Internet of Things

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Social Internet of Things

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Internet of Things

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ISSN 2199-1073 ISSN 2199-1081 (electronic)
Internet of Things
ISBN 978-3-319-94657-3 ISBN 978-3-319-94659-7 (eBook)
https://doi.org/10.1007/978-3-319-94659-7

Library of Congress Control Number: 2018945462

Printed on acid-free paper

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The Internet of Things is here to stay. Looking backwards, it is hard to retrace the steps that led to its creation, as it embodies ideas that have been simmering for decades. The name 'Internet of Things' is generally credited to Ashton [1], and his original idea of an intelligent supply chain in which 'things' can identify themselves and communicate using networking protocols.

For example, in this vision, a yogurt pot is capable of sensing its environment and monitor its location, from when it leaves the dairy, into the delivery truck, down to the shelf of the supermarket, into our shopping bag, fridge, bin and ultimately all the way to the waste facilities. During its journey, the yogurt pot would speak to intelligent devices to check that the chain of cold wasn't broken, the product is not past expiry date, the empty jar is going to the proper recycling bin and so on.

This initial scenario is but a fraction of the current, broader vision. Today's IoT takes inspiration and borrows concepts from a variety of research initiatives, including ubiquitous computing, ambient intelligence, tangible user interfaces, mobile and ad-hoc sensor networks, wearable computing, while maintaining some important differences with each of these. One key aspect that sets the current scenario apart from the fields above is the attention that the IoT is focusing, both from industry and the general public: previous waves of research on pervasive and ubiquitous computing never seemed to particularly capture the imagination of industry and everyday users, and the Ubicomp vision always remained somehow trapped into a perpetual 'proximate future' [2], promising but never quite ripe yet.

When looking forward to the market estimates about the IoT, however, the figures dance considerably depending on who makes the forecast, but everyone seems to agree that they will be in excess of the hundreds of billions of dollars per year. The first movers among big industries are attracted by the promise of traceability, reduced waste, improved safety, and real-time monitoring and optimisation [3], and these applications are driving 10-digit investments by big actors in, e.g. health care, food supply chain, mining and logistics. Although key actors are still to emerge, the enabling technology is still evolving and services and protocols are still fragmented, industry has invested so much that it will deliver an IoT: there is an overall sense of having passed the point of no return.

Under this broad umbrella, the IoT is expanding from the initial vision (today sometimes referred to as *Industrial Internet of Things*, IIoT) to explore the opportunities of interconnecting things of all sorts, making them capable of reasoning about the data they collect and talking to other things. Almost everything, be it a kettle, a fire hydrant, or a motorbike, can be enhanced with sensors, computing and connectivity. Perhaps, it is the tangibility of things, as they are moved around, manufactured, sold, used every day and the possibility of their connection and tracking that makes them irresistible. It is, in fact, when looking closer to the everyday users, at the mundane applications, that the IoT can potentially have the bigger impact, for better or worse. Scattered across the home, embedded in people's cars, even worn as clothes or ornaments, IoT devices can empower or become the instrument of surveillance, engage or deskill, help us to socialise or isolate us even further into our own technological bubble, depending on what standpoint we take in design [4].

Crucially, the Internet of Things we want is not likely to emerge from a technology-driven vision alone. For example, if devices are getting smarter, they don't seem to be getting much wiser. Our appliances, cars, homes and clothes, are becoming more and more nosey and chatty. Internet-connected things, including cars, smart thermostats and door locks, can (and have been) hacked to hand over control to remote attackers. If these issues can be identified and fixed, some 'features' of smart things are even more alarming. From speech activated interfaces responding to TV commercials to robot vacuum cleaners reselling the plan and arrangement of the furniture in our homes, it is becoming progressively clear that a lot of the questions that matter to end users are not central in the current IoT research and development agenda.

Open questions in this sphere move from the details of people's everyday interaction with this novel architecture, to include privacy issues, ethical values and cultural issues. For example [5], how will users control what is communicated? How will they interact with things, and how will things attract their attention? How will people make sense of the things and data? How will people communicate through things?

And delving deeper into the thorny issues, what are the implications of things participating in people's social life? How are privacy and personal boundaries understood and negotiated when things (or through things, service providers) get to know so much about us? What values are implicitly embedded in IoT design, and how do these constitute people's relation with things and with each other? What is lost by delegating agency to smart objects, and what is gained? Finally, what is the value proposition of the IoT to end user? Will people buy (and love) smarter juice squeezers, dog leashes, walking canes, surfboards or is this field still in search of its true soul?

These questions were a starting point for this book, developed through a series of workshops with design researchers and practitioners [6]. Whereas the Internet of Things is often described as a global networking infrastructure [3] (i.e. a special kind of *Internet*) or a decentralised system of smart objects [7] (i.e. a special kind of *things*), we were determined, like a modern Diogenes, to find the people. We call this vision 'the Social Internet of Things', and throughout the ten chapters of this book we set out to explore some of the ramifications of this new computing paradigm.

The first three chapters articulate different visions for the social IoT, with particular attention to how the vision can be situated, respectively, within culture, place and practices.

In Chapter "Beautifying IoT: The Internet of Things as a Cultural Agenda", Jeffrey Bardzell, Shaowen Bardzell and Cyn Liu discuss the aesthetics of IoT products, and how these reflect and embody specific cultural sensibilities with implications that reach beyond technology issues and approaches. Moving from philosophy of art and beauty, the authors develop the concept of 'Beautifying IoT', i.e. object whose aesthetics is a key element of their experience, and that are conducive to a 'fuller, freer, and more meaningful way of being'. These aspects, which are almost absent from much of the discourse on IoT (both in Industry and Academia), are illustrated in two case studies from the authors' ethnographic work in Taiwan. Both cases involve renovation and repurposing in search of a higher sense of beauty: of people's whole lifestyle in the first case study (former city dwellers and professionals turned to farming and living off the land); and of an industrial material and family-owned business (a zinc alloy production plant turned into designer product manufacturing) in the second. The chapter is a call to action for design researchers in HCI to 'attend […] to aesthetic qualities of emerging technologies', and to do so at much larger scale than that of the traditional interface, app or artefact, as the reach of the IoT infrastructure is global.

Jack Carroll's 'Internet of Places' vision, detailed in Chapter "The Internet of Places", aims to capture 'new kinds of experiences and relationships between people and environments' that cannot be fully understood within the techno-centric framework that is typical of the Internet of Things discourse, and that, he notes, requires a further layer of analysis (the 'Social' IoT) above the issues of 'data and data handling'. In this view, place is a perfect case study in that its meaning is 'constructed through interaction and experience', as opposite to the data describing a location, that can be fully characterised and captured using existing techniques and sensors. Carroll explores this meaning at personal, family and community scale: new data and services infrastructures can enable 'richer interactions and experiences', but will surely entail socio-technical trade-offs. For example, configuring and managing security may undermine the vivid agency and partnership of one's places, compromising the social IoT. These reflections extend to all relations involving people and places, from family to neighbourhood, investing these relations of new meaning, that under the social IoT agenda scholars are only beginning to explore.

In Chapter "From the Internet of Things to an Internet of Practices", Thomas Ludwig, Peter Tolmie and Volkmar Pipek extend the reflection on IoT technologies to encompass the ways technologies are situated in *practice.* In the chapter, the authors set off to explore the process of collaborative appropriation, as it can be supported by the smart interconnected devices that form the Internet of Things. IoT devices and their sensors have often been aimed at the environment (to harvest contextual information) or at their users (to collect behaviour patterns). Ludwig, Tolmie and Pipek, rather tune them to the situated action of professional practice, and imagine an IoT where *things* were capable to sense, share and mediate the nuances of their use in *practice*. Designing a tool, a photo camera in the example offered, as a *sociable technology*, means enabling that tool to sense and share detailed information on use, technical and socio-material context, and even the intention of the photographer (process context), in ways that can be communicated and appropriated by other photographers. The 'Internet of Practice' vision then raises the stakes from a current technological focus, towards the more intricate, nuanced and somewhat ephemeral realm of making sense of sharing, supporting and appropriating expert practice.

The next three chapters address aspects of the interaction design of the social IoT.

Nikolas Martelaro and Wendy Ju explore in Chapter "The Needfinding Machine" how designers may interact with users *through* prototypes to better bring to focus users' needs. A needfinding machine is a connected device that embeds a 'conversational infrastructure' through which designers can observe, communicate and interact with users, as well as remotely control the machine, monitor its status and document the interaction. As a design method, needfinding machines draw upon a vast diversity of related methods, from classic in-the-lab approaches like wizard of Oz to purely in-the-wild ethnographically inspired, passing through methods that enlist *things* as co-ethnographers, opening up unusual perspectives to designers. Applied to the context of the social IoT, needfinding machines additionally help us to focus on issues of privacy and reciprocity, and to do so from the sometimes uncomfortable designers' perspective, in their role of performing the machine. Schön's classic description of design as a reflective conversation with a situation is here then taken one step further by likening the user–designer conversation to improvisational theatre, in which 'unplanned opportunities' may arise at any time, to 'understand experience right as it happens'. These remarks may well describe any social interaction, which stresses once more the social nature of the IoT design space.

Donald Degraen in Chapter "Exploring Interaction Design for the Social Internet of Things" delves deeper into the interaction challenges that users will face in understanding and controlling smart objects. Networks of things that socialise can have countless benign outcomes but also pose challenges. Smart objects need to become trustworthy and able to autonomously socialise. Open questions that had been lingering for a while regarding the intelligibility and control of autonomous, context-aware systems are soon to become more pressing as IoT systems appear on the shelves of the retail market. Will users be aware of what is happening behind the scenes? Will they be able to understand and review the data that is being gathered, and the way it is processed? Will users be able to make sense of the role of each *thing* within the bigger infrastructure? And on what basis shall users trust the information that they receive through their things, or entrust those things with their own personal information? Degraen's characterisations of this design space address these questions by unpacking the problem in terms of intelligibility and control on one side, and modelling the behaviour of social IoT objects giving them predictable personalities, on the other.

Maliheh Ghajargar, Mikael Wiberg and Erik Stolterman address how smarter objects and places will influence peoples' reflective thinking. On the one hand, the authors note, peoples' thinking is largely reliant on their interactions with objects and things. On the other hand, things are more and more 'computational, smart, networked and interconnected'. In this vision, our very thinking becomes part of a larger interconnected system, reflection is always socially and spatially situated, and the social IoT is better understood as a relational approach to the design of '*Places for Reflection*'. The relations to focus on are unpacked in the chapter, taking the 'place' as a cornerstone to which the reciprocal dependencies of objects, people and activities are anchored. So the presence of certain smart objects in a space will characterise that as a place for the kind of reflective thinking that is enabled by those objects, the performance of specific activities involving those objects will give meaning to the built environment; and people will inhabit these places creating there their own culture. But if the whole may escape our awareness, the specific relations that bind together places, objects, people and activities offer a suitable unit of analysis to make sense of the social IoT design space.

The following four chapters explore applications of the social IoT at different scales, from the home, to the workplace, the care centre and the community.

Using a toolkit of their own design, Arne Berger, Andreas Bischof, Sören Totzauer, Michael Storz, Kevin Lefeuvre and Albrecht Kurze explored use scenarios of IoT in the social context, the social implications of IoT data and how to engage people in participatory explorations of IoT applications; their reflections are the subject of Chapter "Sensing Home: Participatory Exploration of Smart Sensors in the Home". IoT devices and sensors can be deployed in many different situations to harvest environmental data in the home, enabling people to freely explore the possibilities of the technology and make sense of its limitations; or they can be used to support teaching in the wild, which offers insights into how the IoT can be appropriated into real practices, and on the complexity of contextualising the information gathered; or finally they can be tuned and positioned in ways that reveal unexpected traces of everyday life, raising interesting implications on the ethics of surveillance in private spaces by family members that are seldom explored in current research, and overall showing how open IoT toolkits can be used to explore and generate many different research and design directions.

Markus Rittenbruch and Jared Donovan bring the exploration into the workplace in Chapter "Direct End-User Interaction with and Through IoT Devices" in a quest to understand the growing tensions between increasing automation on one side and the availability of inexpensive and programmable tangible interfaces on the other. Their study shows that when personal devices are used to negotiate collective boundaries people will resort to varied and sometimes hard to reconcile strategies, also depending on subjective perceptions of comfort with the current situation, of alignment with the general preference, and on the feeling of agency, reciprocity and respect (or lack thereof). Rittenbruch and Donovan described how the design can de-emphasise some aspects (and reasons for tension) in favour of others, but also how the physical level (of temperature, settings and sensors) and the social level (of negotiation of preferences, respect for boundaries and feelings of comfort) will always interact in situated and subjective ways.

Chapter "Engaging Children with Neurodevelopmental Disorder Through Multisensory Interactive Experiences in a Smart Space" by Franca Garzotto, Mirko Gelsomini, Mattia Gianotti and Fabiano Riccardi explores applications of the IoT to create a platform capable of supporting multimodal multisensory activities that promote motor coordination, attention and social interaction, for children with neurodevelopmental disorder. Here, the IoT has the potential to greatly improve the quality of life of children and their families, as well as supporting the daily work of therapists. The challenge, however, for a technological vision that is aiming at mass production and mainstream adoption, is to adapt to the individual needs and pace of each young user. For this to happen, end-user development paradigms should join forces with IoT initiatives, so that therapists, families and patients can design personalised, unique interventions that match the therapists' educational goals and the children's needs.

Can Liu, Mara Balestrini and Giovanna Nunes Vilaza finally present their reflections on the opportunities for social engagement with IoT, related to places and communities. When design is aimed to foster positive change, communities are a natural partner to seek, and HCI is effectively riding this wave of research. The roles for IoT technologies in this space are rich and varied, as the authors discuss in Chapter "From Social to Civic: Public Engagement with IoT in Places and Communities", from acting as a social catalyst to fostering awareness on social issues, from facilitating participation to collecting and spreading shared knowledge, up to an ultimate goal of empowering citizens by supporting the gathering of data, articulation of goals and advocacy of community efforts. There are, however, many challenges to address to make IoT in public places a sustainable and scalable tool for civic action, as the authors summarise in their 'lessons learned'. The trade-offs between opportunities and costs are complex and difficult to navigate. Key aspects capable of sustaining engagement, such as providing hyperlocal contents and fostering collective ownership, mean that no one-size-fits-most solution exists, and rather interventions that work tend to be highly specific, participatory and embody shared knowledge and memories.

Together, these contributions shed new light on the numerous implications of designing Internet of Things devices, tools, platforms and applications. The social IoT encompasses all aspects of the IoT scenarios that escape a straightforward technical analysis. One way to appreciate the sociality of networked technologies such as the IoT is to resort to social networks theories to model their architectures and approach their study [8]. This, however, can only offer a partial explanation, as it does not consider the situatedness, in culture, in place and in society, of those technologies, nor can it capture the ways in which technologies, practices and even moral and ethical values are mutually constituted and continuously renegotiated. From the intimacy of the home to the public space and workplace, issues of agency, engagement, reciprocity, privacy, respect and dignity will always emerge as novel technologies are embodied in social interaction.

This book is an attempt to reposition the debate around IoT technologies within a more complex account of its social, political and creative, as well as technical roots, in the hope to spark a more nuanced conversation, and ultimately, contribute to the design and creation of the Internet of Things people *really* want.

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Acknowledgements

The Social Internet of Things workshops, where this work originated, and the editing of this book have been in part supported by the Australian Research Council, grant DP150104001 *Make and Connect: Enabling People to Connect through their Things*. Support received by chapter contributors is acknowledged at the end of each chapter when appropriate. We wish to thank all the participants of the Social Internet of Things workshops for their valuable feedback and for contributing ideas and insights that materialised in this book. We especially wish to thank the co-organisers of the CHI-2017 workshop where many of the chapters included in this book were initially conceived: Peta Wyeth, Daniel Johnson, Aloha Hufana Ambe, Ann Morrison, Shaowen Bardzell, Tuck W. Leong, Wendy Ju, Silvia Lindtner, Yvonne Rogers and Jacob Buur. We finally wish to thank all students and academics of the CHI discipline at Queensland University of Technology that inspire us every day.

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Part I
Social IoT Vision

Beautifying IoT: The Internet of Things as a Cultural Agenda

Jeffrey Bardzell, Shaowen Bardzell and Szu-Yu (Cyn) Liu

Abstract As an IT research agenda, the Internet of Things is often framed according to technical and economic issues, such as protocols, standards, job-creation potential, etc. We argue that IoT also constitutes a cultural and aesthetic vision, that is, a projected image of urban- or region-scale beauty, in which lives are pursued in more meaningful and fulfilling ways than before. In HCI and related disciplines, aesthetics—when not outright dismissed as too subjective and/or confusing to engage—is commonly investigated as individual judgments about individual interfaces. This is a problem, because we know that technologies can produce ugly and unlivable environments at scale—from nuclear disaster sites to urban desolation caused in large part by the automobile. Aesthetic IoT is not a matter of making device surfaces more pretty, but of thinking deeply about the ways it will shape how we live; after all, urban desolation didn't happen because roads weren't painted attractively, but because roads disrupted communities and their established ways of life. This chapter demonstrates that aesthetic theory provides concepts sufficient to engage matters of IoT aesthetics in precise and pragmatic ways. It does so by analyzing a policy intended to beautify a major city in Asia alongside aesthetic interpretations of two design initiatives contemporaneous with it: an agricultural IoT project that proposes a computationally enabled new intimacy between humans and their land, and a kitchen design company that innovates not only on manufacturing materials but also on the aesthetic conventions needed for consumers to recognize those material properties as beautiful.

1 Introduction

The Internet of Things (IoT) refers to a vest network of interconnected objects in our everyday environments [1]. It has received enormous interest and investments aiming to envision a new form of service ecology supported by streaming data through

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_1

interconnected devices to provide meaningful actions in the context. Topics of IoT research and public policy discourses often focus on technical and economical aspects such as infrastructure, protocol, security, privacy, or its potential to create jobs and boost company profits [2]. HCI and CSCW researchers such as [3–5] have broadened this research agenda to encompass the socio-technical experiences that IoT devices bring about by studying the social arrangements of people and technology in everyday life. This literature shows how IoT innovation can go beyond tools to mediators of human social relationships.

Höök [6] takes this argument a step further, when she points to Sweden's traditions of participatory design and technology democratization to argue that the nation is distinctively fit to position itself as an IoT nation and a global innovation hub. On such a view, IoT is not only a product of technology but also a *cultural* product, that is, both a reflection of and a perpetuation of given culture. This view calls attention to issues that technocentric approaches to IoT—as vital as they are—tend not to. How well IoT fits with a given culture likely will deeply shape experiences, with implications for adoption, acceptance, and productivity.

In this paper, we began to pursue this question when we saw that participants in our ongoing multi-sited ethnography in Taiwan were likewise inquiring about it in earnest. Although many of them are engineers, themselves fascinated with the technical possibilities of IoT, they also equally asked what IoT could or should mean in Taiwan—not unlike Höök's ruminations on a Swedish IoT. These engineers wondered how IoT can contribute to and benefit from Taiwan's ongoing efforts to cultivate creativity, including the related question of how to establish innovation hubs [7]. This is in turn led to questions of Taiwanese ways of life, that is, a Taiwanese lifestyle, which reflects cultural tastes and values. Along these lines, we have seen a collective agenda—reflected in policy, social media discussions, public design events, and so forth—to "beautify Taiwan." This agenda includes but is not limited to IT development, extending to issues of environment sustainability, green energy, urban aesthetics, and the formation of a Taiwanese consciousness.

As we witnessed the overlapping discussions between beautifying Taiwan and the development of an IoT imaginary for Taiwan, we began to wonder: *what might it mean to beautify IoT?* To make this question more tractable, we scoped it to Taiwan: *what might it mean to beautify IoT in Taiwan?* We stress that this is a speculative question, not an empirical one. We are not asking, "what did beautifying IoT mean in Taiwan?", because beautifying IoT in Taiwan remains more an aspiration than a reality that can be investigated empirically. Accordingly, our methodology is suited to a speculative investigation, rather than an empirical one. We appropriate a methodology from serious science fiction: we use *cognitive speculation* [8] to constructively and experimentally imagine futures that are *plausible* (because they are based on the best available empirical knowledge) and *preferable* (because they more completely embody our values than the mundane present).

Specifically, we use our empirical knowledge from Taiwan as a launching point for our own speculative investigations of what beautifying IoT could mean if developed as a research and design agenda. Here we rely on a distinction we made in [8] between a technology agenda and a vision agenda. A technology agenda is primarily about the research and development needed to pursue a technology agenda (e.g., improving computational sensing to improve computers' contextual awareness, in pursuit of the ubicomp agenda). A vision agenda is an image of how that technology agenda will play out when situated within society; it is a vision of everyday life when such technological capabilities are widespread, available, and mundane. Beautifying IoT is a vision agenda, in that it seeks to envision a future where IoT is mundane, yet also beautiful or beautifying.

Our contribution to design research is to contribute towards the construction of IoT agendas that take seriously, even centrally, the significance of aesthetic beauty in everyday life. A secondary contribution is to make our speculative methodology explicit, in hopes of supporting other design researchers interested in contributing speculative images that intervene upon and enrich IT agendas.

2 Methodology: Speculatively Contributing to IT Research Agendas

Our methodology can be summarized as follows. From our multi-sited ethnography of creativity and innovation in Taiwan, we identified an agenda of interest to stakeholders in Taiwan, that of beautifying Taiwan, in which beautifying IoT is a subordinate goal. We summarize the relevant discourses to demonstrate both that this aspiration is in the discourse and also that it is under-specified. From this point, we take a speculative turn. Obviously, we cannot answer for Taiwan what beautifying IoT could or should be for the Taiwanese. Instead, we treat this question as a prompt for our own imaginations, for us to envision an answer to take back to the HCI and design research community. We move forward by doing design criticism of two design initiatives in Taiwan that are contemporaneous with the policy agenda, and we turn to philosophical aesthetics to work from rich and generative theories of what "beautifying" might mean.

We have been conducting ethnographic studies on IT innovation and creative industries in Taiwan since 2011, focusing in particular on cultural and creative industry policy implementation [9], urban experimentation [7, 10], making and bottom-up innovation, and everyday aesthetics and traditional craft among others [11]. The present work draws from and is informed by our fieldwork on cultural creativity and making in Taiwan, involving hundreds of ours of participant engagements across different physical sites. We also conducted digital ethnography [12–17] of our informants' use of Facebook groups. While this paper does not primarily report on findings from these ethnographic engagements, it is through them that we became aware of relevant policy discourses, innovation initiatives, and design examples, which we discuss in more detail below. The ethnographic research gives us confidence that the topics and resources that we are drawing on are important to innovation stakeholders in Taiwan—policymakers, entrepreneurs, inventors, makers, educators, manufacturers, etc.

2.1 Policy and Beauty in Taiwan

Taiwan is well-known for its information technology and precision manufacturing. It is home to a host of high-tech companies including Asus, Acer, Foxconn, and HTC. It also has a long history in offering original equipment manufacturing (OEM) services to global IT innovators, such as Apple. IT and precision engineering are often foregrounded in policies because they drive the economic growth in Taiwan. In September 2016, the National Development Council of the Executive Yuan inaugurated "Asian Silicon Valley Development Plan", aiming to upgrade Taiwan's IT industry and innovation ecosystem to support entrepreneurship and the development of IoT [18]. The development plan is part of the government's five-plus-two pillar industries initiatives, along with intelligent machinery, green energy, biomedicine, national defense, high-value agriculture, and circular economy [19]. In spite of its name, the policy goal is not to clone Silicon Valley in Taiwan, but to use it as a hallmark for promoting this island as Asia's technological innovation hub. The plan will run from 2016 to 2023 with an initial budget of US$359 million for 2017. Official measurements of the plan focus on aspects of economic growth and industrial reform, such as "increase Taiwan's IoT global market share from 3.8% in 2015 to 5% in 2025", and "grow 100 successful companies" [18].

