts, where some even compared them to family members or pets. Moreover, when the participants were asked to view Morse Things from a thing perspective, they were perceived as being aware of humans. The participants showed a desire for things connecting to their human practices and having the ability to sense their presence.

Figure 4: Morse Things (Wakkary et al., 2017).

3.2 Maker, open-source, and hacker communities

The maker movement or maker culture is broadly referred to a group of people who are emerged in the creative making of new devices or tinker with existing ones that support the view of knowledge sharing, occasionally through documentation, and OSH instructables. The usage of open-source systems and the ethical views of the open data movement coincide with the maker ideologies that opt to negate tools that require special skills and access privileges, especially regarding the freedom of data and tools (Kitchin, 2014). The open data movement aims “to democratise the ability to produce information and knowledge, rather than confining the power of data to its producers and those in a position to pay for access” (Kitchin, 2014, p. 48). In other words, both communities strive for the ability and freedom of technological intervention in practice through software and hardware systems, but also in theory from socio-political and ethical perspectives. The term “maker” by definition is the practice of making or hacking which is an intrinsic quality of humans, although the maker movement has become widespread through new developments in grassroot movements that concern the manufacturing of technology (Devendorf et al., 2016).

According to Dougherty (2012), the maker movement consists of people’s passion for engagement with objects “in ways that make them more than just consumers”, something that occurred in the early days of the computer industry (p. 12). Dougherty states that nowadays the aspect of enthusiasm for technological intervention in the computer industry creates devices that are so pervasive that users are not as excited to use them (2012). Apart from the view that technology has become widespread, its standardization is also playing a role in user’s lack of interest or need to learn how to operate new technology, as their affordances remain the same or at least similar across devices.
A widely held view of the maker movement is its association with the world of hacking and hackers being represented as a group of tech-savvy people that participate in cybersecurity. Although this may sometimes occur, its mostly a cinematic portrayal and far from what hacking practically is (figure 5). In reality, Hackerspaces today have become known as liberal spaces that go beyond just programming but also include physical prototyping as well as electronics, while they make an effort to move away from the negative associations of the term (Rosa et al., 2018). FabLabs, Makerspaces and Hackerspaces are examples of physical representations of the maker movement, that aim to support “communities, businesses and entrepreneurs with the infrastructures and manufacturing equipment indispensable to turn their ideas and concepts into reality” (Rosa et al., 2018 p. 22).

![Figure 5: Meanings and associations of the word "hacker" from a graphical dictionary. Retrieved from: https://visuwords.com.](image)

Yet, it is important to mention that there has been criticism on the exclusivity of these spaces as well as gender bias, as new spaces specifically targeted for women have emerged, thus questioning and challenging the inclusivity of these spaces (Devendorf, 2016). Nevertheless, the collapse of Maker Media and MAKE magazine in 2019, initiated a dialogue regarding the advantages and the issues with the making practices, ideologies and imperatives of the movement (Bogers & Chiappini, 2019). Consequently, this allowed hackers to focus their attention “in sociocultural histories and futures, as well as the environmental and economic implications of digital machines for subtracting, adding, transforming, and connecting materials” (Bogers & Chiappini, 2019, p. 8). The breakdown allowed makers to rethink and redefine the term and shape what it should represent in the future.

Moreover, hacking practices are not restricted only to spaces such as the aforementioned Makerspaces or Hackerspaces. Instead, automated homes and domestic environments that accommodate smart devices, also support instances of hacking. However, hackers and makers tend to perform these types of exercises and test out ideas by themselves, before sharing their gained knowledge and accomplishments with the community. In their research on smart homes, Mennicken and Huang (2012) discuss how participants with
technical knowledge view hacking as a fun hobby and are generally interested in working with smart home projects which they view as a challenge that offers them a sense of achievement. Furthermore, they address that most research on smart homes focus on simplifying processes, upgrading functionalities as well as making them “universally accessible and eliminate the need for ‘system administrator’ knowledge” which overlooks users that want to hack or simply engage with technology (2012, p. 158).

One example project is *Stimulating Creative Dialogues Between Humans & Things* (Amram, 2016) which presents Sensers, a group of custom-made sensors designed to act as co-ethnographers to support makers with data in various do-it-yourself (DIY) processes (figure 6). Their project presents hacked domestic artifacts transformed into connected things for the purpose of opening up their design space and new sources of inspiration. By introducing these data-enabled things into the maker’s domestic environment, Sensers could observe the surroundings and make suggestions streams of data.

![Figure 6: Sensers (Amram, 2016).](image)

After iterations Sensers project evolved into *MakeDo*, a speculative design concept for DIY recipes that also utilised collected data from things viewed as co-ethnographers to support maker processes (figure 7). Their insights aid in reframing and reconfiguring what role things play in the relationship of humans and things, as well as what is possible in research and design with data technology.

![Figure 7: MakeDo (Amram, 2016).](image)
3.3 The intersection of hacking and speculative design

Looking at speculative design and hacking, these approaches appear very disparate, however from a theoretical point of view there seems to be an apparent intersection between them. That connection can be portrayed through critical making (figure 8). The term was popularised by Matt Ratto in 2009 and was used as a link between pedagogical and research practice that aimed at endorsing critical social reflection through material explorations with technologies (Ratto & Hertz, 2019).