Part of this policy agenda and others like it in Taiwan is to build on Taiwan's cultural strengths, not just its technical ones. This includes constructing images of Taiwan's future out of its cultural past, arguing that its democratic values foster creativity better than alternatives, and that technology and culture are co-implicated [9, 10]. Thus, while the economic message is that Taiwan wants to transition from a service provider (i.e., manufacturing for others) to an innovation pioneer, this work will reflect and perpetuate the cultural identity of Taiwan. Although many have criticized the policy and its implementation, policy analysis is out of the scope of the present work. We are interested instead in the ways that the policy exemplifies the country's aspiration to leverage distinctive cultural knowledge and local infrastructure to foster the development of technology and innovation.

Indeed, cultural concepts have been foregrounded in recent Taiwan policy. We did not ourselves come up with the notion of "beautifying Taiwan"; in fact, the language of beauty is often highlighted in Taiwanese public policy. One example is the "Taipei Beautiful" (台北好好看) urban renewal policy issued in 2009, aiming to make the city "charming" in preparation to the 2010 Taipei International Flora Exposition. This policy offered guidelines and subsidies for renovating obsolescent buildings, creating green parks, and reviving idle spaces in order to "revitalize the [city's] shabby appearance" and transform Taipei into a "beautiful international city" [20, 21]. In this discourse, terms like "revive," "renovate," and "shabby" all suggest similar ideas—a city in a state of architectural decay needing to clean itself up and give it a new life. Green spaces will be used to punctuate blocks of these renovated buildings, the overall effect of which will be "charming."

Related development policies include "Shaping a Charming Taipei" and "Representing Taipei Elegance", in which vocabularies such as beautiful, attractive, livable, visionary, creative, comfortable, humanized, and local characteristics were used in white papers to communicate a public imagination of urban style [22, 23]. As before, we recognize that the policy has been criticized [e.g., 21, 24, 25], but our purpose is to show that the policy wants to pursue a notion of "beautifying Taiwan." One might refer to such aesthetics as aspirational because it builds on a particular culture's traditions to propose a desirable future [10, 26–28].

2.2 Design Criticism

As important as verbal discourses, such as policy documents and press releases, are, IT research agendas are also manifest through non-verbal discourses, such as design initiatives, technological infrastructures, and so forth. For this project, we collected a number of design projects that exemplified some aspect of beautifying IoT. In this chapter, we present two of them: an IoT project often characterized as contributing towards aesthetic experiences, and a collection of kitchen products that exemplify how designers transform material properties into aesthetic properties. The second example does not involve computation at all; we chose it not as an example of emerging IoT, but instead because it exemplifies how products beautify environments. Our contention is that eventually exemplars such as these can be and will be blended, so that IoT products feature sophisticated material aesthetics, and everyday products such as kitchen accessories participate in computational environments.

We interpreted these using design criticism, a practice we have been engaging in for years, reflecting our own backgrounds in the humanities as well as current research in philosophical aesthetics, literary theory, film studies, and more. We have synthesized these practices using labels such as interaction criticism and design criticism, and we have attempted to define them as entailing "rigorous interpretive interrogations of the complex relationships between (a) the interface, including its material and perceptual qualities as well as its broader situatedness in visual languages and culture and (b) the user experience, including the meanings, behaviors, perceptions, affects, insights, and social sensibilities that arise in the context of interaction and its outcomes." Design criticism further seeks to explicate and evaluate "the relationships between present and near-future technological possibility and future ways of being, such that design solutions can be introduced" [29].

Our design criticism methodology included accounting for the qualities of the design as it is embodied in objects (e.g., collecting images of the designs, accounts of their materials and qualities, etc.); as they were intended by their creators (e.g., via media interviews, product descriptions, "About Us" content); and as they have been received by the public (e.g., media coverage, design awards, and so forth). This work provided us with many critical-interpretative statements about the designs, which became the "raw materials" of our analysis. But because our goal was to use these cases to construct an understanding of "beautifying" IoT, we also turned to philosophy of art. This body of work provides theoretical constructs, methodological moves, and a repertoire of examples to help researchers navigate complex concepts such as "beauty" and "aesthetic." In this paper, we emphasize two such theories, that of "aesthetic experience" and that of "aesthetic medium," because they sensitized us to aspects of the designs under consideration relevant to our research question.

2.3 Thinking with Theory: Philosophy of Art and Beauty

In attempting to speculatively develop potential agendas for beautifying IoT, we are faced with the problem of beauty as a concept. Taiwan's policy discourse uses the term, but obviously it is not intended to offer a robust theory of beauty. HCI research also has raised the topic of beauty, but frequently it is investigated in the context of individual user judgments of particular interfaces (e.g., [30]). Neither offers a concept of beauty rich enough to support the sort of speculation that we are proposing: to imagine pathways to beautify IoT. We do not subscribe to the belief that to use a concept one has to be able to define it first (a belief that is patently false, as Wittgenstein's famous efforts to define "game" demonstrates), but we do believe that a rich account of a concept like beauty can be used in a generative way. That is, we turn to philosophy of beauty (commonly, though not universally, found in philosophical aesthetics) to guide how we interpret both concrete design objects and more abstract IT research agendas. Specifically, philosophical conceptions of beauty help identify what sorts of qualities and features we should attend to, how we should attend to them, and what sorts of consequences we can expect from such attention.

To develop conceptions of what "beautifying" might mean, we wanted a theory of beauty rich enough to support generative thinking. Of course, the philosophical discourse is rich with such theories, and they disagree with and rival each other, and none achieves consensus as definitive, so there is no obvious one to work with. Neither do we want to offer our own original philosophically defensible theory of beauty. Instead, we surveyed a range of theories available in current philosophical aesthetics to surface common concepts and mechanics. A common theme in aesthetic philosophy is that sensual perception and intellection—and, in a parallel pairing, individual particulars and universal themes or ideas—are somehow unified through engagement in aesthetic encounters. Phenomenological philosopher Hans Georg Gadamer expresses the idea in his book, *The Relevance of the Beautiful* (1986):

> The ontological function of the beautiful is to bridge the chasm between the ideal and the real [...] in the apparent particularity of sensuous experience, which we always attempt to relate to the universal, there is something in our experience of the beautiful that arrests us and compels us to dwell upon the individual appearance itself. [31]

On such a view, beauty is obviously not about superficial sensual pleasure, but about a form of transcendence that is rooted in and returns to its sensual qualities—that which can be seen, heard, and so forth. Yet as Eldridge [32] writes, this engagement is cognitive:

> It is important to remember that the absorptive pleasure that is afforded by successful arrangement is not a mere sensory buzz or tingle. Instead it involves the active use of the cognitive powers of imagination and conceptualization in order to explore the representational and expressive significance of formal elements and their interrelation. Moreover, this absorptive pleasure is itself significant within human life, not gratuitous. […] A successful work of art can seem to embody and exemplify full action and full meaningfulness as such—a meaning wholly fused to material elements in arrangement—and so to anticipate and promise a human world suffused with meaningful action, rather than emptiness and coercion. In both cases the object of absorptive pleasure is something considerably more significant than an occasion for idle sensory delectation. We are pleased in and through actively exploring the beautiful natural scene or object and the formal arrangement of the successful work. This active exploration discloses in continuous attention dimensions of meaning and presence. [32, 66]

What Gadamer calls "the ideal" in one philosophical tradition, Eldridge in another characterizes as "full action" and "full meaningfulness," as opposed to "emptiness and coercion." The beautiful for both gestures through our senses to a world that more meaningful, free, and whole than our mundane present.

Part of the work of criticism (which operates at the level of individual works) and aesthetic philosophy (which operates as a theory of criticism) is to cultivate appreciation of how *aesthetic properties* contribute to *aesthetic experiences*. Aesthetic properties have been characterized as follows:

> It is widely agreed [among contemporary philosophers] that aesthetic properties are perceptual or observable properties, directly experienced properties, and properties relevant to the aesthetic value of the objects that possess them […] Some of the hallmarks of aesthetic property status that have been proposed are: having gestalt character; requiring taste for discernment; having an evaluative aspect; affording pleasure or displeasure in mere contemplation; [..] requiring imagination for attribution; requiring metaphorical thought for attribution; being notably a focus of aesthetic experience; being notably present in works of art. [Examples of aesthetic properties include] beauty, ugliness, sublimity, grace, elegance, delicacy, harmony, balance, unity, power, drive, elan, ebullience, wittiness, vehemence, garishness, gaudiness, acerbity, anguish, sadness, tranquility, cheerfulness, crudity, serenity, wiriness, comicality, flamboyance, languor, melancholy, sentimentality (Levinson in OHA, 6)

And a classic formulation of aesthetic experience is as follows:

> experience has a marked aesthetic character when it has some of the following features […]: attention firmly fixed on a perceptual or intentional object; a feeling of freedom from concerns about matters outside of that object; notable affect that is detached from practical ends; the sense of exercising powers of discovery; and integration of the self and its experiences. [33, lxii]

Summarizing, aesthetic beauty provides concrete and sensual access to a fuller, more meaningful and free world in the imagination of the beholder. Aesthetic beauty is able to do this because it features aesthetic properties, which in turn are accessible to and constitutive of aesthetic experience. We note as well the similarity of the conception of aesthetics presented here with a definition of aesthetics from design theory:

> in general, I regard aesthetics as an overall matrix for conceptualizing and understanding design as the creation and communication of meaning. [Aesthetics is] an avenue for under-

> standing and investigating design as a medium of meaning construction at the intersection of a concrete-sensual as well as a conceptual relationship with the world. [34, 6]

The concept of "beautifying IoT," therefore, would seem to entail (a) objects or systems that are perceptually accessible, and whose aesthetic properties become a focal point for their experience; and (b) experiences that are rooted in direct perception and yet that invoke imaginaries of a fuller, freer, and more meaningful way of being. That "way of being" is highly contingent: what it means in Taiwan is likely different from what it might mean in Sweden or Namibia. And it is likely to be embodied more fully and more powerfully in design products, works of art, and IT systems than in verbal discourses, which is why we turn to design criticism.

3 Design Criticism: Two Cases

We turn to our critiques of two cases of innovation in Taiwan to exploratively imagine how IoT might be framed as an aesthetic agenda in this island. We will revisit the notion of beautifying Taiwan—in terms of aesthetic experience and properties. Taken together, the two cases yield insights on how the conception of beauty is pursued by local innovators, and how this innovation agenda beautifies Taiwan as opposed to other places of the world. By foregrounding cultural practices and considering subjective experiences, we hope show the benefit of widening HCI research on IoT to incorporate aesthetic concerns, and, in doing so, to appropriate research methods from the arts and humanities developed for such inquiry.

3.1 LASS: From Environmental Sensing to Lasting Aesthetic Experiences

The first design case we discuss is an open source citizen science platform focused, at least initially, on air pollution. Particulate matter in the air is known to trigger respiratory and cardiovascular diseases, and it has been a serious environmental issue across Asia for the past decade [35–37]. According to Taiwan's Ministry of Health and Welfare, 7 out of 10 leading cancers of death are associated with air pollution problems [38]. Although researchers and the media alike tend to frame environmental pollution as a health or climate problem, we add that it is also an aesthetic one. Pollution contributes to cancer, but it also is ugly—not just to our senses (sight, smell) but in the ways that it cuts off beautiful ways of being and doing. Asthma exacerbated by pollution can force someone to stay within artificially lit indoor settings, rather than experiencing the childlike joy of riding of bike or simply being out in the park with friends on a sunny day.

To pursue a cleaner future, several sectors in Taiwan have been working collectively since October 2015 to develop the Location Aware Sensor System (LASS, http://lass-net.org/), an open source environmental sensing system that monitors PM2.5 concentrations across the island [39]. LASS is a grassroots system using inexpensive and small tracking devices, which enables its rapid dissemination and deployment of air quality more agile than systems deployed by the government. According to LASS open data (https://pm25.lass-net.org/), there are more than 4,000 tracking points across Taiwan, enabling citizens to access environmental measurements such as temperature, humidity, CO_2 and PM2.5 concentrations through real-time maps [40].

LASS was first proposed by Wuulong Hsu, a professional maker who retired from an integrated circuit engineering job, and who is now associated with MakerPro, one of Taiwan's largest online maker/IoT communities. As Hsu writes on the LASS development platform GitHub [41], the bottom-up, open source aspect of LASS was key,

> My dream is to display all kinds of environmental data on the map so everyone can access the data with one click […] Is this a dream? It was five years ago, but not anymore in the era of makers. This is what LASS wants to achieve.

Similarly, co-founder of LASS, Ling-Jyh Chen characterized LASS as a project of "participatory environmental sensing" and "saving your own environment" [42]. Pursuing environmental monitoring in an open-source, democratic way is, first of all, characteristic of many IT movements in Taiwan [26]; and second, it opens up the possibility of emergent uses that go beyond the initial intentions of the project. And our focus here is an emergent use of LASS. To date, LASS has expanded to include different fields of application, such as forest protecting, flood sensing, and sea monitoring [43].

It is lifestyle farming that we focus on here. By lifestyle farming, we refer to former city dwellers and professionals (many of them former engineers) who gave up their urban lifestyles, moved out to the countryside, and are living off the land. Many of them can be found in a small farming village in Yuanshan Township in Yilan, located in northeast Taiwan. This village is populated with small-scale, eco-friendly farmers who pursue an alternative lifestyle, one that fosters intimacy between themselves and their land, their families, labor, and sustenance. We view this lifestyle as above all a kind of aesthetic choice.

Yuanshan was one of the sites of our ethnography, which we visited in the summer of 2017. In Yuanshan, we encountered the Open Hack Farm (Fig. 1). The Open Hack Farm is a side project of LASS, featuring on-going experiments in agricultural sensing. In it, LASS is being repurposed and augmented for assisting the practice eco-friendly farming and the concept of open source ecology. Aiming to establish a sustainable land management system, devices created and implemented in the actual farming fields collectively create a self-circulatory ecology. Our first impression of Open Hack Farm was that it was small and sloppy, with a worn hand-written sign said, "Open Hack Farm, RC2." A large machine of unclear purpose was taking most of the empty space, and three quarters of the area was covered in plants that looked to us like weeds.

Fig. 1 Open Hack Farm. The blue barrels in the back collect rainwater for irrigation and organic composites for fertilizer, the counter on the right-hand side is a nursery, and the multi-functional FarmBot in the front contributes to seeding, plant monitoring, and growth recording. Photo taken by the authors

As we came to know the space better, we discovered that its haphazard appearance belies its sophisticated design. For example, sunlight is harvested through solar panels to charge agricultural machinery, including an auto-seeding system, an electronic weeding machine, and crop monitoring sensors for mobile tracking. Other low(er)-tech implementations include collecting rainwater for the irrigation system, composing food residue and chicken manure as organic fertilizer, and preserving seeds in preparation to future cultivation. There is a circulatory ecology happening onsite, where machines and natural cycles and processes are integrated. But this project is not in service of industrial agriculture. In this small village, we see farmers/developers utilizing IoT technology as a medium of self-expression, that is to embody the claim that eco-friendly farming is a beautiful lifestyle. Yen, who created and runs Open Hack Farm told us in an interview, "by introducing technology to the farm, I do not mean to replace human labor with machines; instead, what I aim to achieve is to propose an alternative to industrial conventional farming, to disseminate the idea of small-scale ecological farming, and to invite more people to join this practice." For him, agricultural labor is not an economic or productivity problem to be solved by technology. Instead, agricultural labor is practice that can be made more meaningful, intensifying the relationship between humans and the land. In short, Yen wants to make agricultural labor more beautiful.

"Aesthetic" is a loaded term, as we indicated above. Here, we focus on those aspects of aesthetics that have to do with human experiences. Dewey has a notion of aesthetic experience [44] that has been highly influential in HCI research [45], which analyzes the qualities of "an experience." Dewey claims that a good experience has a beginning, middle, and end; it is interactive and rhythmic; it is consummated or completed; and it has an overriding felt emotional quality. While many even most theories of aesthetic experience are tied to contemplation of specific artworks, one of the strengths of Dewey's account is that it can be extended beyond art—to the mathematician's experience of solving a math problem or a child learning in school.

In developing his own account of aesthetic experience, philosopher of art Noël Carroll [46] observes that often when people are having aesthetic experiences, they attend to the structure of a work, noting how it hangs together (or fails to). Carroll calls this "design appreciation," not referring to design as a field but rather to the human tendency to discern how individual choices contribute to the overall effect or purpose of the work, and to derive aesthetic pleasure from that act of discernment. For example, in a poem we might notice how devices such as rhyme, alliteration, and meter (all aesthetic properties) give acoustic emphasis to words that happen to be especially important to the poem's meaning. Or, upon re-watching a favorite film, we might appreciate how the director uses props, camera angles, symbols, and cuts to foreshadow something important that will happen later in the film.

Open Hack Farm seems to bring these two notions of aesthetic experience together. The farming labor that it supports has the high potential to meet the qualities of a good experience as Dewey describes them: the activities of farming are holistic, interactive, rhythmic, meaningful, and directly linked to outcomes. But Open Hack Farm also provides an experience where what Carroll describes as design appreciation seems to do a lot of work. These farmers' public accounts, reinforced in our data, suggest that this type of farming is aesthetic by achieving a kind of harmony among a small plot of land, a family, a close-knit neighborhood, and a tight coupling between one's own labor (e.g., farming activities) and its product (e.g., one's own food). Here, the "design" is not that of a work of art or a single artifact, but that of an ecosystem, where the human lifestyle or way of being is well integrated into natural rhythms (e.g., the diurnal cycle, the seasons, etc.).

But this is no mere romantic harkening back to a nostalgic past. This is an IoT farm, a farm so technologized that "Hack" is part of its name, and hacking is as integrated into the ecology as physical labor and the rotation of the Earth around the sun. Obviously, IoT is used as a resource to support farming. But we must not overlook that the relationship also works in the opposite direction: the farm—as a lifestyle, not just a physical place—presents a new opportunity for these former IT professionals to hack, to develop and extend the concept and practice itself of hacking. That this whole ecosystem is experienced aesthetically is key to its interest to research in IoT.

All of this suggests that "beautifying IoT" can refer to IoT's potentials to contribute to aesthetic experiences understood in a relatively precise way. Specifically, it poses the question, how do the individual elements of our environments "hang together" to achieve an overall effect of aesthetic composition? What is the whole, the parts, and the principles of composition of the parts? For example, a "Smart City" is an environment (i.e., a city) that is intellectually grasped and pursued as a kind of Gestalt (i.e., it is "smart"). But "smart" is intangible—we cannot point to it the way we can point to a device or even a city. "Smart" is a principle of organization, and it is aesthetic not to the degree it can process information, but rather to the extent that this information processing enriches and validates how all of the elements—including but not limited to human experiences—fit into its whole, the way a rhyme scheme and an apt metaphor convey a sentiment—say, of love lost—poetically. And Dewey helps decompose the dense notion of human experience similarly into a structured composition of parts, including material engagement, sensemaking, enlightenment, and emotional fulfillment. The Smart City will be aesthetic when the diverse elements of the smart city (the environment, human activities, technologies, the scales at which these are experienced, their mutual integration, etc.) are so well composed that they stimulate and reward the human desire to attend to their structure.

3.2 No.30: From Industrial to Aesthetic Material

Our second case, as indicated above, is not technical. Instead, it features an example of "creative living" in Taiwan, which refers to the aestheticization of everyday life. no.30 (http:/no30-inc.com/) is Taiwanese home decor brand specializing in zinc alloy accessories and giftware. It has received international recognition for crafting products of high aesthetic quality. No.30 was founded by Shu-Jen Chang, daughter of the owner of Chi Hsing Metal, a family-run zinc alloy manufacturer based in Changhua, with almost 40 years of experiences in producing die-casting products for automobile, machines, and household appliances. Changhua is a county in central Taiwan that is home to the largest cluster of kitchen and bathroom hardware manufacturers in Taiwan. Zinc alloy is an industrial material with great strength and flexibility, high resistance to corrosion, and the ability to be polished to resemble the precious metal platinum. Although zinc has wide industrial applications, the material itself is rarely used as the primary material in high-end products.

The story of no.30 started with Chang's appreciation for zinc, motivated in part by pride in the quality of zinc manufacturing achieved by her family's business. The name, no.30, references the position on zinc on the Periodic Table of the Elements in chemistry [47, 48]. According to an interview conducted by Global Views, a popular magazine publisher in Taiwan, Chang recalled that she thought her family was a jeweler when she was young, because there was "glittering stuff all over the place" [48]. She wanted to make this hidden gem the center of appreciation. Together, she and her father founded no.30 in 2014.

Chang turned to Office of Product Design and Five Metal Shop, two design and creative studios with a presence in Taiwan, to reimagine the possibilities of zinc alloy products and to revitalize the family business. As the Office for Product Design characterizes the collaboration on their website, "We believe each material has its own unique qualities and, when thoughtfully used, the result can display integrity, honesty and beauty." They add, "The no.30 objects are varied in terms of typology and surface finish, but unified in material, thought and purposefulness.[…] The objects are designed to add a special touch and ambience to any environment without dominating it or demanding too much attention" [49].

Fig. 2 Two views of Ganbei, a circular bottle opener. *Image Source* no.30-inc.com

Looking at no.30 products as a collection, we see how the designers make use of zinc alloy's visual reflectivity to achieve a product identity, which we would characterize as understated and elegant. Let us consider Ganbei as an example. Ganbei (Fig. 2) is an award winning circular bottle opener, whose name is the Mandarin term for "cheers" during a toast. This product is finished with frosted zinc alloy on one side to assist a firm grasp and resembles the natural appearance of a pebble when not in use. Flipping it to its opposite side, polished stainless steel suggests its purpose as a bottle opener while expressing a modern, industrial aesthetic.

In fact, Ganbei is typical of no.30 designs, which share key features of its aesthetic. Most no.30 products are constructed in simple geometries with chamfered or rounded edges, combined with natural materials such as bamboo and glass to add contrast to the zinc alloys, and different production techniques, color coatings, and surface treatments are applied to create intriguing product personalities. No.30 designs feature aesthetic principles of rhythm, balance, and harmony.

No.30's Ganbei is not literally an example of IoT, obviously. Rather, it is of interest for the way that it transformed an industrial material into an aesthetic material. This entails far more than seeing the aesthetic potential in a material. Philosophers of art such as Joseph Margolis [50] and David Davies [51, 52] distinguish between the physical medium and the artistic medium of a work. The physical medium is what gives it its physical form—marks of pigment on canvas for a painting or bodily movements in dance. The artistic medium is "a set of conventions whereby performing certain manipulations on a kind of physical stuff counts as articulating a particular artistic content" [53]. To continue from before, whereas marks of pigment on a canvas are part of the physical medium, delicate brushstrokes are part of the artistic medium; likewise, where bodily movements are the physical medium of a dance performance, a pose or articulated steps are part of the artistic medium. Key to this distinction is that the artistic medium is recognizable by others; in other words, what makes a mark of pigment a delicate brushstroke, or what makes a bodily movement

Fig. 3 Two views of Tetra, a fruit platter. *Image Source* no.30-inc.com

a dance pose, is a shift in viewing physical properties into viewing them as aesthetic properties.

In the context of no.30, this means that it was not enough for Chang to perceive aesthetic potential in zinc: in developing aesthetically pleasing zinc alloy products, she had to develop and successfully propose zinc alloy as part of an aesthetic medium—that is, as having a set of publicly recognized conventions whereby certain uses of zinc would count as aesthetic. Prior to her work, zinc was seldom used in upscale giftware; doing so meant developing conventions whereby zinc could be a primary material in such design. Now, such conventions need not be invented ex nihilo; it is clear Chang made use of existing aesthetic conventions in the giftware and the upscale kitchen product domains concerning the use of shapes, textures, contrasts, and functions. Nonetheless, in doing so she exploited material strengths of zinc, including its reflectiveness, strength, ability to bond with other materials, and capacity to be expressed with geometric shapeliness.