*Figure 8: Diagram illustrating the overlap of hacking practices and speculative design, where critical making exists.*

Nowadays, the term has effectively incorporated instances of various concepts and has borrowed from areas of art, science, engineering, and social interventions, as a means of connecting the critical practice with technological development; a bridge between “critical thinking, typically understood as conceptually and linguistically based, and physical ‘making’, goal-based material work” (Ratto & Hertz, 2019, p. 18). According to Ratto and Hertz, “built technological artifacts embody cultural values” thus, their advancement together with societal reflection can result in provocative objects that challenge technology’s role in our culture (p. 19). The authors, coming from different backgrounds – one from a technical/scientific and the other from art and design – continue by reflecting on their own pedagogical practices in interdisciplinary learning. Although their sides differ majorly, both educational explorations share the significance of breaking down covert suppositions and values of current sociotechnical life and argue that critical making can be “an important step in the development of truly trans-disciplinary interventions into the sociotechnical world” (p. 26).

Furthermore, during the implementation stage of a project or design process, and before the actual prototyping phase begins, ideation takes place. Through a speculative design lens, artifacts don’t have set attributes but rather they are
perceived as evolving things that can change characteristics, which can challenge their past inherited idiosyncrasies and permit openness for interpretation of what they could be. Speculative design artifacts are not meant to be understood as industrial products that society should embed in their homes and lives, rather they are conceptual, unique and typically one of a kind. On the other hand, hacking fosters “innovation and the creation of new products and services, but these spaces seem to focus more on the ideation and prototyping phases (makerspaces are not suitable for mass-manufacture)” (Rosa et al., p. 13). Therefore, although these two practices come from different starting points, both hacking and speculative design do not have limitations in functionality or design, they share methodological approaches.

Although design is substantially linked to academic and scientific disciplines, whereas hacking requires prior technical/technological knowledge but does not follow any definite theoretical guidelines, both approaches problematise a current state or envision a possible outcome where the aim is to create, improve or experiment with something. Touching on the materials and characteristics of IoT devices from a speculative design perspective combined with hacking practices, the methodological approaches intersect, as speculative design entails some level of hacking and hacking practices involve instances of speculation.

### 3.4 Summary

Although IoT technology already impacts our lives, the social aspects of domestic IoT lack exploration from the angles of the theoretical frameworks discussed previously. For the purposes of this thesis, IoT is understood from a user-centered approach as a network of data-enabled devices, more specifically OSH that are interconnected and embedded with sensors and actuators.

IoT enabled OSH will be a medium for exploring the hypothesis of humans building forms of subjective relationships with things, without the usage of complex computational modules. Moreover, IoT hardware will be used as a research material, where the focus will be a series of interactive experiments with devices that produce various outputs in a domestic setting to explore the relationships of things and humans.

### 4 Methodology

After establishing and going through examples of prior research accomplished in the field of HCI and domestic IoT, along with the theoretical background that informs and supports the design exploration, this part presents the methodological approaches for the design exploration.

#### 4.1 Research through design

The thesis followed the methodological approach of research through design (RtD) which has gained pace in the field of HCI in recent years, and has been
subjected to multiple alterations and adaptations since its conception. The basis of existing models and frameworks in RtD are based on Sir Frayling’s 1993 speech where he highlighted the importance of research in art and design and proposed three categories: “research into art and design”, “research through art and design” and finally “research for art and design” (p. 5).

In line with Frayling’s outlook many researchers follow with their own contributions, further shaping RtD. One approach to RtD is known as constructive design research which according to Koskinen et al., refers to the design research where construction “be it product, system, space, or media – takes centre place and becomes the key means in constructing knowledge” (2011, p. 5). Gaver’s (2012) view on RtD is that design is “generative”, and it should focus on creating “what might be” instead of focusing on “what is” (p. 940). Gaver argues that conceptual design is not about having the right theories but to create ones that “might be right” (2012, p. 941).

Analogous to Gaver’s perspective, Zimmerman et al. (2007) argues that RtD explorations should be grounded with prior knowledge and research to frame a problem, while also focusing on ideation, iteration, and critique in an “attempt to make the right thing” (p. 497). Additionally, they discuss how the increasing complexity of products necessitate the creation of new design methods and present four lenses for the evaluation of research contribution (p. 495). These “critical” lenses (pp. 499-500) are:

- **Process** – Designers must provide proper documentation of their contributions and specifications of the process they employed along with reasoning for their chosen methods.
- **Invention** – Designer’s inventions must be produced through a successful synthesis of different subject matters that address a specific situation and demonstrate their contribution.
- **Relevance** – Designers need to frame their work within a real-world situation, motivate a preferred state and demonstrate why it is relevant for the community.
- **Extensibility** – Designer’s research must have the capacity to be built upon where the knowledge created could be used for future design problems or extended to the community.

This thesis project followed these lenses to support and evaluate the efficacy of the design experiments.

### 4.1.1 Critical making

#### 4.1.1.1 Ideation through a speculative design lens

Inspired by Stuart Candy’s diagram illustration of potential futures, Dunne and Raby (2013) illustrate their objective and adapt the diagram for their own purposes (figure 9). The diagram consists of four states of potential future scenarios in a diagram from present day stretching in a linear path through time, the probable, plausible, possible, and preferable futures (2013).

The probable is where affirmative design and most design methods take place, which closely relates to the plausible cone that doesn’t aim at predicting the future but to imagine conceivable cases as resilience for possible future issues (p. 3). The possible cone refers to futures that are scientifically possible with
our current understanding and there is a believable scenario that can potentially lead us there (p. 4). Lastly, the preferable cone is an intersection of possible and plausible futures, an area of speculation of alternative future scenarios for initiating debate. Dunne and Raby, argue that design should promote discussion on what the preferable future should be and avoid undesirable ones, by reflecting and discussing current ones.

Through speculation on a societal level that explores alternative scenarios, our current reality can be moulded, and we can build foundations to increase the chances of desirable futures occurring (Dunne & Raby, 2013, p. 6). Based on the diagram, the ideation of the design interventions and material explorations with IoT enabled hardware were conducted, to answer the initial research question.

4.1.1.2 Exploration through material-centered design and hacking practices

The method of conducting research through a material lens, such as crafting or sketching in hardware approaches, has been gaining attention in the field of HCI, and numerous frameworks have been created as material dimensions and technological complexities grow. For instance, Jenkins’s (2015) approach to material-centered design is the use of self-programmed prototyping platforms that augments simple everyday objects to engage with IoT as “a site for contestation in interaction design” (p. 449). Jenkins is using hardware prototypes to outline alternative visions of IoT, while arguing for the simplicity and low cost of hardware which facilitates the creations of various types of smart things (p. 450).

According to Wiberg (2018), a material-centered approach regards interaction design as a practice that imagines and designs interactions through material manifestations (p. 200). Consonantly, Doering (2010) argues that the tangibility of objects as a source of interaction across physical and digital
designs, offers qualities that “stress” the importance and potentials of materiality. However, while there is a growing number of studies using this research approach, frameworks that explore interaction design through a material lens also grow. Wiberg (2018, p. 204) presents the following three components and main activities for doing material-centered design:

- **Exploring and defining** the form of interaction that is being designed.
- **Exploring and evaluating** the range of possible materials that can be used for designing the interaction.
- **Working iteratively** between the integration of different materials in the design of the interaction, while recurrently revisiting and if necessary, revising the initial idea of the interaction.

The design exploration in this research followed a material-centered design approach and Wiberg’s framework for successful design activities.

### 4.1.2 Sketching and prototyping artifacts

During the initial stages of implementation in a design project or research, various prototyping techniques can be useful for the exploration as well as the materialization of ideas, one of them is *sketching*. Prototyping through sketching enables the designer to quickly visualise their thoughts in a simple manner. Moussette (2012) describes sketching as a “sense-making” dialogue that is constantly evolving between the human and the medium (p. 77). Furthermore, Koskinen et al. (2011) argue for the importance of sketches and how they are “helpful in nailing down design ideas; they also help to understand things like service flow, scale, form, and how people will interact with the concept” (p. 134). According to Buchenau and Suri (2000) prototyping is a key activity within interaction design and a representation of an artifact’s design before its “final” form, with methods including scenarios, storyboards, sketches, and simulations amongst others.

An example of a sketching activity that was applied in this thesis as a prototyping method, are storyboards. Storyboards allow the designer to tell a story, while they also enable the reader to experience the visualised interactions and reflect on them from their own perspective by withdrawing from the experience and looking at the unfolding event from the outside (Van der Lelie, 2006, p. 160). In this thesis, the prototyping in the form of sketching storyboards was used as a means of exploration on the different types of interactions that were possible more vividly, once the kitchen appliances that the IoT boards would be embedded on were chosen.

### 4.1.3 Autobiographical approach

This thesis followed an autobiographical approach in terms of methodology of the inquiry of a dynamic and open-ended design and material exploration, where instincts and self-reflection contributed to the discovery process. According to Neustaedter and Sengers (2012) autobiographical design draws on the researcher’s own experiences which are “embodied in the design of a system and its exploration” (p. 514). In other words, an autobiographical approach supports fast tinkering where designers build real systems, evaluate, and iterate them while using their personal experiences to support their decisions and make choices (Neustaedter & Sengers, 2012). Furthermore, the
authors argue for the validity of using autobiographical design and discuss how this approach “goes beyond simply using a system to test for bugs or validate the system before presenting it to end-users” but rather postulates a genuine use as well as critical reflection (p. 515).

An autobiographical approach was adopted in every decision making throughout this thesis research. The combination of speculative design approaches and hacking practices which entail levels of criticality, along with the method of RtD, required constant reflection. Coming from an interaction design background and a hacker in the making, the method of autobiography was an ideal form of research in my case, as it enabled me to add my own background knowledge and relate to a target group that I identify myself in.

4.1.4 Contextual portfolio as RtD documentation and dissemination

Under the umbrella of RtD, Sadokierski (2019) discusses the challenges of documenting complex research processes outside the traditional text-based reporting and how only a few models for such practices exist. The author proposes a two-part framework for the documentation and dissemination of RtD processes through critical journaling and contextual portfolios, where journaling is divided into three types of documentation “contextual research, overview maps and ‘experiment logs’” (p. 4). Combined with data from the critical journal, a contextual portfolio is a synthesis document that can take diverse forms and incorporates miscellaneous media depending on the best way to communicate the research (Sadokierski, 2019).

In this manner, the design experiments were documented in the form of an open-ended tutorial, to reflect the OS values of sharing knowledge that acts as a starting point for further iterations by other designers. Similar to a step-by-step instructable tutorial that makers are familiar with, the form of the prototype was also created with a designer’s perspective in mind which might be less focused on the technical details of functionality. Rather, it reflected a more inspiring, speculative, and imaginative state that bridged the gap between a maker’s technical tutorial and an interaction design research. The tutorial reflected Sadokierski’s framework of a contextual portfolio, as it expressed how creative practices from the design process can contribute to knowledge and further exploration of the topic.

4.1.5 Design workshop

During the final stages of the research, an informal design workshop was conducted as a method of gathering feedback and exchanging of reflections on the topic, from two participants with design and making backgrounds. The workshop lasted approximately one hour and included an overview of the research topic to set the context, presented examples of the experimentation with the OSH devices and lastly, the tutorial was presented to the participants. The participants went through the tutorial and hardware components where a “thinking aloud” activity was encouraged, and in the end a discussion took place. The workshop was framed around the design object, the tutorial, with the generative aim of bringing expressive RtD documentation practices into being that can be shared amongst the community and built upon by others. Furthermore, the sharing of the generated knowledge and past
experimentations could serve as a starting point for further research as well as inspire new ways of interaction with IoT OSH implemented in the domestic environment.