This work is visible in no.30's characterization of a different design, Tetra, which is a fruit platter (Fig. 3). "The design of our fruit platter was inspired the way by piled up fruits at fruit-selling stands. […] The dished areas in the top surface accommodate stacked fruits, various snacks and dry goods, displaying everything in an abundant fashion" [54]. Conventions of traditional Chinese produce markets help make Tetra's design desirable to consumers, or (in the philosopher's language), to "count as articulating a particular artistic content." Making this aesthetic recognition possible means developing not just objects, but also aesthetic conventions: "We want to create a simple, universal language to communicate our own histories and memories to the world." [55].

Not unlike the transformation of a zinc factory from an industrial chemical to an upscale designer product manufacturer, the Internet of Things promises to reimagine and reinvent industrial materials and devices. What will make them beautiful (or not) is not some mysterious or ineffably subjective quality intrinsic to the materials or objects, but rather how they are situated within publicly comprehended conventions, expressive languages, and embodiments of cultural memories. Without these, objects are mere physical objects; they are only beautiful once cultural conventions of beauty are in currency. Put another way: the design of beautiful IoT is not limited to the design and distribution of aesthetic IoT devices, services, or experiences—it also includes the development and dissemination of aesthetic conventions and languages that allow them to count as beautiful in the first place.

4 Discussion

In positioning IoT as a matter of beautification and aesthetics at the outset, we were clearly claiming that the problem runs deeper than, say, hiring a graphic designer to pretty up IoT devices. Yet, as our sketch of aesthetic beauty above suggested, articulating what aesthetics might mean in the context of IoT is no trivial matter. In this Discussion, we explore that difficulty from two perspectives:

- Aesthetics can be justified as a primary, rather than secondary or even tertiary, concern for contemporary computing agendas.
- The scale of IoT poses a challenge to those hoping to appropriate traditional aesthetic valuation (read: criticism) methods.

The overriding characteristic of IoT that has motivated this study is its scale. IoT, including similar concepts of smart cities and ubiquitous computing, propose immersive environments not the size of the Holodeck, but the size of a metropolis, a nation, and potentially even the globe. In such a context, aesthetics cannot simply refer to attractive packaging. One need only consider the regional wastelands that humans have created, wastelands that no longer sustain the kinds of lives that humans want or need to live. This includes literal wastelands, such as the land around sites of nuclear disaster. But it also includes many cities, designed (we are now beginning to understand) for automobiles instead of pedestrians, at a scale that makes it nearly impossible to walk to work or the store, to know or engage one's neighbors. It also includes cities designed to segregate citizens by race or social class, creating unlivable and inescapable concentrations of poverty and violence. These cities are in a literal way ugly: litter, pollution, and shabby buildings dominate lived environments. All over the world, urban planners are seeking to reverse these mistakes by creating pedestrian districts and public greenways, renovating buildings, and much more—Taipei Beautiful policy is a typical example.

What is the potential for IoT to create ugliness at scale? How do we know the IoT vision the HCI community is helping to create and sell will not in fact be the blueprint for future ugliness? Documents of Worlds Fairs from the 1930s and 40s provide visions of how, say, the automobile is going to improve urban life—failing to anticipate the ways that the automobile decimated inner cities, destroying neighborhoods, jamming throughways with traffic, filling cities with noise and air pollution, and enabling white flight. Are today's IoT visions just the latest in the genre?

Obviously, we don't have the answer. But HCI researchers can at least attempt to bring a serious conception of beauty and aesthetics to bear on IoT. Aesthetics is often presented in research as if it is too complicated and subjective even to grapple with. But this claimed vagueness is precisely where art theory—from art history, literary theory, philosophy of art, etc.—can help, if they are used in certain ways. Such theories can make aesthetic issues more tractable, by identifying different dimensions, characteristics, or qualities of beauty or "the aesthetic" and making them easier to attend to. Our engagement with philosophy of art in this paper has not been to engage as philosophers ourselves—that is, we have not tried to propose a new and robustly justifiable theory that can defeat even the most dogged skeptic.

Instead, our use of aesthetic theory has been to help us attend to different aspects of systems, experiences, materials, and things that we intuitively feel are in some sense "aesthetic." Specifically, our use of Dewey and Carroll in the LASS example helped us gain purchase on the ill-articulated but provocative idea that small scale farming is an aesthetically fulfilling way of life. It links the real (physical qualities of actual places and objects) with the ideal (a meaningful, fulfilling, and sustainable way of living). Our use of Margolis and Davis in the no.30 example helped us understand why the development of these upscale kitchen products was an aesthetic, and not merely industrial, use of the material zinc. There are hundreds of such theories, and we do not mean to claim that these are the best or most important for IoT. All we mean to demonstrate is that aesthetic theories can be uses as resources to help us do what we want to do—which is to attend, as design researchers in HCI, to the aesthetic qualities of emerging technologies whose mature uses and look-feel have not yet come into view, and to creatively imagine some ways to carry those qualities forward.

But—and this is our second point—much of traditional aesthetic theory has been developed in the context of traditional artworks—paintings, poems, dance performances, and musical compositions being dominant examples. What these share is that they have human-scale interfaces: for the most part, they fit in a room. A poem can fit in a small book, held by one hand, while one is nestled in a chair. A dance performance takes up more space—but still it fits in an auditorium. Traditional WIMP interfaces, mobile apps, research through design artifacts, and so forth also, for the most part, fit in a room. Interaction criticism (as characterized in [56, 57] seems to assume and build off these similarities of scale).

But IoT and cities do not fit in a room, which is one reason why contemporary urban policies, like Taipei Beautiful, have implications for both. Aesthetics at a much larger scale seems most applicable here, and that is where more broadly scoped aesthetic perspectives are needed. Here, a sense of collective aesthetics, that is, the aspiration for future ways of life of a region, seems especially important. Here we are circling back to the idea of a Swedish IoT or a Taiwanese IoT. We do not mean this in a classificatory sense (e.g., treating Swedish vs. Taiwanese culture as buckets), but rather as an empirical aesthetic question: what ways of being do people in Taiwan collectively pursue, or hope for in the near future, and how can emerging technologies like IoT support them?

We mentioned in our methodology that our examples were chosen in part because technologists, entrepreneurs, and makers themselves identified them as interesting. no.30's Ganbei and Tetra might not have been interesting to a similarly qualified group in another region—they aren't even examples of IoT! But Ganbei and Tetra resonated with these technologists, in part because the designs speak to specific Taiwanese aesthetic concerns. This includes obvious aesthetic qualities, such as the meaning of "ganbei" in Chinese culture, or the way Chinese fruit markets present their wares, as alluded to by Tetra. It also speaks to one of the dominant questions in IT discourses in Taiwan: how can traditional manufacturers be more creative, so as to benefit from the innovation economy? Finally, the attraction to these designs also happened in a population where manufacturing expertise is far more dense than it is in many other places. In other words, technologists, makers, and entrepreneurs in Taiwan are more likely to appreciate a clever new use of an industrial material, because that is something many of them have been thinking about their whole professional lives.

5 Conclusion

In this research we have sought to push the limits of our own aesthetic thinking about IoT by identifying a set of aesthetic objects of interest to a group who focus quite seriously on IoT as an R&D agenda, and then seriously yet also playfully considering them in relation to computational aesthetics and aesthetic interaction in HCI, because they specifically address technology and interaction; urban/regional policies on aesthetics, because they address questions of scale and ecology; theories of aesthetic experience, because they account for the human scale; and theories of aesthetic medium, because they account for both the material and cultural dimensions.

We hope in doing so to have revealed some of the stakes of thinking about IoT in relation to beauty and aesthetics, and thereby to have motivated more research in this space. We also have sought to demonstrate a methodology that facilitates researcher appreciation of subtle aesthetic qualities, where they might not have been obvious on first glance. Finally, we have contributed to research recognizing the importance of, and meaningfully building on, IT R&D in Asia.

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The Internet of Places

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Abstract The Internet of Places is a specialization of the Internet of Things. Personal places (like home) and intimate public places (like neighborhood) are comprised of "things". Such place-things can be instrumentally empowered through sensors, data sharing, and computation, thereby exemplifying and contributing to the Internet of Things. But places are distinctively significant to people in sheltering, in anchoring memories, in evoking meanings, and in providing settings for social interactions and human development. To that extent, the Internet of Places should be analyzed as a special case, and an especially social case of the Internet of Things.

Keywords Place · Personal space · Community · Neighborhood
Internet of places

ACM Classification Keywords H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

1 Introduction

The Internet of Things is a dramatic and inspiring step ahead in distributed computing, but also in emotional and social computing. Trucks and factories that manage their own inventories, and share their data with other smart objects to optimize workloads and maintain themselves can make supply chains more reliable, and accessible to query. However, sensible objects pervading daily life can create new kinds of experiences and relationships between people and environments. In this paper, I reflect on the "Internet of Places" at personal-scale and community-scale [4]. We make our places, but they, in turn, make us.

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_2

2 Things and Places

The Internet of Things is an exciting vision of the not-to-distant future when many of the devices in our midst can exchange data and coordinate their operation. If you image any scenario in which useful data is or could be sensed, and then directly guide action, this is the Internet of Things. Autonomous vehicles constantly map and monitor the area immediately around them, interact with databases to calculate and update their routes, anticipate and plan for lane changes, turns, and other events, and improvise their operation for road hazards. Smart buildings monitor occupant presence, and adjust their subsystems, warming/cooling and lighting spaces that are occupied, and reducing energy directed to spaces that are not currently occupied. These are Internet of Things scenarios. Sensors that measure the temperature, moisture and chemistry of soil in a field to determine recommended planting and harvesting times, watering and soil enrichment regimes, and crop rotation would similarly be Internet of Things. Medical implants that report status and adjust their operation through interactions with medical systems outside the body would also be Internet of Things systems. The schema for Internet of Things systems is highly generative; pretty much every interaction could be envisioned as an Internet of Things scenario.

A key element in this vision is consideration of the amount of data and data handling that is relevant to actions, and technology affordances of pervasive Internet connectivity. Thus, various kinds of driver distraction problems plague human drivers, and have become key arguments for autonomous vehicles. Particular sensor systems, such as radar and video, and cloud services, such as maps and other databases, can be integrated, continuously synchronized, and support intelligent guidance that is completely reliable with respect to distractions that humans cannot resist.

Internet of Things systems will surely change the world. They already have. But it is plain that there are concerns that are not significantly addressed, or perhaps addressed at all, through alleviating the demands of data. For example, even if it were possible to closely monitor all relevant bodily concomitants of various experiences, like the emotions of love or experiences of fine food, no one alive would want to make these experiences faster and more accurate by augmenting them with sensors, decision making, and operational interventions, such as notifications.

One way to understand the social Internet of Things is as those aspects of Internet of Things scenarios that transcend issues of data and data handling. The era of Internet of Things entails more than powerful data management; it entails new sorts of interactions and experiences for people. In this view, social Internet of Things is a further layer of analysis required to understand Internet of Things. The distinction between *place* and *location* illustrates this. Places are different from locations in that place is constructed through interaction and experience. Thus, a street corner is always a location; the location can be fully characterized by data such as GPS coordinates, the names of the intersecting streets, driving directions, etc. But a street corner is only a place to the extent that someone has been there and experienced something. Characterizing *that* is more than a matter of data.

3 Jack's Kitchen

Kellogg et al. [13] envisioned Jack's Kitchen as a distributed object, responsibility-based infrastructure in which kitchen interactions are mediated by an ensemble of kitchen services, devices, objects, and supplies. The embodied kitchen, through the ensemble of its parts, is an integrated user interface for kitchen activities. This is an example of the smart home Internet of Things type: The refrigerator manages its inventory to ensure that milk is fresh, and that vegetables and meats will suffice for Jack's next cooking project. The refrigerator shares data with the wine cellar to verify that wine to complement the meal is available. When Jack shops or cooks, inventories are updated. Jack can be notified of anticipated shopping needs, or can just have the kitchen coordinate with his grocery store.

There is a lot of data in a kitchen; for example, variety of food items in the refrigerator each are time sensitive, moving from fresh to spoiled along their individual time lines. Human attention and data processing can clearly be a bottleneck. In Jack's Kitchen the various objects actively manage themselves, communicating their freshness constraints, but also creating a dynamic inventory dependencies and interactions. Jack's kitchen suggests menus, things Jack likes to cook, and things that he ought to eat. And this relatively concrete inventory-oriented advice can enable further opportunistic interactions. Jack can learn about tastes and menu planning, and about nutrition management. He can track his diet against various longer-term objectives.

In the late 1980s, distributed object architectures were still developing, and encouraged such visions. Kellogg et al. focused on envisioning the potential utility of software objects defined by responsibilities they carry out within an implemented system. They offered the "Jack's Kitchen" scenario as an alternative approach to what was then being called "cyberspace". Most views of cyberspace had focused on rich and engaging display-mediated virtual reality experiences, including early conceptions of direct brain-computer connections, as explored in cyberpunk futurist works of that period [2]. The cyberspace of Jack's Kitchen is not apprehended by the eyes (or brain tissues); it is not an experience the self is projected into. Instead, it leverages diverse interactions with connected physical things that surround the embodied self "making reality a cyberspace".

Personal spaces, like one's kitchen, are of great practical importance. But personal spaces are also significant emotionally to people in sheltering, in evoking meanings, and in providing settings for social interactions and human development. For example, in organizing Jack's inventory of food items, the kitchen could motivate and guide Jack to explore and develop new cooking skills. In a sense, this is still a fairly simple example of the original data management motivation for Internet of Things: The combinatorics of his current food items, and strategies for optimally utilizing foods before they spoil, might not be something Jack would invest much time and effort in. But it easy for the kitchen to make a few suggestions, and doing so could fundamentally expand Jack's insights and skills with respect to his own food.

Kitchens are often the central design feature, even the structural hub of homes. Friends and family tend to gather in kitchens. In modern life, food preparation, eating, and clean up comprise some of the social family time we still have. Just by managing the inventories and capacities, the kitchen could also enable richer social interactions. Thus, menus suggested to utilize food on hand, and to provide learning and development opportunities, also provide topics for family conversation and orientation for collaborative family projects. These could be modest in scope, such as discussing which wine to have with dinner. They could involve identifying and harmonizing menu items in the dinner. They could be more ambitious, such as helping two or more people coordinate the preparation of food items so that everything is ready at the same time. The kitchen might sense Jack's partner and children to more precisely suggest, organize, and support joint kitchen projects, and alert family members in other parts of the home, or in the yard outside, that dinner is ready.

4 Past, Present and Future Cohabitation

The kitchen and other spots in our personal living space materialize aspects of what it means to be home. Beyond these places is the intimate public space community, more social, but in many senses no less personal to us [10, 15].

Community places provide support for community projects as a kitchen supports our meal preparation and clean up. The park has its benches, views, places that children play, sounds. The Starbucks has coffee, people staring into laptops, and the din of a few conversations. People in community places can invite social openings through eye contact, smiles, and hellos. Today, they can also subscribe to location-sensitive services to make themselves visible and accessible for invitations to discuss community issues, share lunch, or take a short walk around the downtown shops.

Community is facilitated by common understandings and projects. These are rooted in myths and history, enacted and debated in the everyday now, and pointed toward a vision of the future. They are embodied in community places: the place where a sinkhole was that became the high school football field, the place where a barbershop has operated for 100 years, the place where people go to talk politics, the place where the town has proposed to create a pedestrian zone, and so forth.

Some of these places embody community heritage. History is inscribed deeply in them but it is also easy to miss their significance. The sinkhole is now gone. No one can see directly that it was ever there, though one might wonder why the level of the football field is somewhat lower than the level of the streets and sidewalks that surround it. Some of these places embody community practices; they are essential props for daily experiences. Conversations at the barbershop continue, though no one there knows how similar they are to the conversations a century ago. And some places embody the community's future; their current locations and appearances are contingent, temporary. People who have read the town's master plan might look at these places and see things that do not exist yet.

Location sensitive community apps can help articulate the meanings of places, and facilitate collaborative use of community space [5]. Thus, a person could walk around a local community space and get access to information about local places through the location sensing of a mobile device. In this type of design, the places themselves do not carry out computations or literally hold data, rather their geospatial coordinates are recognized by other devices, such as smartphones, and serve as keys for accessing data and interactions (e.g., [1, 7, 14]). However, from the standpoint of human experience, information and activities that pertain to a location, and are enabled by being at that location, can contribute directly to the meaning of the location.

Our design, Lost State College [8] provided place-based access to old photographic images and textual information we obtained from local historians describing what had happened at a collection of significant sites of local history; users could access these locations by being there, and engage in a variety of social media interactions to acknowledge and elaborate the meanings of the places. Thus, we combined the ideas of allowing places to speak for themselves and of allowing visitors to react, elaborate and develop the information comprising the places in order to make the curation of local heritage into an ongoing and open community project.

Our experience with the use of Lost State College focuses on 32 town residents who used the app for about an hour and were then interviewed. We found that people who had resided in the community for more than 4 years were more likely to contribute content to places, including both textual comments and photographs. The content contributed tended to be reports of personal experiences with various places and personal reflections on the significance of places. People who were new to the community, residing there for less than a year, were significantly less likely to post personal content, comments and photographs, but they were just as likely to view user comments and photos as more established residents. This suggests that making personal meanings of community places more visible can quickly be appreciated and utilized by new residents.

In interviews, people who used Lost State College expressed surprise and excitement about the history of particular community places. For example, one place consisted of a small sculpture of the members of a pig family. The sculpture commemorates the early history of the town when farm animals were permitted to roam. It dates to 1896, when the people of the town looked back to their rural origins nostalgically. Most participants were already aware of this sculpture, but few had a specific idea of its meaning. They were quite engaged to learn some details about its history while standing there with the pigs.

For places that had changed dramatically, people were intrigued to imagine life in the town at an earlier time; for example, when the site of the current football field was a sinkhole used as a dump. Places that had persisted in their role for many years, such as the Hotel State College and the barbershop, evoked reverence. For these places people were especially interested in studying the old photographs: *"I love the long history and also food"* (hotel); *"wow this is cool that they keep it original!"* (barbershop). Participants commented on how places had changed, and how people in the places had changed. They were surprised by what had happened in the past in places they walked by every day. One person said that made him feel greater pride in the community to more directly appreciate its past place by place.

At about the time, we were experimenting with Lost State College, we also we engaged in studying the town's master plan process. This is a serious of envisioning how the town could develop through the next decade. The process results in architectural models and plans, sketches and drawings, and digital images of future streets, sidewalks and buildings. At the municipal level, citizen participation is critical to legitimizing public plans and initiatives; the town invests enormous and continuous effort in attracting, involving, and listening to citizen perspectives [12]. In the master plan process a series of formal presentations, and interactive sessions with models and other design artifacts was carried out. Although some spirited and productive conversations occurred, attendance was fairly low, often consisting mostly the same reliable group of residents. Most residents were not even aware that this process was going forward. Making sense of the many architectural drawings and reviewing the substantial planning documents are quite significant tasks for anyone who is not trained and does not regularly practice those tasks. Our partners in the local government wanted more citizen input.

To begin to explore this problem, we created Future State College [6]. This design is analogous to Lost State College, but presented imagery of what places in the town would look like in the future, based upon the town's master plan, and invited people to comment. For example, one block of a central street in the town was planned to be converted to a pedestrian zone, with much wider walking areas and more extensive tree planting. A person using Future State College could walk in the one-block area and see the digital modeling and environment for the pedestrian zone. The user would be queried about this design direction, and the specific plan for achieving it.

Our hypothesis was that this sort of focused interaction would be both more engaging, in that the user could directly compare the current reality to an element of the master plan, and also more manageable, in that the scope of the interaction was limited to just a part of the whole master plan. Future State College asked people to focus on a specific design question instead of posing the vast and somewhat amorphous question of how they felt about the whole master plan.

Our implementation and study of Future State College was limited to elements of the master plan in a 2-block region of one central street in the town. Citizens were excited to experience the municipal master plan, and liked experiencing it and commenting on it at the same time. This is important in that participation or even awareness of the municipal master plan process is extremely rare.

We have also explored design concepts for using location sensitive services to make fellow community members more accessible to one another. The basic idea is that community places can mediate human encounters and interactions: If you and I are near the same place, then we are near one another, and might be able to exploit that proximity, participating in a joint community project. For example, Community Animator allowed citizens to join discussions of community issues with others interested in those issues, who were also physically nearby [6]. It lowered the bar for people to become community animators, engaging themselves and others in "spontaneous" community discussions. The idea for the app was to make every community place into a "third place", in Oldenburg's [15] sense.

Mobile Timebanking [9] is a similar approach focused on exchanging and pooling effort, rather than sharing conversation and discussion. In timebanking, people offer to do simple things for others and invite others to do things for them, such as giving/receiving lessons and carrying out domestic chores, or invite others to join them in simple activities such as dog walking, eating lunch, taking a walk or engaging in other physical activity. These interactions are valued by the time required to engage in them (hence, timebanking). Mobile timebanking emphasizes service exchanges and collaborations in the immediate spatial vicinity and timeframe. Community Animator and Mobile Timebanking are similar to services like Meetup, but are more real-time and opportunistic than planned in advance, and do not have central leadership. Both have the concept of leveraging co-location in community places. People who tried these interactions reported the formation of new ties, connections to others in the community they might never have encountered.

5 Sociotechnical Change

The integrated data infrastructures of the Internet of Things entail a *social* Internet of Things. They can enable richer interactions and experiences in personal, family, and community places. They can provide new possibilities for human development and social engagement. Sociotechnical change is never simple though. Concomitant with new affordances and opportunities, the Internet of Places may reshape aspects of life that we value and need. As we go forward "making reality a cyberspace", we should remain mindful that every inspiring vision also entrains downsides. Indeed, the cyberpunk reworking of cyberspace in the early 1990s wound up basically dystopian.

Consider security issues. Easy and pervasive access to things, and among the things that help constitute a place, is essential to the visioning for Jack's Kitchen and Lost/Future State College. If such interactions require too much security configuration, or real-time protocol, they will be much less compelling to people. They will enrich places less effectively. The places will seem more like a bank than a kitchen, more like the workplace than the neighborhood. Yet Internet of Things systems that are more open will present a wide assortment of "weakest links" for intrusions. Indeed, security challenges is one of the primary contemporary discourses of the Internet of Things [11].

The enhanced interactions and experiences of Jack's Kitchen change what it means to be a kitchen and to prepare one's food. Such places become agentive. They do not merely store materials that enable activities; they do not merely evoke human memories. By integrating and organizing data about the materials and activities, the kitchen provides richer interactions for people, as Kellogg et al. emphasized in their slogan "making reality a cyberspace". But this also changes the relationship of people to their kitchens. The kitchen does not merely evoke memories, and store food, it notifies and recommends things to consider and do. It is possible that people would be both stimulated and undermined by places like Jack's Kitchen, for example, they might learn new techniques and preparations, but lose some existing capacity for improvising meal with a couple unorthodox substitutions. Similarly, people might lose some of their amazing place-based memory skills if their places reliably remind them of what would have otherwise been cued recall.

Recent developments in autonomous vehicles have reawakened discussion of how automation can undermine human cognition by supporting it. For example, there is evidence that autopilots and even programming tools undermine the human skills they are designed to support [3]. Downsides of automation are debatable also though. If autopilots and programming tools reliably enhance our performance, and are always available, it does not make sense to insist on being limited by human limitations. Perhaps the same should be said for food improvisation and spatial memories.

Family life and community life may become more accessible in the world of Internet of Places. Newcomers, peripheral members, and children may more easily come to know the family, the home, the neighborhood, both its places and the experiences, interactions and activities that give those places their meaning, more quickly and easily than now. This could be a good thing in that one of the traditional dysfunctions of intimate human social arrangements is the time and effort required to initial and maintain them. It's quite hard to become a family member or a community memory, and this encourages not bothering to do it.

On the other hand, public backtalk directly from the objects of personal places might demystify them too easily, and perhaps too superficially, thereby attenuate the experience of coming to know, moving closer, and so forth. This could undermine the subtlety with which we understand people and places, and the agency and responsibility we feel and exercise in coming to know. Psychology research has shown in many ways that people are attracted to, attend to, and are stimulated by experiences of moderate complexity. Many rich and rewarding experiences in the world as we know it now require us to do some intellectual and perceptual work in order to enjoy fully. Of course, making the kitchen a bit more transparent and responsive to the cook, and the neighborhood more aware of its past and future, does not remove all complexity. It may remove just enough to enable more cooks and neighbors.