4.1.6 Ethical considerations

This thesis follows the guidelines for ethical research conduct retrieved from Vetenskapsrådet (2017), on how to properly gather participant data after informing them about the nature of the study. Therefore, there was full disclosure and transparency on the premises of this research with the participants, although no personal private data were collected.

The design workshop was conducted online due to the current pandemic and an explanation of what the workshop would entail was disclosed from the beginning, to make sure the participants were comfortable with the process before we started. In respect to the participant's data privacy and according to the General Data Protection Regulation all participants were granted anonymity and all participants verbally agreed on being a part of the study and the use of anonymous quotations from the workshop.

5 Design exploration

This part of the research will present the various stages of the design work for the purposes of answering the initial research question. The first chapters illustrate the processes and the experiment stages of the design explorations with OSH in a domestic setting, through an autobiographical approach. Following that, the design workshop and discussion session with the participants of the study is presented.

5.1 First round of experimentations

5.1.1 The space and objects of interaction

With the research question in mind on how one might design IoT for the exploration of the relationships between humans and things, first the space of the interactive instances with domestic smart things had to be defined. The choice was to limit the experimentations solely to the kitchen area, as it’s a space that is commonly used multiple times a day and where all occurring interactions happen mindfully, compared to the bedroom for instance, where people might be less aware of their interactions with their surroundings.

For the implementation of the scenarios the chosen OSH consisted of three Arduino boards, one MKR WiFi 1010 board attached to a MKR IoT Carrier that would act as the central device, and two Nano 33 IoT boards (figure 10). These boards have multiple embedded sensors, but the one used in these experiments was the inertial measurement unit (IMU) module sensor, which includes a gyroscope, an accelerometer and oftentimes a magnetometer. The next step was to choose which appliances would be the chosen objects that the OSH devices would be implemented on, and these were the microwave and
the toaster. The reason behind this choice was the fact that both appliances were used daily, along with the fact that both devices had some type of feedback to communicate their functional state. Between the toaster’s lever that jumps upwards and the microwave’s visual countdown, whether it’s a digital clock or in my case, a physical rotary knob that pings when done, both devices provide visual and auditory feedback. Sometimes these feedbacks can be perceived as irritating or intrusive in cases when the user does not live alone but that was outside of the scope of the study.

Moreover, there is also some level of playfulness while waiting for food, where one could try and rush to finish another task before the device indicates that it’s done, creating some form of a silent race with the thing. Cila et al. (2015) discuss how things exist in specific temporalities and how people tend to do other things while waiting for appliances to finish, so “things occupy time, but also create empty times for other things” (p. 4). Encouraged by examples as such, the appliances were chosen in the hope that any potential pre-existing relationship with these devices will be amplified by the addition of IoT enabled interactions and thereby a notion of smartness.

5.1.2 Ideation through storyboards

The possible interactions with the chosen devices, the microwave, and the toaster, were explored initially through sketching. The use of storyboards enabled me to think of possible scenarios of functionality for these devices, that build on existing daily interactions as a starting point, that later enhanced the interaction through the addition of OSH. As stated by Koskinen et al., moodboards and prototypes used for research purposes are applied similarly in design, as they are used for bringing people together to imagine better futures (2011, p. 139). Attaching the IoT enabled microcontrollers to the appliances facilitated additional interactions that previously were impossible and transformed them into smart things, thus enriching the communication
between user and thing. Consequently, the user’s freedom of programming their own interactive instances with these devices can have an impact on the relationship between them and how they are perceived by humans. After a sketching session of various possible interactions between a user and the devices, two scenarios were chosen that could be implemented with the hardware at hand as well as my programming skills level.

The first storyboard showed a scenario where a toaster with an attached microcontroller is placed on a kitchen shelf and when it is being picked up for use, the motion sensor triggers an output from the central device as some type of signal to the user (figure 11). The specifics of the outputs were left open for exploration at this point, as I felt that it would limit the design experimentation and have me focused instead on aiming to make said function work. Therefore, as the hardware had potentials for the utilisation of the various embedded sensors, the outputs were only limited to capabilities of the boards at this stage of the design work.

The second storyboard depicts a scenario where a microwave has a microcontroller attached on the top of the door where the motion of opening and closing the appliance, triggers an output on the central device (figure 12). Here the output was still undefined until more basic steps of the process were achieved, such as the establishment of a functional interconnection between devices that could be developed further on.
5.1.3 Connecting the OSH through MQTT protocol

For the first programming round, the MKR WiFi 1010 board and one Nano 33 IoT board were chosen for convenience, to test the proper connection between the two before adding the other Nano board and try to interconnect all three devices. All boards supported wireless communication through their stand-alone multiradio microcontroller units (MCU), so the chosen tool for connecting them was MQ Telemetry Transport (MQTT) network protocol.

Through a publish/subscribe protocol that transports messages between devices also known as clients, multiple boards can communicate through a mediator, the broker. The broker used in this experiment was the Eclipse Mosquitto platform. The clients published and subscribed to topics through the broker to establish communication, so the next step was to configure the interactions and the additional board/client (figure 13). The word topic refers to a variable-width character encoding string that the broker uses to filter the messages for each connected client.
Figure 13: Illustration of MQTT communication with Arduino boards.

The goal was to use the sensors on the Nano 33 IoT board to trigger a reaction from the MKR WiFi 1010 board, as a first experimentation with MQTT. More specifically, the inertial measurement unit (IMU) sensor published the values from its movement on a topic that the broker had subscribed to, while the MKR board was subscribed to the same topic and listened for the value threshold that triggered the board’s in-built LED as an output. After multiple instances of trial and error of programming the two boards, they successfully interconnected with the use of MQTT protocol, and the code was uploaded through the Arduino Cloud platform (figure 14).

Figure 14: Preview of the pub/sub code through the Arduino Cloud platform.
5.1.4 Limitations of MQTT as a tool of exploring IoT

Connecting the devices and programming them to communicate in a simple manner of utilising the embedded IMU sensor to trigger an output on the other device, took effort and time and did not prove as fruitful as expected. Although a form of feedback was set up, the blinking of the LED alone was too abstract to be interpreted as an addition to the development of the user-thing relationship. Simply connecting a third device would require even more time without a guarantee that it would benefit the inquiry. Revisiting Dunne and Raby’s work, when discussing the realisation of a project they argue that it does not have to be “real” in order for it to be valuable, instead it can function as a “probe” (2013, p. 57). From a speculative point of view, design is not restricted by functionality nor should it be defined by it. Rather it should serve the purpose of conveying the message that the designer has intended instead of focusing on the technical aspects being purely operational.

Therefore, using an MQTT protocol for the addition of extra functionalities that a speculative design scenario would encourage, together with my coding limitations had me questioning the validity of this tool for the specific objective of this thesis research. Designing IoT that would explore the subjective relationships between humans and things required some pre-existing knowledge of coding, though coming from an interaction design background it turned out to be too challenging. Thus, after a short ideation a new method had to be used that would allow a richer experimentation without the limitation of the technically demanding MQTT protocol.

5.2 Reflections on the MQTT experiment

Confronted with the available time margin and the technical constraints, this was an opportunity to reflect on what is important and prioritise what would be productive in order to gain further insight. Going back to Wiberg’s (2018) framework for successful material-centered design activities, the second and third components of evaluating and working iteratively were limited by the approach of using MQTT. More specifically, the range of possible materials that could be used, for instance the addition of another board, and the further iterations with the materials were hindered.

Therefore, I concluded that this research could be enriched by employing different design mediums that would enable a smoother programming experience and provide more tools for material exploration, the Arduino IoT Cloud platform.

5.3 Second round of experimentations

5.3.1 Connecting the OSH through the Arduino IoT Cloud Platform

Consequently, the second part of the experimentation utilized the Arduino IoT Cloud platform as the tool for interconnecting these devices, that facilitates device-to-device communication. Compared to MQTT protocol which also facilitates a device-to-device communication, the Arduino IoT Cloud platform helps makers build connected objects in an easier manner through a user-friendly interface. The platform’s user-interface allows the syncing of devices with each other through simple steps, thus the devices can be monitored and
controlled through a dashboard to make sure the devices are online and functional (figure 15). Following the storyboards, the interactions with the Arduino hardware were programmed, tested and then attached to the appliances for approximately two weeks to investigate my relationship with these IoT artifacts through daily interactions.

Figure 15: The Arduino IoT Cloud setup page. This screenshot is an overview of the setup pages of things which receive real-time data from all boards.

5.3.2 The microwave

The experimentation began with the implementation of the scenario depicted on the storyboard as well as the programming of the devices, the central device: MKR WiFi 1010 attached to the MKR IoT Carrier, and Nano 33 IoT attached to the microwave (figure 16). The Nano board was placed inside a wooden box for practical and aesthetical purposes and the MKR IoT Carrier was placed into its case.

Having previously decided that the main interaction will be utilising the IMU sensor of the Nano 33 IoT board, I ideated on what output each board will trigger to the central device. As the embedded IMU module reads the motion values from the accelerometer and gyroscope and the microwave included some type of movement in their operability it was the ideal choice of sensor.
On that premise, I mounted the Nano board on the microwave door and decided to start with coding simple light outputs where the central device would blink once the door was closing and opening (figure 17). After trying out the blinking LEDs I decided to create a pattern that would provide feedback when the microwave door was open/close, where the LEDs would light up one at a time clockwise. This action ended up being a great indication of the door having opened, while the light sequence was perceived as a game.

5.3.3 The toaster

Following the activities with the microwave I explored the ideal placement of the Nano board on the toaster, which ended up being on the side of the device to avoid any potential heat damage to the board (figure 18). Alternatively, a good placement for the board would be the lever of the toaster which also includes a movement, however as the toaster was placed on a shelf attaching it to the side was more convenient.
Initially, the Nano board on the toaster was also programmed to activate the pattern of the blinking LEDs on the central device once it was moved. In addition to the lights, a playlist of mainstream songs were played through the piezo buzzer (speaker) every time the toaster was moved for use (figure 19). The songs performed were retrieved online and were coded to play in a random order so there was no knowledge of which one would be the output. The purpose of the randomized selection of songs was to create a sense of expression from the device, as it chose which tune it would perform without any human interference.

Although it was possible to attribute more technically advanced processes to the IoT boards, i.e., to make the central device emit an mp3 sound with the addition of a speaker instead of using a piezo buzzer, the experimentation was successful and lyrics were not necessary to understand the songs. The achieved goal was reached as the tunes were recognized during the experimentation, and each time a random song was playing a different emotional response was induced. Some tunes were giving off a funny and playful vibe, such as the birthday song which was an odd song to hear while using a toaster, while some movie theme songs were more exciting to listen to. Regardless, there was a build-up expectation of what song would come next, which quickly became a fun experience that I was anticipating. Therefore, the allocation of time on creating a high-fidelity version of the
5.4 Reflections of the second round of experimentations

In line with the hypothesis that proprietary and complex systems are not necessary to establish a human-thing relationship, the experiments showed promising results in the enrichment and increased connection of humans and things, through the implementation of OSH in existing appliances. After days of experiencing the IoT hardware in action, my outlook on the relationship with the appliances was positively enforced where the additional functionalities made me pay closer attention to the interactions, which were a source of entertainment. Furthermore, the perspective of their intelligence has been heightened although not in the degree of animism as Marenko’s (2014) neo-animism paradigm suggests. Nevertheless, the further iteration and the employment of different anthropomorphic interactions programmed onto the OSH, could presumably help establish a more personal relationship with these devices through a daily interaction.