Another consequence might be enhanced mindfulness. Enriching various places with signature experiences, memories, issues and discussions, and plans for the future would make it harder to turn off attention, to be inert as to where one is. It is definitely a good thing in many respects to enable a more mindful human experience, a way of living in which one is more aware of one's own thoughts and feelings moment-by-moment, more aware of others, and just awake to life. More specifically, Internet of Places might make us more mindful of our friends, loved ones, neighbors, homes, neighborhoods, and communities, more aware of the now-invisible personal narratives and currents of emotion that constitute our local places. Greater engagement and awareness of family and neighborhood is a finger in the dyke of contemporary isolation [16].

But here too there can be a downside. No matter how rewarding it is to be socially engaged and mindful, sometimes people want to disengage and turn off. Places that are responsive and agentive might easily intrude on human solitude, on the right to be left alone. The quiet of the kitchen and the anonymity of the street are also places to be alone, to psychologically recharge through solitude.

These tradeoffs are grist and guidance for designers of the social Internet of Things. As in most design spaces, we can identify some dimensions of concern, but we do not know in detail how these dimensions would work in detail for an Internet of Places world, how they might interact, and how people would appropriate and transform them through use. The social Internet of Things emphasizes both the possible social concomitants of Internet of Things infrastructures, but also the constructive processes through which the Internet of Things will become socially embodied.

Acknowledgements I thank my collaborators Kyungsik Han, Wendy Kellogg, Jess Kropczynski, Patrick Shih, John Richards, and Mary Beth Rosson. IBM and the US National Science Foundation supported this work.

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From the Internet of Things to an Internet of Practices

Thomas Ludwig, Peter Tolmie and Volkmar Pipek

Abstract In his ground-breaking work on the *habitus* Bourdieu (Outline of a theory of practice. Cambridge University Press, 1977, [4]) understands practices as the permanent internalization of the social order in the human body. Others have taken this idea and described practices as 'normatively regulated activities' (Schmidt K, *Proceedings of the International Conference on the Design of Cooperative Systems (COOP)* [28]). Our own interests here arise from the fact that during the performance of all of these various activities, which may implicate and draw upon the material environment, the surrounding context, their own capabilities, interests and preferences, people often use supportive devices and technologies that help to enable and support their realization. Where these supportive technologies make up a part of the Internet of Things (IoT) they are usually small, interconnected cyber-physical devices and are typically used in social/collaborative settings. As a consequence, the (re-)appropriation of these new devices and technologies is not only a technical, but also a social process. Within this exploratory paper we focus on the potential of IoT technologies for supporting collaborative appropriation within Communities of Practice (CoP) from a practice-oriented perspective. We outline the vision of an Internet of *Practices* (IoP). This vision encompasses and addresses a range of phenomena that has been associated with how CoPs evolve and the resonance activities that can arise as specific bodies of practice adapt, by adding integrated support for the documentation of practices and the sharing of relevant representations such that mutual improvements in practice may take place. Based on our vision of the IoP, we outline some directions CSCW research could take regarding the potential of the IoT and new emerging technologies, thereby expanding the scope of CSCW's areas of interest.

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_3

1 Introduction: Learning Technology Practices

Imagine you are a new photographer within a well-established photographic agency and you've got a new expensive camera for starting your job. The photographic agency demands that all of its employees use a consistent style for each photo set. You've already used the camera a lot and it has encouraged you to think that you might one day become a more professional photographer. However, having compared your pictures with those of your colleagues who have been in the company for a long time, you've had to acknowledge that their sets of photos always look better than your own. Yet your colleagues and you are both using the same camera, the same tripods, even the same lenses. So you ask yourself: How will I ever be able to take such perfect pictures? This has driven you to search online for lighting conditions, angles for holding the camera and which lenses are best to use in different situations. You've also asked your expert colleagues for help and they have actually described for you how they go about taking pictures. Although you've really appreciated your colleagues' hints, your pictures are still not as good as theirs. The problem is it's just not easy adapting your own activities so they are closer to the established practices of the experts when you only have their explanations to go on, not to mention having to do that alongside of other compounding elements such as the hardware, software and the physical context in which you are using the camera (as well as your own physical abilities). So you continue to struggle to appropriate your camera effectively—or at least the practice of taking good pictures.

But what if the camera was itself able to mediate your colleagues' professional camera-handling practices? What if you were able to perceive expert photographic practices directly when taking your own pictures? What if the cameras were equipped with multiple sensors and were connected through the internet so that they could enable the gathering as well as the sharing of practices of other camera users? Or, to put it another way: What if we could make use of the Internet of Things (IoT) to move beyond just the 'things' and towards an Internet of *Practices* (IoP)?

In this exploratory paper we expand yet further the existing discussion around the potential the IoT as a set of new emerging technologies may have for extending the scope of CSCW's areas of interest [25]. We do this by introducing the vision of the IoP as a new theoretical framework that can encompass a variety of complementary interests: (1) the socio-technical (collaborative) concept of appropriation; (2) the technological possibilities of sensors and actuators; and (3) an integrated concept of sociable technologies that can be connected through the IoT to support the mediation as well as implicit learning of technology practices. In doing this we outline a socio-technical perspective on the IoT with regard to CSCW and how the design of IoT technologies could be used to inform appropriation and infrastructuring [20] practices.

2 Theoretical Framing

Our vision of the Internet of Practice is a conjunction of two discourses. The first of these relates to both the concept of practice itself and communities of practice. The second is on the other discourse relates to IoT-enabled (collaborative) appropriation infrastructures—what we refer to here as 'sociable technologies' [14].

2.1 The Concept of Practices

Our entire life encompasses various kinds of variably tool- or technology-based practices: whether preparing dough in a food processor; playing soccer with a ball; or—as discussed above—taking photos with a digital camera using a consistent style for each set of photos. From a 'practical' perspective, practices are applied heterogeneously—some people bake tastier bread than others, some people are better at playing soccer than others.

From a theoretical perspective, practice is also often understood heterogeneously [7] and can be described as "routines consisting of a number of interconnected and inseparable elements: physical and mental activities of human bodies, the material environment, artifacts and their use, contexts, human capabilities, affinities and motivation" [13]. This perspective is based on early practice theories that often conceptualize practices as "routinized, oversubjective complexes of bodily movements, of forms of interpreting, knowing how and wanting and of the usage of things" [24]. This understanding is itself based on Bourdieu's [4] Theory of Practices in which he developed the notion of 'habitus' to capture

> the permanent internalization of the social order in the human body". With this idea, Bourdieu understands practice "as the result of social structures on a particular field (structure; macro) where certain rules apply and also of one's habitus (agency; micro), i.e. the embodied history that is manifested in our system of thinking, feeling, perceiving and behaving. The habitus assures the collective belief in the rules of the social game (illusio) and that actors act in accordance with their position on the field (doxa), which depends on their relative amount and structure of economic, cultural (and social) capital [34].

As Kuutti and Bannon [13] point out, although practice theories differ in many ways, there are also a number of common features. By referring to Nicolini [17] they list these common features as follows:

1. A process and performative view on social life: structures and institutions are realized through practices; practices are local and timely and they have histories.
2. The critical role of materiality of human bodies and artifacts; there are no practices without them.
3. A different role of agency and actor than in traditional theories: 'homo practicus' is both the bearer of practices in his or her mind and body, and the one who produces the practices in action.

4. Seeing knowledge as a capability to act through practices in meaningful and productive ways.
5. The centrality of interests and motivations in all human action and a corresponding focus on power, conflicts and politics.

Schmidt [28] positions these perspectives in work contexts by saying that a practice is not just any kind of activity, but a regular activity, whereby the regularity is a normative application of general principles. A practice can therefore be understood as a *normatively regulated activity* that differs from some other practice by the body of rules that govern it [28]. Work is not simply the following of preordained rules, but necessarily involves the local interpretation of these rules in the light of the evolving situation [13]. So, performing the activity of taking pictures by using the photographic agency's demanding consistent style of for sets of photos is understood as a specific type of practice (for now!).

Kuutti and Bannon [13] argue that lasting recent years a new 'practice' paradigm has emerged in the field of HCI. Instead of simply considering the role of design intervention as changing human actions by introducing novel technology, it needs to be understood that human actions and interactions are just a part of entire practices. Practices emphasize the fabric of action, the knowledge and reasoning that surrounds that action and the context in which it takes place [6]. "For some time it has been supposed that context influences what happens in interaction and how it is experienced, resulting in attempts to define richer and richer contexts. But 'practice' can be interpreted as the ultimate context: practices are where interactions take place in real life" [13]. So how should we understand the context of practice when taking good, consistent pictures with a new camera?

2.2 Internet of Things

In the early 90s, Mark Weiser and his colleagues from Xerox PARC came up with the concept of Ubiquitous Computing, envisioning that "the most profound technologies are those that disappear. They [technologies] weave themselves into the fabric of everyday life until they are indistinguishable from it" [35]. The vision of interconnected small computers, which Weiser described in the early 90s, coupled with the penetration of the internet as well as the miniaturization of computers and electronic assemblies is now commonly known as the Internet of Things (IoT)—a term firstly coined by Kevin Ashton [1]. The "things" are often summarized as cyber-physical systems meaning

> physical and engineered systems, whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. Just as the internet transformed how humans interact with one another, cyber-physical systems will transform how we interact with the physical world around us [23].

Although the 'things' offer new possibilities and functionalities that have come along with (and will continue to come along with) the interest in the IoT [2], they will also increase the complexity of the practices associated with the ecologies of technology they encompass. This will be a result of: (a) increasingly complex devices; (b) an increasing number of less obvious connections and dependencies between IoT devices and things; (c) more and more changes that ensembles of IoT technologies will need to undergo in order to fully integrate the most recent technological options and advances (e.g. depth sensors in cameras); and (d) a new interweaving of the ‘digital’ and the ‘physical’ world—such as the one our opening example of the camera sought to illustrate.

By taking the cooperation between cyber-physical things within the IoT seriously, Robertson and Wagner [25] have already outlined issues from a CSCW perspective with regard to how IoT applications may associate with practices. These arguments in turn are built upon the discussions around the “issues people had with not understanding and/or not trusting the ways in which their sensors worked, as well as the practical realities of location and timing and false alarms that render them less useful” [32]. Within this paper we develop a notion of an Internet of Practices that builds upon the IoT and tries to make sense of the IoT from a human-centered perspective to perform practices using IoT.

2.3 *Infrastructuring and Sociable Technologies*

When handling the ‘things’ or the ‘cyber-physical assemblies’ do not meet users’ intended practices (e.g. the camera during taking pictures), either people with specialized knowledge are needed who know how to make them work again or explain the handling [8, 19, 25] or, as is often the case with sophisticated ‘new’ technologies, users will discover new ways of handling them by attempting to manage their understanding in the context of their existing (and changing) practices [9, 15, 21, 20]. The new photographer starts thinking about how to take better pictures and tries new configurations or different positions regarding the angles or lighting conditions. “The recent interest in how people take ownership of artifacts and shape them to their own purposes and practices clearly relates to this practice turn, as it examines the ways in which designed “things” become assimilated into an ongoing set of routines” [13].

Broadening the focus a little, we want to relate this process of adaptation to the notion of ‘intrastructuring’. Star and Ruhleder [30] consolidated the socio-material aspects of an infrastructure by relating technological infrastructures to the practices they were meaningful to. This approach, which referred back to previous work in Science and Technology Studies (STS) on ‘large technological systems’ and infrastructures, was further transformed when Star and Bowker [29] and later Karasti and Baker [12] started to widen the design-oriented and product-focused lense of traditional technology development to the concept of infrastructuring.

Infrastructuring can be understood as the reshaping of a work infrastructure and practices of use by “re-conceptualizing one’s own work in the context of existing, potential, or envisioned IT tools” [20]. Encompassed within the concept of infrastructuring (ibid.) are all (appropriation) activities that lead to discovering and developing the usage of an entire infrastructure and to the successful establishment of a device or system in use.

The relation between an artifact and the practices it supports can be viewed as the trajectory of a artifact when it is confronted with people's practices of 'appropriation' [10]. It can equally be viewed as the trajectory of a practice where breakdowns or innovation lead to the kinds of exploration of technological possibilities and improvements captured by the notion of 'infrastructuring' [20]. Pipek [21] conceptualizes appropriation as the discovery of, and the sense making entailed in, using a device or artifact in practice. This understanding has its roots in established CSCW literature, where appropriation is associated with the process of fitting new technologies to users' practices in situ by both the adoption of, and adaptation to those technologies [3, 10, 16, 26, 31] and is therefore an important aspect of infrastructuring.

One of the major characteristics of infrastructuring is the "Point of Infrastructur(ing)" (PoI). This is the moment in which a (group of) practitioner(s) understand(s) that the current use of a technological infrastructure needs to be reconsidered [20]. The PoI started out as an analytical figure. It sought to capture the moment where people become aware of infrastructure problems or opportunities. This moment can (a) happen at an individual, organizational or even societal level. It is (b) the moment in which the political, social, organizational and technological dimensions of an infrastructure become tangible for the practitioners that depend on it. It (c) initiates a set of activities amongst a variety of stakeholders, which target the infrastructure problem or opportunity. And (d) it may ultimately result in a modified infrastructure and/or a modified (use) practice [21].

The concept of infrastructuring is usually associated with processes of exchange and interaction in networks of co-users where experiences and stories are shared between actors involved in the appropriation process [11, 16, 21, 22]. The new photographer starts searching for help, asking professional colleagues or just has some kind of interchange with other camera users who have similar issues. These processes of exchange and interaction require a variety of communication and cooperation practices, but often come with the burden of being cumbersome and hard to adapt to pre-existing practice [8].

As Pipek [21] suggests, appropriation and its encompassing collaborative activities around things defines a Community of Practice (CoP). This is in Wenger's [36] original sense of a CoP as a social compound in which technological practice can be observed, passed on and further developed. CoPs are viewed by many in business settings as a means of capturing tacit knowledge, or know-how that is not easily articulated [18, 36]. Jean Lave and Etienne Wenger's theory of legitimate peripheral participation sees learning within a CoP both related to, and a specific form of, a particular practice [13]. It is therefore obvious that considering the IoT on a purely technological basis misses important points that practitioners (and CoPs) have to consider when developing, re-inventing and 'infrastructuring' their practices [14, 20, 25, 29].

In a first test of using improved functional components that are grounded in this way of thinking we turned to 3D printing and argued that new IoT-based technologies are particularly capable of supporting the (collaborative) appropriation activities of their users by making the devices more 'sociable' [14]. In relation to this we coined the term'sociable technologies' to capture the kinds of hardware-integrated affordances for communicating, documenting and sharing practices of use that can arise through the adoption of new IoT technologies.

Taking network printing technology as a case in point it is worth noting that, in previous work, Castellani et al. [6] uncovered a number of dislocations between various aspects of technology-based CoPs. Here their focus was on the work of troubleshooting where there was:

> 1) a physical dislocation between the site of the problem and the site of problem resolution; 2) a conceptual dislocation between the users' knowledge and the troubleshooting resources and 3) a logical dislocation between the support resources and the ailing device itself [6].

For the purposes of our own argument here we would build upon these observations by noting that sociable technologies need to operate on three contextual levels: (1) The *internal context*, where they provide information about their inner workings and current state as well as about their component and behavioral structure; (2) The *socio-material context*; which encompasses things like their location and surroundings, environmental data like room temperature, and maintenance or user/usage data; (3) The *task/process context*: which will relate to things like the purpose and goal of device use [14].

Sociable technologies aim to lower the burden of documenting and sharing insights about practices by encompassing the IoT and by gathering as well as communicating sensor information. With the idea of sociable technologies we follow the idea about the mediation of practices by artifacts [13]. In the case of 3D printing, the printer itself communicates captured sensor information such as print temperature or the movements of the extruder in association with the model and its material characteristics, to give details of use practices [14].

2.4 Resonance Activities

In order to (semi-)automatically sense the actual use practices of a 'thing' in a certain situational context and support the sharing of this information, and its visualization to users with similar practices within a CoP, new design approaches are required that transcend the notion of technology as a product. How might the new camera user experience the practices and infrastructuring activities another experienced camera user has already made? How might a novice learn about new ways of taking pictures with a camera when they've just acquired new lenses?

As we have already pointed out, one of the major characteristics of infrastructuring, understood as a technology development methodology, is the "Point of Infrastructur(ing)" where a (group of) practitioner(s) understand(s) that the current use of a technological infrastructure needs to be reconsidered [20]. Now Pipek and Wulf [20] suggest that points of infrastructuring do not happen arbitrarily during the course of performing a practice. Instead, they argue, there are specific factors which are likely to trigger this reconsideration and that there is a strong dependency between a practice and its supporting infrastructure that, having developed previously, will have become largely invisible to the actors who are engaged in the practice in question.

Here, the concept of infrastructuring suggests that, based on this initial impulse, there is a period of technology (re-)configuration, tailoring and development of conventions, in which the 'last mile of technology development' will be mainly performed by (not necessarily technologically skilled) practitioners. This will continue until the point has been reached at which a new technology usage has been successfully established [20]. In terms of infrastructuring, the work infrastructure has been further developed and may "sink into the background" again, re-establishing and strengthening the dependency between the (work) practice and work infrastructure [20].

Infrastructuring occurs in ways that are based upon the nature of the dependency between a practice and its work infrastructure, and as Pipek and Wulf [20] argue, it is difficult to suggest a general model that would help to describe or suggest details of infrastructuring activities. They adopt the position that activities relating to the 'last mile of technology development' are less about a predefined division of labor and rather more about the development of a network of cooperation between practitioners (and developers). As Pipek and Wulf [20] argue, this network of cooperation is inspired and driven by other PoIs that have happened earlier in related practices.

Inspired by this perspective, we can identify processes of infrastructuring that surface to connect 'global' infrastructures to their 'local' usages. Here the appropriation of an infrastructure becomes a part of designing it and putting it to use. As Pipek and Wulf [20] argue

> each point of infrastructure does not only provoke in situ design activities and makes visible prior preparatory activities, but it also creates *resonance activities* of observing and communicating aspects of what has become visible within the work environment or to other work environments.

The concept of resonance activities is understood to be all of those kinds of activities that may become visible to people engaged in other, related practices, or to technology developers who laid the technological foundation of an ongoing practice innovation (initiated by points of infrastructure).

The concept describes the connections between different points of infrastructuring. Through such resonance activities, the changes that emerge around the PoI become accessible to others engaged in practices that have a connection with the one where the PoI occurred. Taking a step back from the IoT as it is currently conceptualized, expertise-sharing platforms like photographer forums cover a lot of the interactions that might count as resonance activities and that might therefore serve to extend infrastructuring around a single PoI. But the limited depth these discussions are able to reach in terms of addressing the relation between infrastructure technologies and a concrete situated practice where a PoI has occurred, show that there is much room for improvement to support these kind of interactions. By examining resonance activities "the social appropriation of certain technology usages can be captured, and the relations between different points of infrastructure become clear" [20].

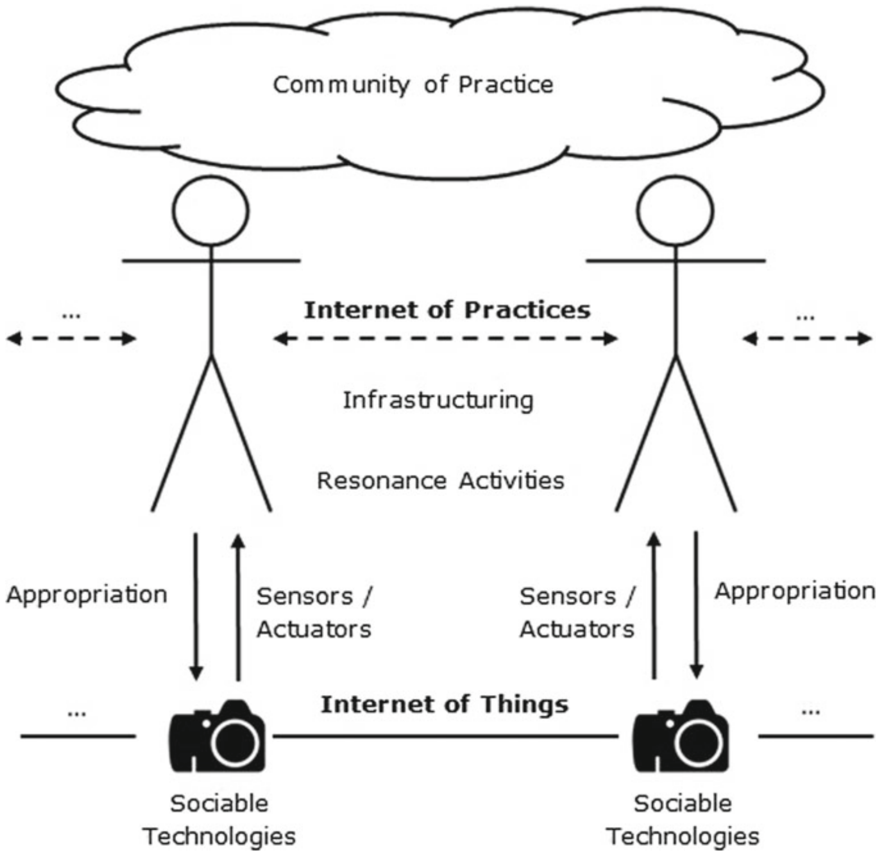

Fig. 1 Internet of Practices (IoP)

3 The Internet of Practices

So, how could a new photographer who is struggling with the practices involved in taking good pictures be supported by professional photographers? How could appropriate bodies of practice pertaining to particular needs mediated through technology?

The purpose of shifting towards the notion of an *Internet of Practices* is to reconsider the IoT and the cooperating cyber-physical systems that characterize it in ways that will allow us to move beyond a limited technological point of view and towards something that recognizes us more strongly the practices and communities that surround its use [20, 29]. The position we are arguing for here is that we start to work towards understanding how the Internet of Things is also an Internet of Practices—or, perhaps more accurately, an evolving Internet of Practices (Fig. 1).

The IoP encompasses the socio-technical (collaborative) aspects of appropriation and infrastructuring coupled with the technological possibilities of actuators as well as sensors and the integrated concept of sociable technologies connected through the IoT to support the practices of artifact users and therefore (evolving) Communities of Practices by documenting, sharing and communicating their practices.

Adapted to the practice of taking pictures, a camera, when designed as a sociable technology, is also able to gather information about the width of a wide-angle lens or the resolution of a high-contrast display (internal context); the lighting conditions and the position in which the camera is being held (socio-material context); and current interests such as acquiring a sharply focused image of a specific object in a broader landscape (task/process context). All of this documented information can then be shared via the IoT and suggested to another camera user who has similar interests and who is working in a similar socio-material context directly in situ. In these ways the digital cameras of other users can themselves be adapted to meet the shared internal context.

This perspective supports the Practice paradigm by encompassing bodies, artifacts, performances, and routines as a more encompassing frame [13]. This begins to illustrate how the dependencies of practices on new and complex layers of technologies might be managed by continuous infrastructuring efforts and appropriate methodologies that not only address the development of an IoT product, but the preparation and reflection of how it is used and situated in practice. In relation to the theoretical framework we articulated earlier, documented aspects regarding the practices through which a technology is used are able to create resonance activities to users using the same technology (or where there are similar practices), thereby helping other users to appropriate similar bodies of practice.

So returning to our original example, by making use of the IoP, the new photographer is able to not just acknowledge the expert colleague's *explanations about the practices* best suited to that camera, but also to *directly appropriate these actual practices* in situ. Drawing upon the IoT as a resource, the new photographer's camera is able to give feedback and suggestions to its user, such as when the camera has been positioned at the right angle with regard to the actual lighting conditions; when a specific lens would be much more appropriate with regard to the distance of an object; or when the optimal distance between an object and the camera is reached.

In their own discussion of the future possibilities for the IoT Robertson and Wagner [25] suggest that "in due course we will have opportunities to study people's practices that include the everyday use of IoT technologies". We argue that in the future we will not only be able to study people's practices and their particular use of IoT technologies, but also, by applying the concept of sociable technologies, users themselves will be able to *harness the IoT to detect, share and mediate these (use) practices*—or, as Schmidt [28] would have it, they will be able to share the norms of their regulated activities.

4 Conclusion

Practices are not just any kind of activity. Based on early practice theories, they might be understood as "routines consisting of a number of interconnected and inseparable elements: physical and mental activities of human bodies, the material environment, artifacts and their use, contexts, human capabilities, affinities and motivation" [13]. Within work contexts they could further be described as normatively regulated activities, whereby the notion of 'normative' refers to the application of general principles [28].

Schmidt's [28] argument is that it is possible to observe and determine the normative make-up of a practice, e.g. when people are making excuses for particular actions, when they are asking for guidance, when they are instructing novices, and so on. Within this exploratory paper, we have sought to explore the potential of IoT technologies for mediating the normative character and the collaborative appropriation of the bodies of practice from a practice-oriented perspective. To accomplish this we have outlined how the Internet of *Practices* might address phenomena relating to evolving Communities of Practice and resonance activities by adding an integrated support for the observation and documentation of practices. This can be further reinforced through the sharing of relevant representations for mutual practice improvements. In our view the concept of an IoP has a great deal of research potential for the CSCW community. Here are just a few avenues that might be explored:

- As Schmidt [27] has argued awareness is not the product of passively acquired information, but rather a feature of highly active and highly skilled practices. In relation to this Robertson and Wagner [25] raise the question of how technology-provided and technology-focused awareness could inform, complement and support the people using such applications so that they are aware of relevant issues. With the IoP one could also ask: how could one become aware of other members of a CoP as well as (potentially) interesting activities through the technology? And how to detect similar practices as well as how to compare kinds of practices?
- Devices or cyber-physical systems are often situated within highly collaborative settings and often serve as enablers and mediators for communication (whether co-located or remote). However, if people's practices are connected through IoT technology and they are performing collaborative tasks, the question is how could the activities be aligned or structured at a physical level? This is especially pertinent when almost every tool or device (e.g. a hammer or drill) might count as a cyber-physical system that could be connected through the internet.
- Practice-based research agendas and researchers are usually interested in real-life practices. The practices must therefore be studied where they occur including the natural setting. Suchman [33] outlined that the aim of research should be an exploration of "the relation of knowledge and action to the particular circumstances in which knowing and acting invariably occur". However, when moving from laboratory studies to in-the-wild studies and understanding the full context (and not just the most immediate one) this becomes challenging and is (right now) all but impossible. So, how to examine the entire practice as the ultimate context?

- As already outlined by Kuutti and Bannon [13] we are nowadays increasingly faced with digital ecologies and at the same time every practice has a particular set of artifacts that make it possible. We therefore need to broaden the viewpoint on the world about us. How to detect media disruptions and changing artifacts during a practice? How to detect the co-evolution of practices and an entire ecology of artifacts?
- Through the IoT there are increasingly new types of inter-connected devices that are able to further support the mediation of practices such as virtual reality or augmented reality technology. New smart glasses such as Microsoft HoloLens, for instance, could support the mediation of practices between people or the technology (learning) practices within CoPs. However, new technologies require new types of methodology for researchers to examine the distributed practices that are facilitated through those new technologies. A question is if and how qualitative research methods will need to change to cope with studying the use of new types of connected data resources such as sensor data about lightning conditions or information about people's movement patterns.
- Due to the diverse inter-connectedness of infrastructures, their socio-material relations, and the heterogeneous practices associated with the use of technological tools, one question remaining is how to capture related resonance activities across communities? Furthermore, if this can be done, how might one approach designing technological support for them?
- The IoP also requires taking into account the privacy issues that surround CoPs and how they may seek to document and share practices. There is work to be done in that case regarding how best to support the effective negotiation of privacy and security interests within groups of users.

Within this exploratory paper we have introduced an initial vision of an Internet of Practices and how it could evolve from the existing Internet of Things. For this initial foray we have framed our concept theoretically and have related it to existing discourses in CSCW. We have adopted a quite pragmatic view upon how the IoP might serve to support things like CoPs. We are aware there are bleakly portrayed dystopias of a technocratic future, whereby everyone is augmented and adapted to a point of equal competence and capability. In such dystopias differences and the heterogeneity of people are typically devalued and this can also be seen to relate to older debates about de-skilling [5]. However, the position we adopt here is that the IoP may preserve or even enhance the diversity and skills of people, perhaps even cross-culturally.

In future work we expect to work on much finer specifications of the IoP and will be conducting design case studies [37] in different application areas in order to examine the scope, applicability, and potential consequences of using this concept in practical settings. Our primary hope at this stage is that this exploratory paper will inspire researchers to think about other possibilities for the IoT that have not previously been articulated as IoT technology becomes more clearly established as a feature of our everyday lives, thereby expanding—as Robertson and Wagner [25] requested—the areas of interest to which CSCW research might actively contribute.

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Part II
Social IoT Interaction Design

The Needfinding Machine

Nikolas Martelaro and Wendy Ju

Abstract Interactive systems present new opportunities for creating devices that attempt to learn the needs of people. However, inferring from data alone may not always allow for a true understanding of user needs. We suggest a vision of Social IoT where designers interact with users *through* machines as a new method for needfinding. We present a framework using interactive systems as *Needfinding Machines*. Acting through a Needfinding Machine, the designer observes behavior, asks questions, and remotely performs the machine in order to understand the user within a situated context. To explore a Needfinding Machine in use, we created DJ Bot, an interactive music agent that allows designers to remotely control music and talk to users about why they are listening. We show three test sessions where designers used DJ Bot with people listening to music while driving. These sessions suggest how Needfinding Machines can be used by designers to help empathize with users, discover potential needs and explore future alternatives for Social Internet of Things products.

1 Introduction

The Internet of Things has expanded beyond industrial settings to encompass everyday products from toothbrushes to autonomous cars. Cheap microprocessors and wireless networking allow designers to make everyday objects "smart," with the capabilities to collect data, make decisions, and interact with people. But what is the best way to *design* these Internet of Things products so that they fit into the social context of people's lives? How can designers learn more about the environments these products will be deployed in, the uses people will want, and the problems people will encounter? During a human-centered design process, *needfinding* is an

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_4

activity used by designers to explore and understand people in relation to the design of new products [32, 65]. Needfinding ideally occurs during the early stages of a design project where the designer's goal is to *design the right thing before designing the thing right* [43]. While discovered needs themselves do not present immediate solutions, they help to align the designer's perspective and empathy with the user. This subsequently helps the designer generate ideas that are more likely to satisfy the user.

As machines collect more data about their users, there have been efforts to develop ways for computers to observe and learn how to service the needs of their users. Some examples include the Lumière Project by Horvitz et al. [45], which aimed to automatically identify a user's goals and provide task support while using desktop office software; Chen and Cimino's [18] use of clinical information system logs to identify patient specific information needs; and Radhid et al.'s [68] "Getting to Know You" techniques for helping recommender systems learn about the preferences of new users. Though these systems can allow machines to automatically characterize users in limited settings, we argue for an alternative approach in which machine capabilities enable designers to perform needfinding in new ways. Central to this idea is the insight that data—and even needs—do not automatically lead to solutions; we still need designers to probe situations and synthesize the meaning of observations towards potential alternatives. While data-driven design may allow us a new lens, there is no replacement, as Dreyfus [29] suggests, for field research to educate the designer about the needs of people. With new capabilities though, we can explore how designers might augment their needfinding abilities.

This chapter explores how designers can use interactive technologies as a way to do needfinding with Internet of Things devices. We call this framework for doing needfinding the *Needfinding Machine*. Working with a Needfinding Machine allows designers to discover people's needs by allowing the designers to observe, communicate and interact with people *through* their products. While our work is similar to the idea of using things as co-ethnographers [41, 42], it differentiates itself by using things as a way of mediating direct interaction between the user and designer. The Needfinding Machine provides a "conversational infrastructure" [30] by which the designer can build their understanding of a person in an evolving fashion and in the user's real context. This means that the Needfinding Machine is not a machine that discovers needs on its own. Rather, the Needfinding Machine extends a designer's ability to preform traditional person-to-person needfinding by interacting with the user and observing the user experience *through* the machine. It is computer-mediated communication between the designer and user under the guise of the Internet of Things. This is shown in Fig. 1. The outer loop represents person-to-person needfinding, such as interviews and personal observations. The inner loop shows needfinding done through the machine.

In this chapter, we outline the concept of the Needfinding Machine and detail the motivations and prior work that have inspired the development of this concept. We then present a case study in which we built a Needfinding Machine, DJ Bot, that allows designers working with a streaming music service to act as a smart agent that talks to people to figure out what music to play. In the process of "being the

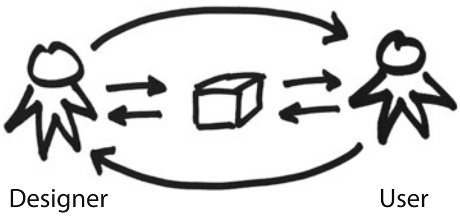

Fig. 1 The Needfinding Machine: a method for designers to interact *through* systems to understand user needs

machine," the designers are able to explore people's connection with their music and potential needs that would drive intelligent music recommendation agents. We conclude by discussing the implications that this Needfinding Machine framework has on how designers discover user needs in relation to the design of new products and experiences.

2 What Is a Needfinding Machine

Faste [32] defines needfinding as an active process of perceiving the hidden needs of specific groups of people. He has outlined a non-exhaustive list of needfinding methods that designers can use to better understand people, including market-based assessments, technology pushes and forecasting, and personal observations and analyses. Patnaik [65] further describes needfinding as an organized, qualitative research approach to support new product development that has been adopted within human-centered design processes [52]. Within human-computer interaction, needfinding is often focused on developing user requirements to guide product development and usability [10, 50] and to help designers develop empathy for their users [85].

A *Needfinding Machine*, then, is an instrument we intend to be used by designers to further their efforts to understand user needs in relation to a specific context. It is embedded in some product or device that itself is embedded in the user's environment and in their everyday life. This setup allows the designer to explore distant environments, interact over large time scales, see data, elicit information from the user, and prototype interaction in ways that overcome previous limitations of observational design research [49]. The information flows for a Needfinding Machine are shown in Fig. 2. Moreover, Needfinding Machines are inspired by Forlizzi and Battarbee's [33] framework for understanding the experience of interactive systems. Like Forlizzi and Battarbee, we center on user-product interaction as a way to understand user experience and focus on exploring situated interaction within the real-world.

During use, Needfinding Machines provide designers with real-time access to objective system data (sensor readings, system logs) and qualitative observational data (video, audio). Moreover, they allow the designer to actively converse with the user through Wizard-of-Oz [25] interfaces (voice, screens, tangible interfaces, etc.). This 'conversational infrastructure' [30] allows the designer, user, and the machine to interact in a situated manner [78] towards the goal of understanding the user's needs

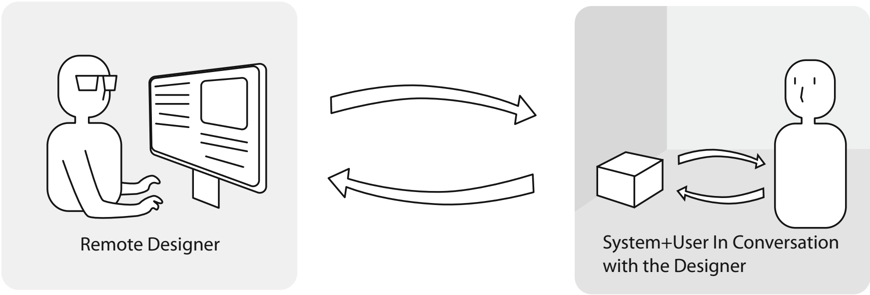

Fig. 2 Information flows in a Needfinding Machine. The remote designer interacts through and performs an interactive system situated in the user's environment. They can observe these interactions in real-time. This enables conversation between the designer and the user, mediated by the machine

in relation to a specific context. The Needfinding Machine uses an interactive device as a meeting point between the designer and the user [75]. By allowing observation and interaction, the designer can use a Needfinding Machine to understand the user and take preliminary action towards satisfying the user's needs [75].

2.1 Considerations for Needfinding Machines

Remotely accessing a user's environment through an interactive device can provide a designer with many potential ways of collecting data about the user. With this in mind, we actively steer the Needfinding Machine away for certain kinds of data collection in order to respect the user and obtain honest feedback on a design concept. Specifically, we do not advise that Needfinding Machines be:
Spybots—Needfinding Machines help the designer build understanding through *interaction* rather than *surveillance*. This interaction is intended to be an overt conversation that builds a relationship between the designer and the user and is conducted with respect toward the user. To that end, Needfinding Machines should not be solely observation devices. Rather, they allow for observation, action, and analyses simultaneously as a way for designers to explore unknown needs around a product [46]. By interacting with users through an artifact and by engaging the user in conversation, the Needfinding Machine can "amplify designer understanding of the intended purpose(s) of the artifact and may provide information that does not come out of initial interviews, observations, and needs analysis" [1].

Machines that ask "How am I doing?"—Though a Needfinding Machine enables remote user observation, the goal of a Needfinding Machine is to aid the designer in developing an understanding of the user in context, not to justify the existence or usability of the machine in that context. A machine that asks "Do you like this?" or "How am I doing?" can lead to overly polite responses from users [63]. Just as a designer should not lead off needfinding by telling users what they plan to build or asking if the user likes a prototype, Needfinding Machines should focus on how the user feels and experiences the interaction rather than on confirming how well they are functioning.

3 What Is in a Needfinding Machine

In this section, we describe what elements are required to make an interactive device into a Needfinding Machine. We use a hypothetical Internet of Things coffee maker as an example device that designers can use to do needfinding work in a home environment. Specifically, we can imagine a design team tasked with understanding the user experience of a smart coffee maker as well as understanding that broader relationship that a user has with coffee and the kitchen.

The essential elements of a Needfinding Machine are functional blocks which support the user-machine interaction and the designer-machine interaction. These elements are show in relation to the interaction loop in Fig. 3. For the user-machine interaction, we build on Eric Dishman's formulation of design research [26] where designers *observe*, *ask*, and *perform* in order to understand users. A Needfinding Machine should allow the designer to *observe* the user in context, *ask* about the user's experience, and *perform* the machine's interactions with the user. We extend Dishman's elements of design research to include functions required in a Needfinding Machine for the designer-machine interaction. A Needfinding Machine should provide ways to *display* data about the machine and user, *control* the performance of the machine's interaction with the user, and *document* the observations that occur during the interaction. We now describe each element in more detail and suggest how it can be realized in our Internet of Things coffee maker.

3.1 Observe

Observation allows the designer to see how users behave within a specific context and respond to different events. These observations can include both qualitative and quantitative information streams, depending on what the designer is looking to perceive.

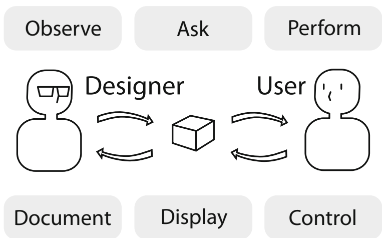

Fig. 3 Functional elements of a Needfinding Machine in relations to the user and to the designer

Cameras and microphones can provide a high bandwidth picture of the user's environment and actions. Sensor and system data can show the designer information about the user's context that is often not directly observable in-situ. This information is streamed back to the designer using a high-speed internet connection and displayed through various indicators and data visualizations.

The placement of the cameras and the selection of the data to be monitored by the designers is critical to consider; these decisions about what to instrument in the user's environment embody hypotheses on the part of the designer about what sort of information they might be looking for or need to support their interaction. For our Internet of Things coffee maker, we might put a camera facing into the kitchen that can see the user as they approach the machine and interact with any physical interfaces. This camera can also give the designer a view into the kitchen, allowing them to observe people's morning rituals and interactions with other kitchen objects. A microphone lets the remote designer hear the participant as they answer questions and talk about their morning experience. Buttons and knobs can be instrumented so that the remote designer can see how the user interacts with the machine and what settings the user changes.

3.2 Ask

Asking questions though the machine allows designers to elicit information that cannot be observed, such as what the user thinks and feels. By asking the user questions, the designer establishes the interaction as a conversation, inviting the user to engage and participate in the needfinding process. These questions can be planned before an interaction with some goal in mind. However, just as with any conversation, the appropriate questions for each situation are often revealed over the course of interaction with the user.

To enable question asking, a Needfinding Machine needs a communication interface. We use speech based communication to ask users questions. Perhaps there are ways that questions can be asked without speech, such as through physical movement of the device, but for our work, speech offers the easiest way to ask the user questions about their experience. In our work, we use text-to-speech on the interactive device to ask questions through the machine. In the case of our Internet of Things coffee maker, we can use a text-to-speech system on the machine to ask the user questions about their coffee making experience such as "What is important in a coffee machine?" and "How much customization would you like in a coffee machine?" We can also ask broader questions about the user's relationship with coffee, such as "What is the best part about drinking coffee?", "When did you first start drinking coffee?", and "What would life be like without coffee?" Furthermore, the designer can also ask about the rest of the user experience in the kitchen. For example, asking questions about the microwave and fridge, or what type of cooking the user likes to do. Using text-to-speech allows a Needfinding Machine to maintain its machine alibi, and aids in creating a consistent voice and persona around the user's interaction with the machine over time. Using machine voice also keeps the interaction situated in an Internet of Things context, making discussion about other things in the kitchen somewhat plausible.

3.3 Perform

Interacting through the machine allows the designer to *perform* as the machine. This allows the designer to explore potential interaction opportunities and use physical or digital interactions as a means of eliciting needs from the user. In addition, the designer can also explore the machine interfaces themselves, giving them a sense of the machine's needs and limitations in relation to potential design ideas.

Depending on the specific context, the designer can perform as the machine in various ways. This performance may include tangible, graphical, or auditory interfaces. It may also include interactions with other devices in the environment such as phones or Internet of Things products. Each interaction that the remote designer can preform represents a degree of freedom that the designer can experiment with throughout their interaction. This may require the designer to build functional rapid prototypes of an interactive system. However, commercially available products could also be re-purposed for needfinding. For example, technology such as VNC or TeamViewer can enable remote control of GUIs.

In our coffee maker example, the designer might augment a commercially available coffee maker with smart capabilities. The designer can perform various functions of the coffee maker, such as setting the coffee preference of each user or controlling when the coffee is made each morning. The designer can also explore new functionalities that a future coffee maker might have, such as providing the user with their morning news update, adding coffee to the user's shopping list when they run out, or even starting up the user's car once their coffee is ready to go. By preforming as the machine, the designer can explore functionality that is not yet available. The designer can also test new interaction dynamics between the user and the machine, helping them determine how the machine ought to interact and what technology may be required to enable new machine behaviors.

3.4 Document

By capturing interactions with a Needfinding Machine, we can preform post-analysis and revisit our observations made during the live interaction. Actions that occur in the user's context and within the remote designer's environment should be recorded. It is critical to document what happened on the user end of the interaction. Documenting the designer's environment can also help the designer to reflect upon their actions during the session.

Documentation can include recording video, audio, and data streams from the session. By recording the designer's control interface and any conversation they may be having with other designers, the Needfinding Machine can capture important moments that reveal the designer's thinking during the interaction. Special interfaces such as pass-through audio/video recording devices, web-based data logs, and devices with built-in logging all contribute to the documentation of Needfinding Machine interactions. Our Internet of Things coffee maker can record video and audio from the user's kitchen during the interaction and log button presses, coffee levels, or voice commands from the user. On the remote designer's side, we can keep a log of every question that was asked and each interface that was controlled. We can also record what the designer sees on their screen and any conversation they might have with other designers participating in the session. After the session, these data streams can be synchronized for later viewing and analysis by the design team.

3.5 Display

The video, audio, and data streams coming from the user's environment should be displayed in real-time to the remote designer. The display supports the designer's observation and allows them take action on any data that may be relevant during their interaction session. These include video and audio from the user's environment, state changes in the system, and time series information of certain product features. Often, the designer is presented with more information than they would naturally be able to see during an in-session interaction, such as multiple camera views and data from the machine that is usually hidden to the user. When creating the display interface, the designer should take into account what they need to see and what aspects of the data may be interesting.

The display interface for our coffee maker might include a video window and a data dashboard. We have found that designers should set up their display to facilitate easy viewing of the data. In this case, the designer might have one screen dedicated to the live video feed from the user's kitchen and another screen with the data dashboard. The dashboard might include live displays of the system settings such as supply levels or coffee temperature. If the designer is testing voice interaction, there could also be a running text log of what the coffee maker hears and interprets from the user. When laying out the display, the designer should consider what information they will need in real-time and how best to show the information in order to support their performance as the machine. Just as important, the designer should also consider what information they should hide from live display so that they are not overwhelmed with data.

3.6 Control

The control interface that allows the designer to preform as the machine should be considered with similar care as the display interface. Message boxes for asking questions should be prominent in the interface so that the designer can easily send custom messages for the machine to speak. Any scripted speech should have easily accessible "play" buttons. For each element that the designer wishes to preform, there should a corresponding controller on the designer's remote interface.

For our coffee maker, the interface can have a list of questions or news stories that have been scripted for the interaction and a message box for sending custom messages that the designers create in the moment. Graphical toggle switches can turn elements of the coffee maker's graphical display on an off. Buttons can be used to send messages to another device in the environment, such as the users phone or to control something on the user's Internet of Things enabled car.

With the high number of degrees-of-freedom in a Needfinding Machine, the job of observing and interacting can become overwhelming. Depending on the rate of interaction, controlling the machine may require two or more people. With our coffee maker, it may be best for one remote wizard to control the speech, while another controls the physical interfaces on the machine or helps look up information like news to tell the user. In order to facilitate collaboration between multiple designers controlling the machine, control interfaces should be easy replicated in different locations and allow for split control of different interfaces. We use web-based technologies to create display and control interfaces so that all members of a design session can participant from any location. This reduces the load for each designer and supports collaboration among a design team.

4 Why Needfinding Machines

The purpose of the Needfinding Machine is to extend the designer's gaze and reach [49] by allowing them to see and understand user interaction in real-world contexts. Working through a Needfinding Machine can let designers engage people beyond themselves and their local technology community when working on the design of new technology products. Consideration and awareness of people who are different from the design team gives designers a more informed position about the technology they are developing. While needfinding, understanding the experience of more people who are further from the design team can lead to designs with further reach and more impact on people's everyday lives. Furthermore, understanding and designing for more people provides an economical benefit by addressing a broader customer base.

A Needfinding Machine also helps designers explore new technologies as tools for crafting new interaction design and as way to better connect with their users in the real world. The Needfinding Machine framework takes advantage of several concurrent trends in technology:

- **Embedded computing**: Imbues everyday objects with computation, sensors, and network communications [83]. Allows for devices to communicate with the Internet of Things and provides a way for designers to collect data remotely.
- **Cloud services**: Allow software and hardware to communicate across the internet, store data on remote servers, and enable new interaction capabilities such as machine vision and speech.
- **Online machine learning**: Allows systems to continually learn and update their models of users from streaming data. Can be used to support intelligent interaction between the machine and user.
- **Conversational agents**: Lets users use natural language to interact with their devices. Provides a way for designers to capture their user's thoughts and feelings about a product or interaction.
- **Adaptive interfaces**: Attempt to change based on the users preferences. Designers can explore what personalizations may be useful and what information is needed from the user to enable this adaptivity.

By utilizing and considering these technologies, a Needfinding Machine works as a tool to help designers understand their users better. A Needfinding Machine also allows designers to understand the needs of the machine better. By interacting through the machine, the designer can assess what it is the machine will need to understand and what data to collect in order to adapt to the user. This interaction helps to expose the designer to the new material of interaction data and allows them to play with potential interaction possibilities that consider this information.