5.5 Prototyping a lo-fi tutorial as a research portfolio

After the material experimentation and the OSH prototyping activities concluded due to the time margin, I revisited Zimmerman et al.’s (2007) four critical lenses for the evaluation of a research contribution. The two experimentation rounds of the design activities on this thesis followed Zimmerman et al.’s lenses, more specifically the first three lenses of process, invention and relevance. However, the last lens of extensibility which suggests that a designer’s research must be able to be built upon for possible future design problems or for sharing with the community, was not implemented in the two design explorative rounds. Therefore, one final design activity took place, as a way of demonstrating the processes of the design work thus far, and allow other designers to build upon the experiments with the existing activities as a starting point.

The final prototype was a variation of a tutorial, similar to the ones found in the maker and hacking community. As a lo-fi tutorial, the prototype was created digitally through a software application called Electric Zine Maker. This zine making tool includes a drawing interface, importing images, text, patterns and a number of other options, while its aesthetic is quite abstract old-school style which was a great source of creating a speculative design artifact (figure 20).
Figure 20: Screenshot of the Electric Zine Maker software tool.

Considering that the intended audience for this research presumably comes from a design background, the content refrained from exhaustively technical explanations. Instead, the tutorial provided a short explanation of the main components used in the activity, the code for each device and illustrations for the configuration for the IoT Cloud platform (figure 21). Overall, it facilitated all the programming parts needed for the setup and maintained an educational agenda, while also encouraging imagination through its abstract aesthetics. By the end of the tutorial the readers were prompted to further iterate and make their own versions of IoT design as a call for action, while also aspiring to provoke thought on how the future of domestic IoT devices could be.

Figure 21: An overview of parts of the tutorial prototype.
5.6 Presentation and evaluation of design workshop

Following the creation of the final design prototyping, an informal design workshop was held as a method of retrieving feedback and critique from the design work that would stimulate a discussion on the topic. Two participants were asked to take part in this workshop that were from different backgrounds, one maker and one designer. The reason behind this choice was to observe how the prototype would be interpreted, when from a theoretical standpoint an instance of speculative design and hacking practice was combined into one artifact. Furthermore, it was interesting to discuss the participant’s views on the field of HCI and IoT, as well as their ideologies on OSH systems.

Due to the current pandemic the design workshop took place online and began with a short presentation of the research to set the scene, as well as an introduction to the material exploration with the Arduino hardware. During this introduction, the participant with the technical background demonstrated knowledge of certain elements of IoT and hardware, while the designer took an interest on the concept of the research and the use of hardware as a design material. The maker participant commented on the entertaining nature of the experimentations where they said:

“It’s nice to see hardware devices placed on appliances for fun, even if I didn’t know the objective of the experiments, I would still want to recreate something like that as a way of adding my own touch to the things in my kitchen.”

Next, the participants were presented with videos displaying a few of the design experimentations and were asked to think out loud while watching. Participants showed an interest in the videos and appeared curious as they made remarks of wanting to see other possible interactions that could transpire with the appliances. While watching, one of the participants made a remark regarding the limitations in the choice of a video medium for showing the experiments at work. Their response hinted at a previous design workshop idea that I chose not to pursue, of implementing the devices on the participant’s house for a few days to get feedback which might be an interesting activity for future works. Their remark was:

“I think that if I could physically play with these devices, I would feel more engaged compared to watching it through a video.”

As a final activity the participants were presented with the tutorial that gave instructions on how to recreate one of the experiments, to study for ten minutes. After a thorough examination of the tutorial, participants were asked to partake in discussion while I asked them relevant questions that reflected the self-critical thinking of the autobiographical approach I followed. The participant with a design background discussed mostly about the aesthetics of the tutorial and called it eccentric, while initially they appeared sort of startled by how non-traditional the tutorial looked compared to modern day design practices. They went on to state:

“The design looked like it was taken from the 80’s but it’s noticeable, I had to stop and look at it and I realised that it is intentionally designed this way. So, in combination with the context recap and the videos showing the
interactions, the aesthetics created the essence of an old-school game, almost retro feeling that was cohesive.”

It was promising to see how the prototype, although it was a lo-fi quality, provoked some reactions. As a speculative design prototype one of its aims was to give a shock factor enough to draw attention to the topic and possibly incite thoughts of imaginable futures. On the other hand, the maker participant was more focused on the practical aspects of the tutorial mentioning how:

“Compared to other programming tutorials, this tutorial lacks illustrations of the actual working hardware devices, to hint at its purpose.”

The maker’s reflection revealed that more technical instructions were missing from the tutorial, as they showed minute consideration for the visuals. However, the participant made an interesting remark when asked why they think programming your own domestic IoT is valuable. Their response was that a proprietary system would come with set features which can be limiting. A smart fridge for instance saying good morning, is something they wouldn’t want to hear every day for 30 years or any repeated interactions. Instead, the design participant added to the statement, that they would prefer to create their own smart appliances and program them differently according to their mood or to make them their diet coach that scolds the user once the fridge opens.

Overall, the design choices for using a more unconventional design as well as the addition of QR codes for instructions, made the tutorial more approachable to the participant with less programming knowledge and made the hacker philosophy intriguing to them. At the same time the maker participant viewed the tutorial as a fun approach on using OSH in domestic appliances, as a way of bringing the user closer to the device and enrich their communication. Thus, both participants expressed an interest in further engaging with OSH hardware and perceived the workshop as creatively engaging. As a result, the informal design workshop effectively shared aspects of the generated knowledge of the experimentations and presented a tutorial that could be built on for further research.