5 Related Methods

In this section, we review methods that have been used by designers to help them understand users. Each of these methods inspire some of the elements of the Needfinding Machine. For each method, we provide a brief overview of its use in design and discuss which functional components from Sect. 3 are incorporated into the Needfinding Machine.

5.1 Ethnography

Ethnographic research is the foundation for much of what is considered design research in practice. Within many design contexts, practitioners act as participant observers, embedding themselves within a context to understand people. This tradition arises from Geertz's "thick description" of people and their behaviors and situates the observer as having a specific point of view that allows for specific interpretation of people's actions and motivations [39]. For example, when users quickly change a song on the radio, are they interested in listening to something else or does that song harbor undesired meaning and emotion?

This process of interpretive, contextually situated ethnography has translated well to design work and allows the designer to observe the lives and experiences of their users. However, most companies do not preform academic ethnography [54], which can often take months or years of intensive study. Rather, designers have adapted ethnographic methods into short, focused participant observations often lasting on the order of hours or days [61, 67]. Even with short observations, ethnography-inspired methods have become staples for finding user needs and supporting generative design activities [52, 55, 71].

Within human-computer interaction, ethnographies are often required to report on some *implications for design*. Though Dourish argues that requiring design implications of academic ethnographies can undermine the richness of these studies [27], interactions through a Needfinding Machine are specifically situated to support design work and thus help designers generate implications for future design. Additionally, Needfinding Machines are interested in understanding user needs in relation to a specific product or context. While designers can learn about the broad aspects of user's lives, the designer's performance as the machine grounds needfinding around the user-product interaction.

5.2 Things as Co-ethnographers

As the Internet of Things becomes an everyday reality within people's homes, there is growing interest in how designers can use information from the viewpoint of things to understand and empathize with people in context. Projects such as Comber et al.'s BinCam [20] and Ganglbauer et al.'s FridgeCam [36] used cameras attached to products to collect pictures of everyday interactions. By collecting images and video from the point of view of the objects, the research teams could observe aspects of user lives that would usually be out of view during interviews and short observations. After using similar methods of collecting pictures from cameras placed onto everyday objects, Giaccardi et al. [42] have suggested that the software and sensors of Internet of Things objects can give designers access to "fields, data and perspectives that we as human ethnographers do not have, and therefore may help us to 'see' what was previously invisible to humans." By providing a different viewpoint, the things become "co-ethnographers," working in conversation with the designer to help them understand the user from a different and situated perspective [41, 42]. Wakkary et al. [81] extend this idea of thing-centered understanding of people to focus primarily on the relationship between things rather than focusing on direct observation of people. Their work explores how focusing design inquiry on things and their interactions can inform the relationship that people have with internet connected products. For example, during interactions with "Morse Things" [81] people attributed human-like qualities and an ability to identify people in the home to a set of plates and bowls that communicated with each other and on Twitter.

The Needfinding Machine is related to the use of things as co-ethnographers. However, human designers remain in the interaction loop with users with a Needfinding Machine. While things as co-ethnographers allow designers to observe and document people's interactions with things, they do not provide the designer the ability to control the machine's performance or view real-time data about an interaction. Moreover, by acting as the machine, the designer can gain an understanding of interaction challenges the machine will face. By mediating their interactions through the machine, the designer can reveal both the needs of the people as they interact with the technology and the needs of the machine as it interacts with a person.

5.3 Remote Usability Testing

With the rise of high-speed internet and mobile devices, designers are now able to remotely explore user experience. More traditional usability testing methods have been modified to be performed remotely so that the designer does not need to physically "be there" in order to build understanding about the user and the product [11]. Waterson et al. [82] and Burzacca et al. [16] each test the usability of mobile web sites by collecting data from people using the website on devices outside the lab. Often, these methods have been created to explore the use of mobile devices beyond traditional lab studies. English et al. conducted remote contextual inquiry to improve enterprise software [31] and Dray and Siegel used remote usability testing to explore international use cases for their software [28]. Depending on the study setup, remote usability testing can be done synchronously, where the researcher is observing the remote activity as it is happening and interacting with the user, or asynchronously, where the researcher is analyzing data logs or recordings at a different time [11].

Although being out of the lab can reduce study control and be more challenging for data recording, Andreasen et al. [5] and Brush et al. [15] have found that synchronous remote methods can be just as good for designer understanding as being present with the user. In addition, remote interaction and observation can reduce the pressure participant's may feel from having a researcher constantly looking over their shoulder [5].

The Needfinding Machine is inspired by the kinds of observation and documentation that remote usability testing provides designers. Similar to remote usability testing, a Needfinding Machine enables designers to synchronously observe and engage with remote users. The Needfinding Machine also documents data from the interaction in a similar way to remote usability testing. However, Needfinding Machines differ from remote usability testing as designers engage with the user by performing as the machine rather than being on a phone call with the user as they are trying an application. The ability for a designer to perform the machine moves a Needfinding Machine ahead of usability testing and focuses the designer on learning through interacting with the user, not just through data collection. Furthermore, the intent of a Needfinding Machine is to help designers understand the broader needs of users, rather than only test how usable a product is.

5.4 *Data-Driven Design Validation*

As devices generate more data, there is a growing interest in using this data for the purposes of understanding users. Christian outlines how web sites have tested and refined new designs using A/B testing [19] and Geiger and Ribes use system logs to conduct 'digital ethnography' about users of online blogs and wikis [40]. These methods provide a way for designers to observe how users engage with a product based on objective data measures. The use of objective data can help designers avoid some of the challenges with direct observation such as researcher interpretation of events and participant bias due to the researcher's presence [66]. Data-driven methods also allow for designers and researchers to observe at a much larger scale, helping designers see a range of interactions that users have with an interactive system.

Still, many methods that rely solely on data logs can only show what a user is doing and only can see data from what is instrumented. Attempting to understand users only from interaction logs can run the risk of being too granular (if the data is too noisy) or too high-level (if too many data points are aggregated).

Some projects bring qualitative experience in by bringing experience surveys into the physical world, such as Cadotte's Push-Button Questionnaire for understanding hotel experiences [17]. A modern version which simplifies a questionnaire into four simple smiley face emotions is Happy-or-Not's (https://www.happy-or-not.com) customer satisfaction kiosks seen in airports and sport complexes [64]. These systems allows for businesses to quickly gather some level of satisfaction data. Often, when many customers rate things negatively, a member of the business can go to the site an figure out what is wrong. This shows how small bits of focused emotion data can be used to understand some aspects of customer experience. Still, data-driven approaches often prove more appropriate for design validation and optimization rather than generating new design ideas. While data-driven design can be useful for beta testing usability or optimizing the experience of a particular location, designers are often interested in *why* users are behaving in a certain way; what are their motivations, their goals, challenges, and thoughts?

5.5 *Experience Sampling in the Wild*

To help understand both the *what* and *why* during mobile-based user experience studies, Consolvo and Walker [21] and Froehlich et al. [34] blend interaction logs with randomly timed text message based questions about the user's experience based on Csikszentmihalyi and Larson's Experience Sampling Method [24]. Aldaz et al. used similar experience sampling questions through a phone app designed to help hearing aid users tune their hearing aid's settings [2]. Through collecting user experiences while tuning their hearing aids, Aldaz et al. suggest that blending interaction data and the user's in-the-moment experience can allow for new forms of needfinding beyond in-person interviewing and observation [2].

While the projects above aim to elicit the user's experience with a product, they focus on text based descriptions of experience. Froehlich et al.'s My Experience system did allow researchers to see images and video that people captured on their phones, helping researchers to better understand the user's context [34]. However, these media clips were captured when the user took them rather than when the researcher may have wanted to see an interaction. Crabtree et al. captured video clips from third person cameras while exploring ubicomp games blending online and real-world tasks [23]. They then synchronized these clips with sensor readings and device logs to "make the invisible visible and reconcile the fragments to permit coherent description" of the player's experience. The Needfinding Machine builds upon Crabtree et al.'s insight of mixing video and data to provide designers with a high-fidelity view of the user's experience. What is critical for a Needfinding Machine is the real-time *video* of the user's environment. This not only allows the designer to observe the user's experience but also allows them to inquire about the user's experience at the moment of interaction, rather than after post analysis of data or through a random experience sample. Live video also allows the remote designer to control the interactive device rather than only observe preprogrammed interaction, letting the designer explore a wider range of interactions. Finally, video provides a rich context for the data logs that are captured from the interactive device providing documentation beyond click-streams and system logs.

5.6 Probes

The Needfinding Machine concept takes many inspirations from the development and use of probes in design and HCI. Gaver, Dunne, and Penceti's Cultural Probes [37] provide designers with a means to understand and empathize with geographically distant peoples. Cultural Probes, often consisting of postcards, cameras, and guided activities, help to elicit contextual information from people and help designers build a textured and rich understanding of people's lives. Hutchinson et al.'s Technology Probes [47] extend Cultural Probes to include the use of technology as an eliciting agent. These probes allow technologists to understand how new devices may fit into everyday life and inspire new potentials for computational products. Originally, probes were intended to be provocations for collecting stories about user's lives that would lead designers to reflect on their users and their role in the design process [37]. Even when technology is used, Hutchinson et al. suggest that probes are not prototypes to be iteratively developed over time, but should focus on eliciting user engagement and open up design spaces [47]. This being said, Boehner et al. describe how HCI researchers have expanded the use of probes to include diary studies, photo journals, longitudinal studies, and participatory design prototypes [12]. Boehner et al. also discuss how probes have expanded beyond their original goals of promoting reflection to also help designers collect data and generate user requirements for future design ideas. Amin et al. [3] used a probe during a participatory group exercise to help develop a set of four design requirements for mobile phone messaging. Kuiper-Hoyng and Beusmans [53] and Gaye and Holmquist [38] each use probes along with interviews to help users discuss their experiences in their home and city, respectively. The use of probes helped each group to refine and iterate on more specific design projects.

Needfinding Machines build from using probes as a way to understand user needs but still focus the designer on considering implications for more specific product ideas. Thus, Needfinding Machines exist somewhere in a space between probes and prototypes. While probes can help to document user experiences asynchronously, Needfinding Machines are focused on helping designers observe and interact with users in real-time. Needfinding Machines also aim to collect data from the remote environment and display this to the designer so that they can continuously change how they control the machine's behavior. By preforming as the interactive device, designers can test specific interactions with users; however, these interactions are not intended solely for usability testing. Needfinding Machines retain the goals of probes to help designers understand the user's experience and life more broadly. Furthermore, Needfinding Machines build upon the ability for probes to elicit textually rich information from people in contexts that would be otherwise unobservable. Information collected from these interactions is intended to be analyzed in holistic and interpretative manners but will also include more actionable data about the user's experience with the interactive product. By allowing the designer to ask the user questions and perform the interactive product's behavior with the user in real-time, Needfinding Machines aim to collect what Mattelmäki and Battarbee call "inspiring signals" for developing empathy with the user [59] and develop what Boehner et al. state is a "holistic understanding" of the user's experience with a product [12].

5.7 Wizard-of-Oz

Wizard-of-Oz methods have often been used in design to simulate technologies that are currently unavailable. This method uses the "wizard behind the curtain" metaphor as a way to control prototypes when the product's technology is unavailable or intractable at the time of experimentation. Prototypes such as Kelly et al.'s exploration of natural language understanding [51] and Maulsby et al.'s simulation of multimodal interfaces [60] show how designers can learn a great deal about their proposed designs before allocating significant resources to technical development [25]. When performed early in the design process, Molin et al. suggest that Wizard-of-Oz experimentation can help to define user requirements and promote collaboration between designers and users [62].

Along with prototyping new interactions, designers can also use Wizard-of-Oz experiences to gain insight into what a user is feeling and thinking during the moment of interaction. For example, Sirkn et al. used Wizard-of-Oz to control a simulator based autonomous car while asking a driver questions about their experience [76]. The improvisational style of these interactions allowed the driver to experience a potential future for autonomous vehicles and allowed the designers to gain insight into how drivers would react and respond to the car's behavior. This playful style of Wizard-of-Oz interaction prototyping and inquiry provides a foundation for how designers can collaboratively work with people to explore new interaction potentials and reflect upon their current and future needs. Furthermore, Maulsby, Greenberg and Mander found that one of the most important aspects of Wizard-of-Oz prototyping is that designers benefit by acting as wizards; seeing uncomfortable users and finding product limitations while acting as the machine can help motivate further prototype iterations [60].

The Needfinding Machine extends the capabilities of lab-based and controlled Wizard-of-Oz for use in real-world contexts. Designers interacting remotely keeps many of the same aspects of control, performance, and documentation of lab-based Wizard-of-Oz studies. Needfinding Machines also use Sirkin et al.'s use of improvisational interviewing through the machine with the goal of helping the designer understand a user's lived experience and potential needs around the specific interaction that is being designed.

5.8 Conversational Agents

Conversation around the experience of products is a powerful tool for understanding and moving forward with design ideas. Dubberly and Pangaro [30] describe how conversation between project stakeholders allows for design teams to co-construct meaning, evolve their thinking, and ultimately take an agreed upon action in the world. This echoes Schön's [73] conceptualization of design as a conversation between the designer and the situation. With this in mind, designers can use machines that converse with users, or conversational agents, as tools for understanding user experience.

Although human conversations can be quite complicated, even simple questioning from a machine can elicit meaningful responses from people. By the mid 1960's, systems such as Weizenbaum's [84] ELIZA teletype Rogerian psycho-therapist could use simple rules to engage people in deep conversation about themselves. As conversational agent technology is becoming more popular within contemporary product design, design teams are exploring how to use chatbots to inquire about user experience in the real-world. For example, Boardman and Koo of IDEO have used Wizard-of-Oz controlled chatbots to prototype a fitness tracker application, a text-based call center for public benefits, and a mobile application for healthcare workers tracking Zika [14]. Using chatbots to engage people in conversation, the designers on these product teams were able to continually engage people and develop empathy for the everyday lives of their users. The chatbot conversations helped the designers uncover needs around the services they were designing. For example, the need for users to track healthy and unhealthy activities in their day and the need for users to feel safe while asking health related questions. Additionally, by acting as the chatbots, the design team engaged other project stakeholders in controlling the bots. This led to debate and reflection on what the product ought to do and how it ought to interact, helping the team to better understand their own designer values and the needs of their stakeholders.

The Needfinding Machine builds upon the work of Broadman and Koo at IDEO to use conversational agents as a way for designers to understand user experience with interactive systems. While using a Needfinding Machine, the designer can have a rich conversation with the user as the user is interacting with the product. Additionally, using people's innate ability to converse allows more members of the design team, even those without special training in interaction design or user research, to engage a user while acting through the machine. In our work on Needfinding Machines, we have used voice-based conversation rather than text messaging. This allows for more fluid communication and lets users describe their experience and answer questions during the interaction instead of needing to switch to a mobile phone messaging app. By using voice instead of messaging, designers can explore experiences in environments where a user might be preoccupied with other tasks, such as cooking in their kitchen or driving in their car. The Needfinding Machine also differs from using chatbots alone by providing live video and data feeds from the user's environment. Having live video and data allows designers to use context as a basis for their conversation with the user and frees the designer from relying only on what the user is saying to understand the user's experience.

6 Case Study: DJ Bot

To illustrate a concrete example of a Needfinding Machine within a specific context, we present the design and test deployment of *DJ Bot*, a smart agent that talks with people to figure out what music to play as they are driving. *DJ Bot* is a functional system prototype that allows designers acting as remote wizards to play songs and to converse with people about their musical whims and preferences as people listen to music while driving in a car. We piloted the system ourselves and with researchers at a commercial music streaming company exploring future interaction design modalities for music services. These tests show the design research possibilities, benefits, and challenges of using a Needfinding Machine in context. In the process of "performing DJ Bot," the designer/wizards were able to explore people's connection with their music and potential needs that might drive future intelligent music recommendation agents and services.

6.1 Design Motivation

The DJ Bot project began as a way to test the ideas of the Needfinding Machine in relation to real-world interactive systems. We chose the space of interactive music services because these services are heavily data driven and powered by recommender systems [72] but provide a product that is laden with personal meaning and contextual importance [44]. Digital streaming music services allow people to access huge amounts of music and have changed the way listeners discover, share, and curate their music collections [56]. The music recommendation systems behind these services can help listeners discover new music or suggest just the right song to play in the moment. In essence, these systems attempt to know the user in order to make predictions about what music they will enjoy [68].

Music presents a rich and open test platform for our needfinding explorations. Everyone has both a biological and social connection to music [79], allowing for almost anyone to be involved as a user in the development of new music interfaces. Music has been used for therapy to improve one's sense of purpose and is used as a way to convey personal meaning to others [4, 8], suggesting it as a useful mechanism for allowing designers to explore who the user is as a person. Cook [22] states that deciding what music to listen to is a way of signaling who you are. Music is also linked to time and space and is used similarly to personal photo organization as a way of reminiscing and storytelling [9] and creating a personal "musical panorama" of one's life [35].

As we consume more music, interaction design around music listening is becoming more data-driven and focused on recommender systems. This is enabled by previously unseen patterns emerging from analyses of large data collections on listener behavior. For example, Zhang et al. [86] analyzed Spotify listener data to determine when the most popular times during the day for listening were and what devices (mobile, desktop, web) were being used. In an analysis of six years of data from 310 user profiles from Last.fm, Baur et al. [7] were able to determine that seasons had a large impact on listening habits. Still, vast stores of listener behavior data do not provide all of the rich information that makes individuals passionate about their music. While these studies highlight *how* users listen, they do not provide the richness of *why* users listen. Streaming services are now exploring alternate ways of categorizing music to get at this meaningful information. For example, Spotify's "Line-In" interface aims to collect more meaningful tags about music directly from users and plans to use these tags as meta-data in their recommendation system [70]. Building on the desire for users to talk about their music, DJ Bot uses an interactive music agent as a platform to let the designer connect with a listener around music in-context. While situated in the listener's environment and performing as the machine, designers can explore new speech-based music service interactions and build their understanding of individual music listeners.

6.2 Music on the Road—A First Context

For our first context, we explore music listening while driving. The car provides a number of interesting opportunities for exploring the needs of music listeners, as it is a semi-private, semi-controlled environment where people often enjoy music or other audio-based media. From a logistical perspective, the car is readily instrumented with cameras, computers, and interactive devices. With the use of high-speed mobile routers, cars can be fully connected to the remote designer. Finally, while music listening is one of the few safe secondary activities drivers can engage with, current smart-phone based streaming services may be distracting or challenging to use, and present open design opportunities for new music applications.

6.3 Implementation

Functionally, DJ Bot in the car allows a designer to control a streaming music service on the listener's mobile device, communicate with the driver using real-time synthesized speech, and view multiple channels of live video and audio from the car. We modeled the DJ Bot system on a system we previously designed system for conducting real-time, remote interaction prototyping and observation in cars [58]. We use the Spotify streaming service which allows for "remote control" from any device where the user is logged in. This allows the designer to use a desktop version of the application to control the music on the user's mobile device.

Figure 4 shows a system diagram outlining the remote designer locations, the communication streams, and the in-car interactions that occur with DJ Bot. Within the car, the listener connects their mobile device running the Spotify app to the car's audio system. Video cameras and microphones are placed around the car, allowing the remote designer to see both the driver and the road from multiple angles. Having multiple views allows the designer to better experience the driving context. The road facing camera also helps the designer have a sense of the driving conditions, allowing them to better plan interactions and avoid distracting the driver. A computer in the car streams the live video and audio via a video chat client back to the remote designer. The computer also runs a text-to-speech engine and speaks messages sent from the remote designer through a separate portable speaker.

The designer, acting as a wizard, controls DJ Bot through an interface that displays video from the car, the desktop Spotify app with "remote control" enabled, and a custom web-based interface for sending speech messages to the car, shown in Fig. 5. The designer can view information such as the audio level and current song in the Spotify app and can control music using the app's audio player controls. The speech control interface includes a text input area to send custom messages and a list of pre-scripted questions such as: "*What do you want to listen to next?*," "*Why did you choose that song?*," "*What does this song remind you of?*," and "*Can you tell me more?*"

In order to support documentation and analysis, video and audio is recorded using cameras mounted in the car. Because both sides of the interaction are required to reconstruct the dialogue, the designer's control interfaces are also recorded. All speech messages are logged and the music selections stored in the user's listening history.

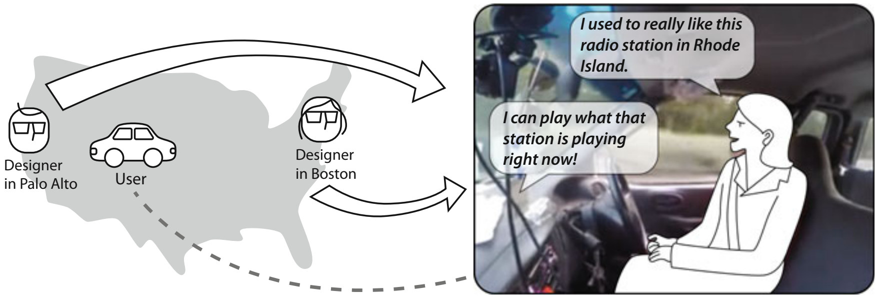

Fig. 4 DJ Bot implementation with distributed designers. Designers can remotely interact with users from anywhere in the world, allowing situated, real-time needfinding through a machine

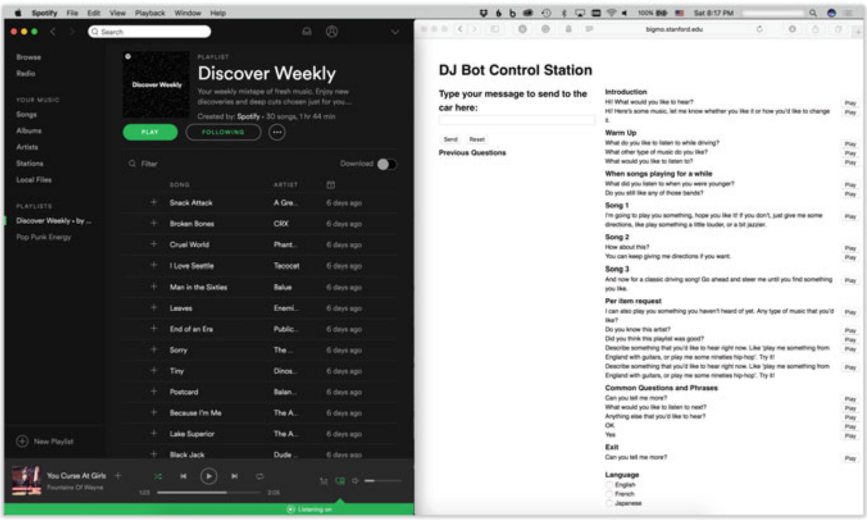

Fig. 5 An example control interface from the DJ Bot project. The designer can remotely control music and synthesized speech with planned or improvised questions

6.4 *On-Road Sessions*

We conducted three interaction sessions for our initial exploration.

1. A 1-h session where Nik acted as the DJ/wizard for a user driving her pickup truck on the freeway
2. A 1-h session where a colleague and interaction design practitioner acted as a DJ/wizard for Wendy as a user driving to visit a friend
3. A 30-min session where two interaction researchers from a music streaming company acted as DJ/wizards for a commuter driving from home to school at 5:30

AM PST. One researcher connected from California while the other connected from Massachusetts, as shown in Fig. 4.

After each session, we conducted an interview with the wizards and drivers, asking questions about the interaction experience and the use of the Needfinding Machine. Our goal in describing these sessions is to present a working example of how a Needfinding Machine can be used and to reflect on the opportunities a Needfinding Machine can have for professional design work. The following sections provide excerpts and commentary from the sessions as a means to give the reader a feeling of the conversations that occurred between the designer preforming as DJ Bot and the listener/driver.

6.4.1 Session 1

During the first session, Nik controlled the DJ Bot for a user who drove her pickup truck on the freeway for about one hour. Prior to the session, Nik setup cameras and the data streaming computer in the user's truck. Nik had little prior information about the listener's musical preferences before starting the music. He began the session by simply asking "What would you like to listen to?" through the DJ Bot. This lead to a back and forth interaction to determine if the listener wanted to hear the song that was selected. At one point in the interaction, the driver remembered a song that they liked and requested it to be played. Nik ended up playing an alternative remixed version of the song, leading to the following conversation:

♫ *I would walk 500 miles - remix* ♫

[DJ Bot] What do you like about this song?

[Driver] This isn't the original, is it? You said it was a remix. But it's just fun and it has a good beat and it's like easy to sing along to.

[DJ Bot] Do you sing along to music often?

[Driver] Yeah! It's pretty weird to sing along to music when I know I'm being recorded.

[DJ Bot] Do you sing along with others?

[Driver] Yes.

[DJ Bot] What songs you do you normally like to sing?

[Driver] Lots of songs. Like Disney songs.

This interaction elicited that the driver liked to sing along to music, enjoyed Disney music, and associated Disney music as music the user would sing with others.

While thinking of other music to listen to, the driver remembered a radio station they liked from a time when they lived in Rhode Island:

[Driver] I can give you a radio station in Rhode Island that I really like.

[Bot voice] Okay.

[Driver] So it's 95.5 WBRU in Rhode Island. It's the Brown radio station, it's alternative rock. The stuff that they play is pretty great. When it's not overplayed songs.

[Bot voice] Okay, let me see what I can find. Did you find this while you lived in Rhode Island?

[Driver] Correct. They introduced me to a lot of music.

[Bot voice] Here's what they are playing now.

♫ *Green Day - Holiday* ♫

During the interaction, Nik switched windows from the control interface to a web browser and searched for the radio station's website. This quick thinking gave him a new source of potential music to recommend. It also presented an interesting example of the listener's relationship between place and music, providing future opportunities for further exploration.

While the system did function, this session was not entirely smooth, highlighting challenges for the designer and the user during the interaction. For example, Nik had trouble choosing songs since he was biased by his own musical tastes and did not have a baseline for what the driver liked. He stated in after the interview:

> [Nik (as wizard)] Actually it's really challenging. I have really strong opinions about music and I kept seeing all these bands and was like "I like this song! Let me play this song." But then I was trying to figure out "How am I supposed to tease out of you what you like?" And the thing is, I have such a limited knowledge of what I could even go off of.

Though this made the interaction more challenging, it pushed the driver to actively steer the music selection. This revealed information about the driver's preferences and kept them conversing rather than simply sitting back and listening.

The driver's comment about being recorded suggests that they were not always comfortable opening up to the machine. After the session, the driver stated:

> [Driver] Yeah, it was weird. It's also weird because I know I'm being recorded and I'm trying to drive and I am telling someone who I don't know very well all about my musical tastes. Which is pretty intimate and so yeah, it was just weird on a lot of levels for me.

This suggests some limitations of the Needfinding Machine method. In this particular case, the driver knew that a person was on the other end of the machine. Though this may have biased their answers during the session, the conversation afterward suggests even when the intentions of the designer are known, eliciting and recording personal information may prove challenging. Still, much of the conversation went smoothly and provided ample information about the listener and their preferences. Moments of discomfort from the user may help designers to identify potential "off-limit" areas early in the design process.

6.4.2 Session 2

Wendy acted as a driver in the second interaction. A colleague who is an interaction design practitioner acted as the wizard. Wendy spent about 45 min driving one of our research vehicles on a freeway and scenic road on her way to visit a friend. This session occurred after a recent and fierce presidential election. When the designer asked why Wendy chose a particular song, Wendy responded as follows:

♫ *Public Enemy - Public Enemy No. 1* ♫

[DJ Bot] This one?

[Driver] Yeah, I love this one.

[DJ Bot] Why this right now?

[Driver] Maybe like a post election thing and it has a lot of energy.

Although the question “Why this song?” was simple, it elicited a response with information about the song and about the context. In this case, the wizard built on the contextual information about the political times. This lead into a longer discussion of the relationship between current affairs and the driver’s music.

After a while, however, Wendy was not interested in talking about politics and asked to change the subject.

[Driver] Let’s not listen to any more Trump songs.

[DJ Bot] Okay.

[Driver] Like, let’s play something by Missy Elliott.

[DJ Bot] How is this song?

♫ *Missy Elliot - Work It* ♫

[Driver] This is good.

[DJ Bot] Why Missy?

[Driver] I really like the way that she plays with words, I feel like she’s like really really creative and like breaks rules. In like really interesting ways and, I don’t know, it’s like one of these things like, is so unlikely and then when you listen to it it’s kind of amazing and then it’s very upbeat and I have difficulty understanding what’s being said and I think it’s like fun to figure it out, like a puzzle. And maybe a little bit like Devo, it just seems like she’s having such a good time, such a good time singing, you know, and I love that.

Later in the session, Wendy spoke about bands from college and her connection with the artist *Fountains of Wayne*.

♫ *Fountains of Wayne* ♫

[DJ Bot] What do you like about this band?

[Driver] You know what, actually the thing I like about this band is it makes me think about college and it’s a little bit funny because it’s not something I actually listened to when I was in college, but when I went to grad school...

...a lot of my thoughts about undergrad are colored by this soundtrack even though like I said I never listened to Fountains of Wayne in college. And I had like this homesickness for college...

This then lead to the wizard to ask “What other bands did you like in college?,” which prompted Wendy to list off 14 other bands, helping to log a number of songs and genres that the driver enjoyed. This interaction showed the rich storytelling that can occur when thinking back on the music people enjoy. The story about college, in particular, paints a textured picture about the driver’s life, helping the designer develop empathy for the driver and a sense of the meaning behind the 14 bands that were listed.

6.4.3 Session 3

The third session highlighted a number of strengths that a Needfinding Machine can have for remote needfinding. This session was conducted in a distributed manner with one designer at home in California and one at work in Massachusetts. To split the interaction load, one designer controlled the bot voice and one controlled the song selection. During this session, the designers communicated on a separate voice channel and coordinated their actions between music control and the bot voice. The session was done at 5:30 AM PST (8:30 AM EST), during the driver's 30-min commute from their home in the city to school. While interacting through the machine, these researchers were able to experience the user's local context, despite the geographical, temporal and logistical challenges.[1]

Early in the session, the designers asked about what the driver listened to when they were younger.

[DJ Bot] What did you listen to when you were younger?

[Driver] Classical music. And a lot of Christian rock.

[DJ Bot] Do you still listen to that music anymore?

[Driver] I'm not really religious anymore.

After this comment from the driver, the remote designer controlling the DJ Bot voice moved on to another subject. However, after the session, she remarked that there was a tension in her own interest as a researcher and the role of performing the machine.

> [Wizard 1] When he said things for example about religion, I was like "Oh!" but then "no, I probably shouldn't go" you know the car goes digging around into your personal history. It wouldn't be on brand for the car or music service to go digging into your childhood.

This interaction further shows that even simple questions about one's music can lead to meaningful answers. However, in this case, the designers chose not to follow the topic. Being confronted with such an unique situation during conversation prompted the designers to reflect on how the machine ought to interact and what the machine should and should not talk about. The designers' in-the-moment and post-session reflection can be useful for understanding their own designer values and brings to light potential issues to consider for future design ideas.

7 Discussion

The Needfinding Machine is a method to allow designers to explore people's needs by interacting with the user through an interactive system. It enables the designer to observe and act in real-time, allowing for in-the-moment design inquiry with data elicited from the user. This lets designers explore potential design ideas *by*, *with*

[1]The driver's car was instrumented the evening before by the research team.

and *for* new types of social data [77]. Designers engaging with users through a Needfinding Machine can also explore the *why* behind the user's behaviors. These aspects of the Needfinding Machine present a number of benefits to the designer.

7.1 Designing By, With and for Data

By interacting through a Needfinding Machine, designers actively engage with and elicit data about people in order to understand their potential needs. When considering how designers should approach this data, Speed and Oberlander [77] ask three questions around how we can design *by, with* and *for* data. Specifically, they consider:

1. How might designers develop new methods to capture data that reveals people's values in a respectful way?
2. How might designers capture how data influences people and machines in a system and intervene in the system?
3. How might designers mediate systems developed by other machines while considering people's values?

The Needfinding Machine is one method to address these three questions. By framing the interaction through the machine as needfinding, designers act and observe so that they can understand, empathize, and learn about the user's life and the user's values. Active interaction with the user, rather than covert surveillance of the user's behavior, allows the designer to explore useful data features while being sensitive to the user's values. During the first session with the driver who spoke about singing along to her music, the driver was acutely aware they were being recorded and interacting with a person through the machine. While the user's awareness may seem to inhibit needfinding, it engages the user in a participatory way, allowing them to better consider and control what they share with the designer. For example, in our second session with Wendy, we saw that Wendy would explicitly ask to change subjects of discussion. Though this cut off some avenues of conversation, it helped to guide the interaction in directions aligned with what Wendy would be comfortable discussing.

From the designer's perspective, we saw that by interacting through the machine, designers actively confront the implication of machines that elicit data from people. Interaction ideas and questions that feel okay in the abstract may turn out to be creepy or weird when implemented. In our third session with the driver on their morning commute, the interaction researchers explicitly refrained from discussing the user's religion or childhood because they questioned if a machine *ought* to engage such discussions. The in-the-moment setup caused designers to consider what information can and should be used for the design of new music services. As the Internet of Things enables more data about users to be collected, designers will need to confront whether this data should be collected or used at all. This need for designer reflection around Internet of Things data has been seen in other work such as Berger et al.'s Sensing Home [6], seen in this volume.

Instrumenting and documenting user interactions in context allows designers to see and understand how data flows through the context. The Needfinding Machine's functional elements allow for data to be captured and viewed in-the-moment and reviewed later during post-analysis. Capturing the data live allows designers to see how the information that is collected about the user is representative of the user's values. The live interaction allows designers to explore interventions that can enhance the user' experience and engage with the user's values. For example, the interaction during Wendy's drive indicated a political dimension to her music tastes. This in turn reveals aspects of Wendy's values to the designer. The designer can then work from this understanding of the user's values to assess what information is useful for the design. The designer can also consider how systems that collect data on their own or generate data, such as a music recommendation engines, might become better aligned with the user's values.

7.2 Understanding the Person and the User

Bill Verplank argues that there are three key questions when designing interaction: *How do you feel?*, *How do you know?*, and *How do you do?* [80]. By conducting needfinding through a contextually situated system and by explicitly asking the user questions during the interaction, the designer can answer all of these questions. The designer can ask how the user feels about the interaction and how the user knows what is happening during the interaction. The designer can also see what the user does during the interaction.

For example, during the second session, Wendy discussed a long list of bands she liked in college. This interaction helped the designers collect data about what music could be included in Wendy's listener profile. Additionally though, the conversation allowed the designers to see how Wendy felt about the bands she listed and how she developed the feelings for the music. By getting the list of bands along with the personal meaning behind the bands, the designer could gather a set of meaningful information from the interaction. Information such as this could be directly used to design new features into a product, such as ways to seed new playlists or potential new voice commands. Furthermore, seeing this meaningful information allows the designer to feel a connection to the interaction participant as a person rather than just another member of a user group.

The relationship between the designer and user does have some asymmetries due to the Needfinding Machine setup. The interaction designers who participated in the third session during the morning commute noted that they felt that they learned a lot about the driver, who they did not previously know, through the interaction. However, to the driver, the designers were still complete strangers. The interaction researchers stated "Oh, I should introduce myself!" during the post interview. This suggests that there are unresolved questions about how designers should frame these interactions, and how much reciprocity is expected from a Needfinding Machine. Should the user know that they are interacting with a designer? Should they know who that designer is? And, how should the designer utilize the information gained to benefit the user? Interacting through the machine may give the designer an opportunity to reflect on these questions and on their own practices and values. Designers performing as the machine and eliciting meaningful information should consider how they want to engage with the user as they can understand both functional aspects of the interaction and personal details about the user.

7.3 Implications of Real-Time Interaction

Situated, real-time interaction supports designers in developing a rich view of the user's life in context. For example, one of the interaction researchers from the morning commute session noted that (virtually) being in the car at 5:30 AM was an eye opening experience. The time of day painted a picture for the designer of a an everyday user experience that they had not considered before. It was a departure from the designer's previous work with stationary voice interfaces and their experience as a remote wizard identified previously unknown needs around how people might listen to music as a means to wake up or ease into the day. The experience suggested that the interaction needs of the user might differ as the day goes on. This ultimately changed the interaction researcher's thinking about how often a music agent might interact based on the user's context.

Real-time interaction puts designers in an improvisational theater, where designers need to treat each utterance from the user as a gift to be responded to in kind [48]. While planning is required for the logistics of the session, designers need to be very awake to the unplanned opportunities that open up in the course of an engagement. Reacting to moments as they happen can give the designer the opportunity to understand experience right as it happens. Designers can also improvise the machine's behavior as they are performing in order to quickly explore different ideas and to elicit different types of information. One readily improvised characteristic which can lead the designer to elicit different information is conversational style [13]. For example, the wizards interacting with the woman driving her pickup truck in the first session and with Wendy in the second session used more human-like conversation. This lead them to focus on having deeper conversations about the music. During the morning commute session, the interaction researchers focused on a more machine-like interaction. Being more machine-like allowed them to shape the interaction to be closer to a what a product might be, but still allowed them to explore some of the more meaningful aspects of the user's music preferences.

We can liken the way interaction designers employ their intuitive and embodied sense of context and timing during in-the-moment dialogue to construct interaction with the way industrial designers and architects prototype and design in-the-moment with pliable materials. The industrial designer Henry Dreyfuss describes how using clay as a material allows the designer to explore form beyond what is possible with sketches [29]. Working in three dimensions allows the designer to experience a model in a form closer to what the everyday experience would be. It also allows the designer to alter a design as they build, similar to how designers can alter as they sketch, but with less thought devoted to simulating what something may be like. The architect Eero Saarinen, for example, created “huge models that you could put your head into and really look around the architectural space and surfaces” [69] as a means to experience the architectural design in one moment, and then rework them in the next.

The real-time interaction enabled by the Needfinding Machine parallels the designer’s need for a tactile and embodied way to prototype a design in-situ. Using a Needfinding Machine, the designer can get their head into the action and converse directly though the machine, shaping the interaction over time. The conversation with the user through the machine acts as the pliable material with which interaction designers can form new alternatives for future designs.

8 Limitations and Future Work

Although we have discussed a number of benefits that a Needfinding Machine can have for interaction designers, we have also identified some limitations in their usage. During our sessions, we recognized that some people were uncomfortable with being recorded, given the intimacy around the discussion of music. In some cases, users did not want to engage beyond a certain point during the interaction, closing themselves off and reducing the amount that a designer can learn. The tension that these moments cause for both the user and for the designer can be useful during early phases of design as a potential way to identify both user and designer values.

We also noticed that there can be issues on the designer’s end when considering what information they have been given and how they should proceed along with the conversation. The designer may question if they should act as a person or if they should perform the machine, potentially muddling their needfinding efforts. This being said, we found these moments to be interesting points of reflection for the designer, potentially working as a way to help the designer consider their own values during the design process [74].

From a systems perspective, it is tempting to fall into the trap of adding “bells and whistles” that enable higher and higher fidelity prototyping and realism. We feel instead that it is important to develop the system so that it maintains focus on the actual needs of the user [43, 57]. At present, the Needfinding Machine depends upon having environments with easy network access, power, and the ability to host cameras, microphones, and the interactive system itself. Adaptations to remove these types of requirements will enable us to better perform needfinding in less-resourced environments, where better longitudinal needfinding is direly needed. Developments in embedded computing and global network connectivity, as well as carefully budgeting bandwidth needs, might open Needfinding Machines to these new arenas.

Finally, the practicing interaction researchers noted that documenting and sharing the data from Needfinding Machine sessions is challenging within the corporate environment. Aside from the technical knowledge required to set up a Needfinding Machine, instrumenting and recording the live interaction is beyond what many designers can easily perform today. There are opportunities for finding out methods to communicate the results of the multidimensional data and in-the-moment learning that is collected during a Needfinding Machine session. Synchronized data from the user interactions, system logs, and designer reflections should be turned into easily shareable and interpretable artifacts so that this information can more meaningfully guide product discussions.

9 Conclusion

As interactive Internet of Things become more embedded in everyday life, there will be an even higher need for interaction designers to find and understand unmet user needs. The Needfinding Machine presents a method for using the devices themselves to allow designers anywhere in the world to interact with users in situated contexts. This provides opportunities for designers to extend their needfinding capabilities.

As machine learning enabled adaptive systems change the nature of products, designers will play a large role in defining how these systems interact and learn from users. Needfinding Machines can help designers to understand what data may be relevant to new interaction experiences and can help them simulate and communicate what interactions are most valuable to a user. Moreover, they present a vision for a future where designers can use interactive systems to understand and impact the lives of people.

Acknowledgements The authors would like to thank Kyu Keough, Henriette Cramer, and Jenn Thom for participating as DJ Bot wizards. They would also like to thank Paul Pangaro, Henriette Cramer, Jenn Thom, and Alessandro Soro for providing comments on an early draft of this chapter.

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Exploring Interaction Design for the Social Internet of Things

Donald Degraen

Abstract The Social Internet of Things (SIoT) builds social capital by incorporating principles of Social Networks (SNs) into the design of the Internet of Things (IoT). With the ambition of improving network navigability and service availability, research targets granting smart objects the ability to autonomously socialize with each other. The resulting independently defined social network for things will allow devices to communicate with both human beings as well as other devices. Autonomous decisions made by social things require them to understand the context in which they operate. However, the perception and interpretation of context remains fallible. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. By providing intelligibility or defining personalities, the user gains a better awareness of the system's functionality. In this chapter, we start by providing a short history of things that socialize and review related research. By gaining insights into the nature of interaction with both the world and autonomous systems, we frame interaction challenges with social things. We look towards literature in both the SIoT and context-aware computing to outline possible design techniques for addressing these challenges. Lastly, we discuss how future work can build upon our considerations to ensure natural and intuitive interaction with the SIoT.

1 Introduction

The Internet of Things (IoT) has long been a speculative paradigm as the next wave in computing. Interconnected networks of everyday objects with integrated sensors range from smart phones and smart watches that monitor the user's location and state, to vehicles capable of analyzing the driver's behavior. The increase in autonomous processing capabilities has guided the integration of these objects into embedded and connected systems towards more general cyber-physical systems, such as smart

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_5

homes or smart cities [26, 52]. The ongoing evolution of the underlying technologies opens up vast opportunities for applications of the IoT to improve the quality of our lives.

The Social Internet of Things (SIoT) builds social capital by considering the integration of social networking principles into the IoT [4]. Research in this field explores techniques and benefits of the incorporation of social structures and behaviors. Ensuring network navigability and service discovery can be guided by defining the composition of a SIoT network similar to the structure of a social network and can increase trust management between interconnected objects by leveraging relationship types. Consequently, existing models to study social networks can be reused to study SIoT. The resulting independently defined social network for things will allow devices to communicate with both human beings as well as other devices.

Throughout this chapter, we use the notion of a *social thing* to indicate autonomously socializing things within the SIoT. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. Autonomous decisions made by social things increase the system's complexity and require an understanding of the context. As the perception and interpretation of context remains fallible, the user must be able to retain control over the system's actions.

In this chapter, Sect. 2 starts by providing an overview of the history SIoT and its basis of social capital, followed by basic relationships for social things, an architecture for the SIoT and example platforms and implementations from both literature and commercial applications. Section 3 considers how we interact with the world, how autonomous socialization changes this, the need for contextual awareness and the interaction challenges that arise. The role of the human is framed in Sect. 4, followed by two techniques to improve and enrich the interaction in different fields, namely designing for intelligibility and control and designing the behavior of interactive objects. We conclude by discussing how future work can utilize and build upon our considerations to ensure natural and intuitive interaction with the SIoT.

2 An Internet of Social Things

The vision of the Social Internet of Things (SIoT) encourages the adoption of social networking paradigms into the Internet of Things (IoT). This work focuses on socialization between SIoT objects which aims to benefit from the concept of social capital. We elaborate on the history of social objects and address the basic SIoT relationships. From a literature perspective, we describe platforms and implementations that advance towards socializing objects.

2.1 Social Capital for Things

The SIoT applies social networking concepts and technologies to the IoT [4]. This work focuses on socialization between objects, which builds on the idea that networks of social relationships provide benefits to the entities functioning within that society. This is founded on the theory of *social capital* which states that these relationships are valuable resources providing members with ‘credential’ [10]. In turn, credential allows to build trust and trustworthiness which facilitates the actions of individual members [27]. As members gain access to previously inaccessible resources, their exchange and more specifically their integration results in value creation through innovation.

Social capital in terms of a SIoT environment transfers the benefits of social relationships to IoT objects [3]. Essentially, autonomous socialization adds a highly adaptive aspect into the smart environment. Social relationships, being dynamic by nature, are able to shape the network structure based on the active requirements. This leads to improved network navigability which opens up the IoT environment for cooperation and collaboration between objects. Social navigation enhances resource visibility and service discovery while scalability is guaranteed. Based on the level of interaction between things and the type of relationships, a level of trustworthiness can be imposed on objects, providing reputation management. Most importantly, social relationships lead to value creation though service composition and source crowding within the SIoT.

Social networking paradigms support the connections between the users’ social organization model and their ubiquitous IoT devices [53]. As these principles are gathered from existing literature, models and algorithms for analyzing social networks can be re-used in SIoT environments. This provides us with the tools to allow social awareness to increase system performance and Quality of Experience [2]. Social relationships and socialization between IoT objects will be essential properties of future smart environments.

2.2 Things that Socialize

The foundation of the IoT refers to interconnected networks of everyday objects equipped with sensors and actuators, while having individual and autonomous processing capabilities. The integration of these objects into embedded and connected systems, results in more general cyber-physical systems such as smart homes or smart cities [26, 52]. This leads to a highly distributed network of devices communicating with human beings as well as other devices.

Considering economic and sociological studies, Atzori et al. [5] motivate that the technological advancements of smart devices enable them to undergo an evolution similar to that of human evolution. To illustrate, three categories of IoT objects can be distinguished in relation to their social consciousness, namely *res sapiens* or smart objects, *res agens* or acting objects and *res socialis* or social objects.

In the first phase of the IoT, proposed systems comprised of mainly heterogeneous devices that functioned within personal ecosystems. As these smart objects inhabited their own supporting infrastructure isolated from interaction with external environments, initial *res sapiens* were bound to these fragmented networks. Innovations in inter-device communication, object visibility, and service discovery and integration, have improved the operability of these objects with external systems. The ability of communicating with the external world through common standards and protocols enabled them to participate in human social networks.

In the second phase, objects are granted the means to actively participate in their surrounding environment. *Res agens* are able to manifest their own pseudo-social behavior, such as the creation of a spontaneous networking infrastructure through temporal relationships with their neighbors. Objects are not only connected anymore, but actively participate in social networks.

In the natural world, the creation of a network of social relationships enables animals *to master complexity and the difficulties that characterize the environment in which they live*. In the last phase, *res socialis* considers autonomous socialization between smart devices as a means to collaborate in self-constructed social networks, creating complex services in object social networks. The novelty in the future evolution towards *res socialis* lies in the fact that the autonomous networks are defined by the relationships among objects. This results in social networks by objects for objects in which they may exchange information and utilize each other's services. Even though communication is still aimed at supporting humans, they have no direct role or control over the network.

A similar construct can be found in *Cybermatics*, a concept which considers a cyber-physical-social-thinking (CPST) architecture or hyperspace [28]. Cybermatics builds upon the notion of cyber-physical systems by considering characteristics of the *social space*, i.e. social attributes and social relationships, and issues of the *thinking space*, i.e. the process of analysis, synthesis, judgment and reasoning. Within the social space of the CPST hyperspace, relationships between human beings, physical objects and cyber entities build both human and thing societies. The SIoT resides within the thing society established through autonomously created relationships between *res socialis*.