6 Discussion

6.1 Methodological approach of research through design

This thesis followed a qualitative RtD methodology as its main approach for the material exploration of OSH in the context of domestic IoT as well as answering the initial research question:

How might we design IoT for the exploration of subjective relationships between humans and things, through speculative and hacking approaches in a domestic setting?

The method of RtD proved beneficial in the investigation of these complex technological devices and their impact in the relationship between humans and things, as it facilitated a hands-on approach to the exploration of the OSH through unrestricted design activities. Working with OSH devices such as the
Arduino microcontrollers used in this research, especially for personal objectives instead of business-related purposes, is predominately an individualistic activity. As previously discussed during an explorative phase of a creative activity both hackers/makers and designers tend to perform experimentations by themselves. Therefore, an autobiographical approach provided a strong framework for the evaluation of self-critique that occurred during each design decision.

Moreover, the framework for the documentation and dissemination of RtD processes through contextual portfolios, which in this case was the tutorial prototype, contributed to the capacity of communicating the research and sharing the potential knowledge production. Although the tutorial was a lo-fi prototype the results from the design workshop revealed that it was enough to inspire the adoption and recreation of the existing experimentations, to further iterate on them and explore the topic. However, the aesthetics of the tutorial could have been further iterated to explicitly demonstrate the objective of researching human-thing relationships, as a stand-alone prototype. Nevertheless, during the design workshop the combination of a short topic introduction and a visual presentation of a few experiments together with the tutorial was enough to communicate its purpose. For this reason, the adoption of the contextual portfolio as a part of the research holistically, was successful.

In addition, the interaction with domestic IoT and its influence on users, is quite a subjective experience, where there is not one single outcome that affects everyone the same way. Furthermore, in this thesis the aspect of exploring and implementing technological artifacts on societal matters is not concerned with the creation of a perfect solution nor does it follow a problem/solution type of framework. Instead, the goal was to problematise, generate knowledge and gain a better understanding of the subject without the limitation of producing a final functional product as part of a solution. The ideal outcome was the creation of an artifact that other researchers could adopt as a starting point and further iterate upon. Therefore, RtD was an exemplary methodological choice for the design exploration and the use of Zimmerman et al. ’s (2007) critical lenses helped the formalization of this method and a proper evaluation for the research contributions discussed in the design workshop section.

6.2 Theoretical combination of speculative design and hacking practices

The theoretical contribution of this study provided a new insight in the combination of speculative design and hacking practices, by highlighting the common ground between the two approaches and demonstrating how together the two practices can be utilised to enrich a RtD study. Although both approaches come from a different theoretical background and have been used in previous research individually, there are evident points of overlap observed during the ideation stages of a project or activity. Hackers use their imagination to ideate on an artifact’s desired state before and during their technological intervention, whereas designers also use similar methods but tend to base their design decisions with a greater focus on established theories and methods. In this research I argue how these combined practices can be
portrayed through critical making, that can act as a bridge between making and designing, which complements each other according to the strengths and weaknesses.

The two practices were used as a part of a critical making methodology which combined the theoretical advantages of speculative design in the ideation stage of a project, with the technical and material exploration of OSH during the experimental phase. As prior research suggests, the work of speculative designers and the work of hackers during exploration and prototyping, is not about the end goal being of the creation of a finalised product. Analogously, the material experimentation with domestic appliances in this study was not about transforming the artifacts into a conventional service and bringing them into an Arduino framework standard for products. Instead, expanding the notion of what these devices could be and do through this theoretical approach lens, is my contribution.

6.3 Constraints of open-source IoT hardware

The IoT experimentation required at least a basic level of programming knowledge, some technical skills and previous experience with the use of an IoT cloud platform, which some designers might find challenging. Although OSH and IoT permit direct manipulation and possess great potential for creating anything possible within their technological limitations, being able to operate them is a learning curve. However, design practices such as wizard of oz have illustrated that the performance or functionality of a prototype or an artifact during a design experiment, does not depend on its operation to be rendered successful.

Therefore, from a technical point of view design prototypes don’t necessarily have to work for them to provide results and insights during a design research. Instead, a designer can implement various mediums for creating something that looks functional, which in fact is also one form of hacking, as they utilise various tools differently than what they were invented to do. Another such example could be by narrating a scenario on what the said artifact would do if it was working, or the creation of lo-fi paper prototypes that imitate the intended interaction without the technical features present.

Nevertheless, in this design research the decision of making the devices properly function, as intended and demonstrated in the storyboards using code, was a welcoming challenge. Driven by the employment of an autobiographical approach that allowed me to explore the material and evaluate the experiments as authentically as possible, I chose to focus on the actual programming of the Arduino microcontrollers. This decision was to achieve a more objective and realistic experience of the interactions, in order to avoid any personal preconceptions or expectations of the situation, since a self-evaluation method was conducted.

Nonetheless, there were obstacles along the way due to my limited knowledge in achieving some of the hardware interactions, which was more time consuming as initially expected. Although this is not an argument for the physical constraints of IoT, such as their technical capabilities in accordance with the industry, there can be intellectual constraints in acquiring a sufficient understanding of the technology for the ability to utilise it.
6.4 Speculative design theory

The use of Dunne and Raby’s approach of the future cone for the ideation stage of this project, was successful in enabling creative scenarios for the actual design work. Nevertheless, it seems like the diagram (figure 9) presented in chapter 4.1.1.1, is a simplified representation of a present time, which starts from one single point as if there is a collective present reality, when in fact it applies to a small percentage of the developed world. Therefore, it might be perceived as biased since there is not really one present reality that can be defined as the same for everyone, which shows a lack of inclusivity for the less developed parts of the world. In addition, it can be argued that speculative design overall, is a rather exclusive approach that only represents a small niche in the design field. This lack of inclusivity was also sensed previously, for instance the MQTT protocol was technologically heavy which felt exclusive by making assumptions about who can benefit from it and has the skills to utilise it. This research shows that these requires an ongoing reflective process.

Nevertheless, speculative design regardless of its abstraction and potential exclusivity, brings value to designers as it encourages us to be reflective of what we design, view past the present circumstances, and imagine possible futures that may arise. The idea that all design should be critically made cannot guarantee a perfect future, but it can aid in influencing and shaping how the world could get there.

6.5 Future works

This material exploration of OSH and IoT was conducted through the use of various tools, and the implementation of these technological artifacts in a domestic setting as part of interactive experiments. However, due to the time constrains of this thesis the experimental opportunities for the creation of new instances of interactions, were limited. Going forward, equipped with additional programming knowledge it would be interesting to effectively conduct more complex experimentations that would uncover new insights on how humans perceive intelligent things. More specifically, to explore living with custom-made IoT things and to investigate the possible differences in how the interactions are perceived between different appliances, other than the microwave and the toaster.

Furthermore, by conducting a series of planned out experimentations, it would be interesting to target specific human emotions, sensations, or reactions etc. by focusing on the nature of the interactions rather than only the placement of the technology. The exploration of OSH applied in a domestic setting showed promising outcomes of increased subjective connection with the appliances that could be further iterated for additional knowledge contribution to the field of HCI and IoT. Thus, the production of the design tutorial which was meant to bridge the gap between design and making and provide substantial documentation of the tangible activities, can function as a starting point for other designers interested in continuing this research.
While some paradigms of prior research on IoT things view devices as co-ethnographers and try to understand the world from their perspective, these methods can be risky as the interpretation and understanding of these devices are uncertain. Compared to a material-centered design, these approaches can be restrictive for design as that they might overlook the actual understanding of hardware and software functionalities. Although perspectives of humans attributing such power to things that permits them to contribute to design decisions has offered some interesting outcomes, the results can be vague and too open-ended. Given that things do not possess sentience nor are they able to express themselves, the validity of a scientific contribution through a thing-perspective can be debated, on the provision that things are created by humans and for humans. It is only rational that design inquiries and scientific findings derive from a user-centered perspective as humans are at the center of design, however, there doesn't have to be a choice between thing-centered or user-centered for the successfully design explorations.

7 Conclusion

To answer the initial research question, this thesis explored ways of designing domestic IoT through various experimentations with OSH that investigated the subjective relationships between humans and things through the methodological approach of RtD. More specifically, a material-centered autobiographical methodology was adopted, which supported a more engaged series of qualitative research experimentations and entailed levels of criticality, in accordance with the RtD method where constant reflection is required. The established theories of speculative design and hacking practices were combined to form a new approach of critical making, that contributed to the exploration of IoT enabled OSH. The approach of critical making supported the ideation and speculation of the creations of possible interactive scenarios, during the initial stages of designing the OSH uses. Through storyboards and simple sketches, the imagined scenarios of the IoT material were conceived and then successfully outlined to function as a guide for future implementations.

Throughout these experimental activities with OSH, a richer understanding of making IoT devices and interesting discoveries on human-thing relationships through new interactions were uncovered. The attachment of the IoT hardware to the domestic appliances, bestowed new smart interactions and additional functionalities that would have been impossible for these devices otherwise. Additionally, the sensors embedded of the OSH facilitated an enriched communication through their supplementary abilities to “listen” for inputs from their surroundings and respond through various sensorial outputs, which was successfully perceived as a form of intelligence.

Furthermore, as part of the RtD documentation the tutorial prototype acted as a bridge between a design and a maker perspective, by maintaining an eccentric aesthetic that drew attention to the subject and promoted creativity. Moreover, the prototype functioned as documentation for knowledge sharing.
with the community and was presented during the design workshop to test out each component of the research. More precisely, the prototype was a lo-fi version that successfully provided the technical steps to recreating the experiment and encouraged further iteration. As it was the first time using the Electric Zine Maker application to create it, there were some obstacles along the way regarding the size of the prototype and finding the best way to illustrate the steps, and the code required for the OSH to function as intended. Initially, the participants of the study demonstrated some uncertainty on the nature of the prototype, which was then understood together with the introduced context during the workshop, but not as a stand-alone prototype. Therefore, to better understand the relationships developed between humans and things through OS values, future studies could build on this research and conduct more design workshops and speculative tutorials.

Based on the results, the assumption that domestic IoT devices need to be artificially intelligent as defined by proprietary IoT companies, to contribute to human and thing relationships, was disproved. Instead, an OS approach to IoT allowed the creations of various entertaining experiments that were perceived as intelligent without the use of complex systems, found in proprietary IoT devices.
8 References


Mennicken, S., & Huang, E. M. (2012). Hacking the natural habitat: an in-the-wild study of smart homes, their development, and the


Appendices

Experiments with MQTT Protocol

1. Code for subscriber client available online at:
   https://create.arduino.cc/editor

2. Code for publisher client available online at:
   https://create.arduino.cc/editor

Experiments with the Arduino IoT Cloud Platform

1. Code for the Arduino MKR WiFi 1010 board for the central device (MKR IoT Carrier), available online at:
   https://create.arduino.cc/editor

2. Code for the Arduino Nano 33 IoT board for the microwave, available online at:
   https://create.arduino.cc/editor

3. Code for the Arduino Nano 33 IoT board for the toaster, available online at:
   https://create.arduino.cc/editor

4. Configuration images for Arduino IoT Cloud dashboard:
   https://drive.google.com/file/dashboard

Videos of experiments shown during workshop

https://drive.google.com/toaster

https://drive.google.com/file/microwave