2.3 Relationships and Architectures for Social Things

While initially framing the SIoT, Atzori et al. [4] described the responsibilities for the SIoT by deriving the basic relationships between social objects and proposing a network architecture to support them. The set of social relationships of objects is built upon the four relational structures for human beings as proposed by Fiske [16], i.e. *communal sharing*, *equality matching*, *authority ranking* and *market pricing*. As argued by Pintus et al. [37], Fiske's model can be mapped to the social aspects of a Humanized IoT (H-IoT). In the domain of *communal sharing*, the IoT can serve as a basis for users to share their things with others. This can in turn serve the basis for *equality matching* to provide a good balance between benefits and contributions of sharing of devices and data. Based on the relationships within an IoT, access and restrictions need to be applied to warrant *authority ranking*. Considering the SIoT, social relationships serve as the ideal foundation for authority through the concept of social capital as things can autonomously build 'credential'. Lastly, IoT systems need to consider *market pricing* of resources to ensure rational cost-benefits over things usage.

As a first approach, Atzori et al. [4] derived the following relationships:

- *Parental Object Relationships* (POR) between objects of the same production batch, usually homogeneous objects from the same manufacturer;
- *Co-location Object Relationships* (C-LOR) established by objects operating in the same environment;
- *Co-work Object Relationships* (C-WOR) built by objects providing a common purpose;
- *Ownership Object Relationships* (OOR) involving heterogeneous objects belonging to the same user;
- *Social Object Relationships* (SOR) constructed because their owners come into contact with each other.

The proposed architecture for the SIoT, shown in Fig. 1, takes a similar approach as the three-layered model for IoT presented in [55]. This model consists of a sensing layer for data acquisition and short range collaboration, a network layer for data

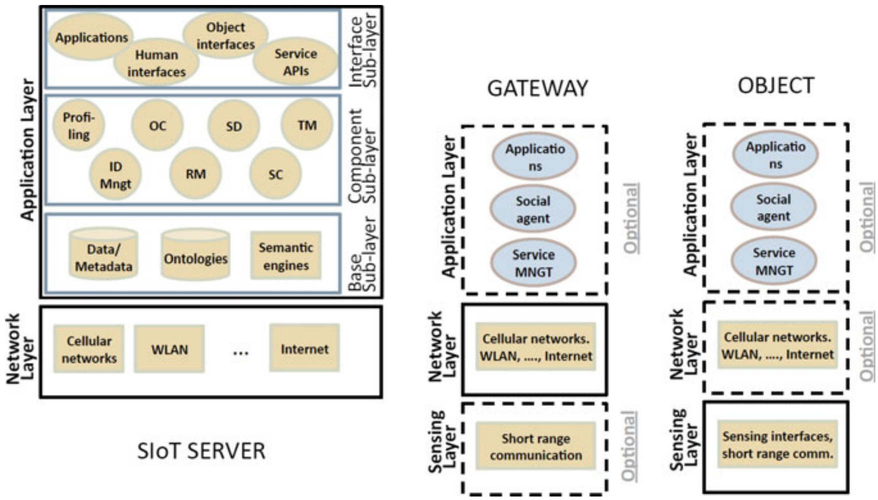

Fig. 1 Overview of the proposed architecture using a three-layer model for SIoT by Atzori et al. [4]. (Reprinted from [4], with permission from Elsevier)

transmission and an application layer for data storage, processing and analysis. The architecture considers three components to be essential for a SIoT system.

The SIoT server is responsible for most of the functionality, while gateways and objects remain mostly limited. Through ID management and profiling, the server respectively assigns objects with IDs for reference and configures information about these objects. The owner control (OC) regards the activities that can be performed by an object, the information that can be shared, as well as the type of relationships that can be set up. The server manages relationships using the relationship management (RM) module, while services are managed and integrated respectively by the service discovery (SD) and service composition (SC) components. Lastly, the reputation or 'credentials' of objects are assessed in a trustworthiness management (TM) part. These components collaborate to support the main SIoT processes, namely the entrance of a new object, the discovery and composition of services, the establishment of new object relationships, and the provisioning of services.

2.4 Example Platforms and Implementations

The first notion of socialization between objects in literature addressed how smart artifacts could establish temporal relationships, and how users are able to retain control over these relationships [19]. In ubiquitous computing, proximity-based communication stems from the notion that the location of devices is central to support temporal connections between artifacts [20]. In this work, authors use proximity-based communication in context-aware devices to propose the idea of *context proximity* for selective artifact communication. Their smart objects called Smart-Its derive their context from an abstraction of raw sensor data, generic perceptions extracted from sensors, and artifact- or application-specific information. Deriving from this context, communication originated from either implicit or explicit connections.

Often referred to as the Social Web of Things, existing platform implementations can be found in both literature and commercial applications. Both the platforms Xively[1] and Paraimpu[2] [36] provided frameworks to interconnect social networks with things and their composed services in a Web of Things (WoT). Additionally, authors describe an interconnection between cognitive robots and the IoT by adding a social dimension to human-robot and robot-robot interactions [45]. However, as connecting objects together was left to the user, there was no notion of autonomously establishing social relationships.

More recently, autonomous socialization between things was supported by the Evrythng Platform.[3] Individual things are assigned a unique active digital identity (ADI) to ensure a permanent online presence. Evrythng proposes manufacturers to

[1] IoT Platform for Connected Devices—Xively by LogMeIn, https://www.xively.com/, last accessed Jan. 11th 2018.

[2] Paraimpu—You are Web, http://www.paraimpu.com/, last accessed Jan. 11th 2018.

[3] EVRYTHNG IoT Smart Products Platform, https://evrythng.com/—last accessed Jan. 11th 2018.

utilize ADIs for their IoT objects to support relationships between devices, however, most interaction is still occurs between the user and an object.

In more recent work, the *Socialite* framework differentiates not only between object relationships, but includes social relationships between users as a requirement to collaboratively reach goals within a SIoT environment [21]. A relationship between human friends, a *Friendship*, is contrasted to a relationship between things, a *Thriendship*. The latter can be considered equal to an SOR, while they support the concept of OOR as *Ownership*, C-LOR as *Collocation* and POR as *Kinship*. The proposed concept and architecture aims to drive more responsibility on the individual objects within the system as to take advantage of the distributed nature of SIoT. In order to empower end-users, the *Socialite* framework was extended to include end-user programming and sharing rules [22].

Utilizing the relationships defined in the *Socialite* framework, a system for autonomous cooperation in the IoT was designed using a virtual proximity based P2P communication protocol [33]. Their implementation aims to support humans to be social with each other by providing users with a personal *mascot* which is able to connect with other *mascots* and smart benches. Their work focused on the autonomous socialization functionality of things within the SIoT application to support communication between users.

3 Interaction in the Social Internet of Things

In order to understand interaction and the role of the human in the SIoT, we start from Donald Norman's stages of action to bulid upon interaction with everyday things. Using this framework, we formulate the changes and limitations autonomous socialization causes and address the need for contextual awareness. These concepts serve as the foundation to frame the challenges which hinder the user's capacity of understanding and interacting with SIoT systems.

3.1 Interaction with the World

Understanding interaction with complex systems starts with an understanding of how we interact with the world around us. The Stages of Action model was conceptualized as a means to analyze how we interact with everyday things in our environment [31]. The model identifies the components and their stages which come into play when we want to perform an action in the world around us (Fig. 2).

A user with a specific goal in mind has to cross the *Gulf of Execution* in order to attempt to modify the state of the world accordingly. During the 3 stages of execution, the user devises a plan to perform the action, specifies the sequence of atomic actions required and performs them. At any given moment the user may cross the *Gulf of Evaluation* to inspect the state of the world. This will provide

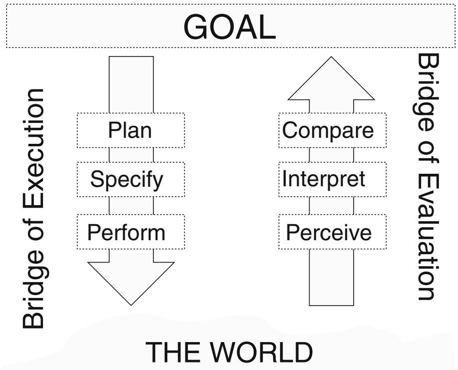

Fig. 2 Norman's Action Cycle. (Adapted from [31] with permission)

valuable information regarding the result of an action and allows to align or modify future actions. Evaluation consists of perceiving what has happened in the world, interpreting these changes and comparing them in order to conclude if this result is wanted. Essential to this process is the understanding of how an item within the world works and which effects it might produce. Norman puts forward the idea that understanding should be mitigated through design.

Two scenarios relevant to the SIoT, namely autonomous system actions and implicit user input, modify the action cycle in such a way that they may cause confusion or frustration with the user [46]. Autonomous system actions occur when actions are performed which are not based on explicit input from the user, but triggered from an event in the environment. The absence of the *Gulf of Execution* might imply that the user is not expecting a change to occur as she is not explicitly paying attention to the system's state. The responsibility to inform the user with appropriate feedback lies entirely with the system. In the case of a SIoT environment, two social things approaching each other might decide to establish a relationship and share resources. A user not notified by the system of this event, remains unaware of the availability of novel resources or even of potential breaches in privacy.

Likewise, while providing the user with feedback of passed events communicates the updated system state, it might not always be the most suitable technique. When these events occur in abundance, the user will be flooded with information, leading her to ignore or mute notifications. In such cases, feedback related to highly important system events will not be able to reach the user's awareness. It is therefore crucial that the system provides *feedforward*, i.e. it informs the user how certain environmental events, such as implicit actions performed by the user, influence the behavior of the system before these events take place. An autonomous system must provide visibility into and discoverability of its functionalities [31].

3.2 Context-Aware Systems

The vision of ubiquitous computing, first outlined by Mark Weiser in 1991 [49], describes the third wave of computing. This era in which many devices become integrated into the user's daily environment by moving beyond the desktop, grows out of the first wave of mainframe computing and the second wave of personal computing. As people are surrounded by intelligent and intuitive interfaces, computers become an integral, invisible part of their lives. This shift demands for a new relationship towards the user as 'the invisible computer' needs to offer its services, without demanding attention. Taking into account the desired state of mind of the user, computing needs to promote *calm technology*, which moves easily from and back to the periphery of our attention [50, 51].

As technology needs to remain invisible unless attention from the user is needed, ubiquitous or pervasive computing systems require a context-aware perspective [41]. A system is context-aware or sentient, if *"it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task"* [1, 13]. In a broad sense, context is defined as *"any information that can be used to characterize the situation of an entity"* where an entity is *"a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"* [1, 13]. Having systems consider the context of the user, allows them to react more accordingly without requiring explicit input.

The growing amount of data accumulated by sensing technologies in IoT environments, will eventually lead to the generation of *big data* [54]. Without interpretation, analysis and understanding, the mere collection of this data does not hold any value [34]. Additionally, as socialization between IoT objects increases the system's level of complexity, autonomy and dynamic behavior, understanding context will be a core element to support the future of the SIoT. By considering contextual awareness, we are provided with the tools to mitigate the gap of comprehension.

3.3 Challenges of Interaction

As there is a growing interest in autonomous socialization between things, it is necessary to consider the implications these inter-device relationships will have on the interaction with the user.

The first issue lies with the user's awareness of what is happening behind the screens. Without explicitly making this visible to the user, social things will communicate various sensor and actuator values with each other. There arises a clear lack of visibility as these network connections and exchanges of data realized by social things are not transparent by default [31]. Due to the dynamic nature of the constructed network connections, a user is left to wonder what is exactly being transmitted and where it has been, leaving awareness of what is happening behind.

Additionally, data received from sensors and actuators and even other objects are potentially being processed using complex algorithms to make sense of this information [14]. As the user is the one generating the data, she has the right to know the reason and type of processing that is applied by the system [31]. Allowing users to see what a system has learned from their behavioral data, is a cumbersome, be it not impossible, task due to the complexity involved.

As social things will coordinate themselves in order to serve novel services for a particular set of goals, the complexity of the network quickly rises. It will be impossible for users to be aware of the exact role and contribution a specific thing and its sensors contribute to each service. Therefore it will be imperative for each object to convey their role and contributions [15].

Adaptability and scalability can be considered core properties of SIoT networks. This leads to the second issue, found within the control a user will have (or lack) over an autonomous social network. A SIoT application will evolve over time by updating, replacing or integrating new social things within the network and these things will have sensors and actuators that can vary greatly in type, precision and behavior. Finding a balance in notifying the user of events in an active and dynamic environment is essential to maintain a certain level of usability. Providing end-user control will be a critical aspect of future SIoT applications [11].

Lastly, while services and relationships are being established and data is actively being shared throughout the network, a social thing needs to have a notion of trust. As indicated by Atzori et al. [4], trustworthiness management builds the basis of reliability, which is connected to the user's privacy and sense of security within an open system. Notions of centrality and prestige in well-know literature are crucial to social networks for things.

While contextual awareness gains a better understanding, its main contribution provides the basis for autonomous acting based on the inferred context [12]. IoT systems with pervasive sensing technologies collect implicit input from the environment which allows them to build a notion of the user's context [42]. However, as autonomous actions taken by a system usually result from complex reasoning, the system's behavior might be difficult for users to comprehend. Additionally, the interpretation of a sensed context might be prone to errors. This leads to users being unable to notice mistakes made by the system since they expect them to do 'the right thing'.

By summarizing the previous statements, we define the following challenges for interaction:

- Providing the user with an awareness of what is happening in the system;
- Granting insights into who has access to the user's data and how it is being processed;
- Presenting an overview of the growing complexity of the autonomous system;
- Warranting control over the dynamic composition of devices within the system;
- Ensuring a notion of reliability and trust based on credential;
- Safeguarding visibility of the system's perceived context of the user and the environment.

4 Designing Interaction with Social Things

In order to design interaction with social things while taking into account the challenges outlined in the previous section, we firstly consider the role of the human in the SIoT. Building upon this, we address two thought-provoking techniques for the design of interaction that have the user in mind, designing for intelligibility and control and designing the behavior of interactive things.

4.1 The Human and the SIoT

To gain a better understanding of how to design interaction with social things, we first need to address the role of the human in the SIoT. Considering interactions with the IoT, the human fulfills three possible roles [32], as a communication node, as a processing node or as an actuator. In the context of a communication node, the devices carried by humans collect data and interconnect disparate systems and objects. In this way, things are able to take advantage of human mobility to more effectively distribute information throughout the network. Secondly, the decisions made and the tasks executed by the human are the result of how they observe the environment and process the information obtained. These actions make the human a processing node as their behavior influences how the system reacts. Lastly, as an actuator, humans directly interact with physical things in the environment, modifying the world around them.

Supporting user-centered interaction, requires the understanding of human behavior and needs by sensing context. Context-aware computing is an important evolutionary step towards better interaction. In the case of context-aware systems that make autonomous decisions, it would be unrealistic to assume that the sensed context is always in line with the expectations of the user. Failure is inevitable as context is a dynamic construct with many dependent variables and might not even be able to be sensed or even to be inferred [8, 17].

Empowering end-users for the SIoT where social things autonomously socialize begs the question how to approach the design of the interaction. Mobile agents are able to mitigate interaction by acting as mediators between the system and the human [6]. They assist the user by gaining an understanding of the their goals and requirements [40]. However, from a more general perspective, it is important to warrant the user's understanding of the system. Two prominent methods are designing for intelligibility and control and designing the behavior of interactive objects.

4.2 Designing for Intelligibility and Control

As argued by Bellotti and Edwards, the increasing degree of autonomy gained by systems which act on our behalf, especially when doing so in relation to other people,

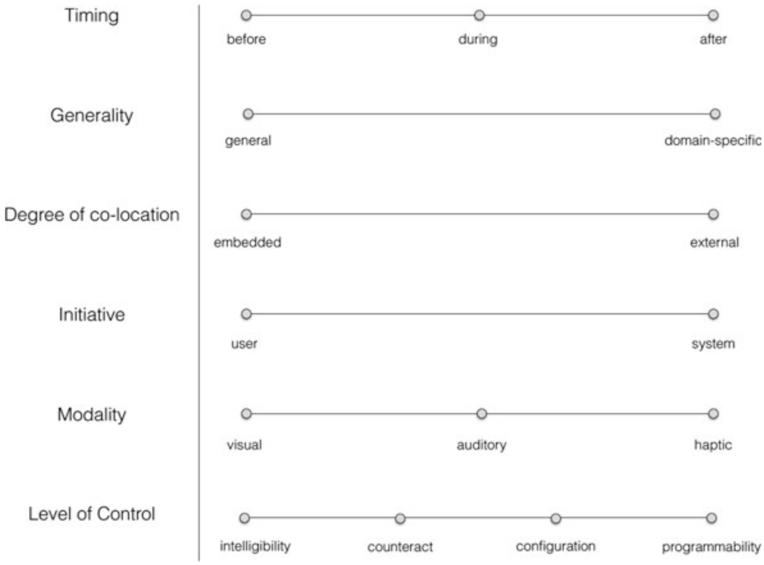

Fig. 3 Design space for intelligibility and control. Image from [46] reused with permission (Copyright 2014 © Jo Vermeulen)

requires us to monitor their every move [8]. This can become a complicated task as the internal process of making complicated decisions might be extremely complex and is not made visible by default. To make this possible, they propose the design principle of *intelligibility*, meaning systems have to inform users about their interpretation and understanding of the user and the environment and provide insights into its functionality. Complementary to *intelligibility*, users should always retain *control* over the system in order to recover from possible mistakes or override inappropriate actions [46].

Design Space

To better understand the possibilities and design opportunities, Vermeulen proposes a design space to support intelligibility and control [46]. This design space serves two purposes. Firstly, it can be used to analyze, compare and relate different existing and future techniques. Secondly, given a specific problem, it can be used to generate and iterate over different design alternatives for supporting intelligibility and control. The design space consists of six dimensions and can be seen in Fig. 3.

Timing During different phases of the interaction, intelligibility and control can be supported. The design space discerns between the moment before, during or after an event takes place. Consider the case of a social thing taking part in a service composition event with another social thing. Depending on the preferences of the user, the timing of the notification for this event would imply different meanings. Coming before the fact, a user is able to prevent unwanted results, while after the fact notifications would be aimed at informing the user of the availability of a novel service. During the fact notifications might communicate live progress.

Generality This dimension indicates if the techniques used, are generally applicable or specific to a certain domain or type of application. Each SIoT environment consists of many different devices which might be configured in their own manner. Providing intelligibility and control can be specific to the properties of the device generating the action or might be generalized by the SIoT environment to become more uniform.

Degree of Co-location The degree of co-location depicts if intelligibility and control are offered embedded within the application or exist externally using a separate interface. Depending on the capabilities of a thing, notifications can be sent using embedded circuits from within every device in the system. Alternatively, things without suitable output can revert to notifications by contacting mobile agents as well as other social things.

Initiative Intelligibility and control can either be offered upon the initiative of the system or by request of the user. Notifying the user of every service discovered, might flood the user with information. In this situation, it might be better for the user to inquire about new services whenever they required.

Modality Depending on the domain, intelligibility can vary in modality, i.e. visually, auditory or haptically. Social things with embedded actuators can notify the user by activating LEDs, using speakers, moving in a distinct pattern or any plausible combination.

Level of Control In this dimension, four increasing levels of control are distinguished. The most basic level of control is defined as *intelligibility*. In this manner, the control users have over the system is based on their understanding of its functionality. *Counteracting* allows for users to undo actions performed by the system, while *configuration* allows users to tweak predefined system parameters. Lastly, the highest level of control is *programmability* which enables users to (re-)define how the system works.

Implementations

The design space for intelligibility and control was used to create the *PervasiveCrystal* system, which allows users to understand the behavior of a pervasive environment by posing *why* and *why not* questions [47]. Using a rule-based behavior model, answers try to explain the causes and consequences of system and user actions. The asking of questions to the system, implements ‘after the fact’ feedback in the *timing* dimension. In contrast to this, the *Feedforward Torch* allows the user to inform about possible events when certain actions are performed, namely by providing *feedforward* information [48]. Note that both systems require *initiative* from the user and do not present information pro-actively.

The *OctoPocus* system guides users while performing gestures during pen-based interaction on a table by visualizing the path the user needs to follow in order to complete the gesture [7]. Extending the interaction to mid-air gestures, the *GestuWan* system provides the user with a hierarchical overview of the gesture to be performed [39]. Similar to the *Feedforward Torch*, both *OctoPocus* and *Gestu-Wan* position themselves within the *intelligible* level of control, while the *PervasiveCrystal* allows for *counteracting* and *configuration*.

Design for SIoT

In the context of SIoT, we address this design space for a dual purpose. Firstly, as intended by Vermeulen [46], developers of social things can utilize the space to analyze, devise and implement different techniques to warrant better awareness and enable richer interaction for the user. Given a specific problem, designers can generate and iterate over design alternatives for supporting intelligibility and control. Secondly, we envision extensions of the design space for empowering end-users of SIoT systems to utilize the dimensions in order to configure the behavior of its environment based on the active relationships between social things. For example, a user set on privacy might configure his social things to provide live embedded notifications before the creation of new relationships, while others might want after the fact notifications in a more general manner such as via email summaries. Using these dimensions to pro-actively configure social things within the environment, the system is able to ensure consistent behavior even while the composition of devices and services remains dynamic.

4.3 Designing for Behavior

The behavior of interactive smart objects is expressed through the autonomous and pro-active decisions they make. As this influences the experience the user has with these objects, designing behavior becomes increasingly important [44]. The field of the Aesthetics of Interaction states that there is a close relationship between efficiency and aesthetics during interaction, as "*attractive things work better*" [30].

Hassenzahl [18] distinguishes between three conceptual levels of the aesthetics of interaction, namely the *What*-, the *How*- and the *Why*-level. The *What*-level includes the functionality offered by a product, i.e. the goals users are able to accomplish through interaction. The *How*-level addresses the manner in which a user is able to accomplish these goals, e.g. by pressing a button or turning a knob. The *Why*-level considers the meaningfulness of using an object, e.g. "*feeling close to a loved one*".

In order to define interaction principles that ensure better aesthetic experiences, connecting the *How*- and the *Why*-levels in an intuitive manner can be done by using an *Interaction Vocabulary* [23]. Previous work has shown that by using this vocabulary, we can consider stereotypical personalities and map them onto the behavior of an object [9, 25, 38, 43, 44]. Norman states that personalities provide humans with a good understanding of behavior and describes them as "*a form of conceptual model, for it channels behavior, beliefs, and intentions into a cohesive, consistent set of behaviors*" [29]. This is closely linked to the field of the Affective Internet of Things, where objects within the IoT gain affective personalities through behavior and enables them to induce attachment [35].

Table 1 Overview of the design process for behavior

Phase	Details
Object improvisation	• Consider objects of interest • Consider physical limitations and possibilities
Personality profile definition	• Start from metaphors or stereotypes • Create personality traits
Interaction improvisation	• Create interaction vocabulary • Improvise and record interactions
Synthesis	• Combine personality traits and interaction improvisation
Behavior implementation & evaluation	• Implement behavior in object • Review if needed

We consider related literature in the field of designing behavior for interactive objects and elaborate on a common design process used by authors. As behavior generates understanding of how objects should behave in interaction and in giving commands, this approach can address interaction challenges related to the user's awareness.

Design Process

While reviewing related literature on designing behavior for interactive objects, we found similar approaches which we combined into a design process consisting of 5 phases, namely *object improvisation*, *personality profile definition*, *interaction improvisation*, *synthesis*, and *behavior implementation & evaluation*. An overview of the phases is shown in Table 1.

Object Improvisation Behavior is highly dependent on the physical limitations of the object in question. Naturally speaking, a device embedded with more advanced output modalities such as displays, speakers or motors, will have a higher level of expression compared to a device with limited capabilities such as having only one LED. During the *object improvisation* phase, the abilities, function, shape & appearance are considered in order to correctly size up the interaction with the device. This phase can either explicitly be explored by observing natural interactions between objects and users, or is regarded as optional when the object of interest is well-known. Examples for this can be found in [44] by Spadafora et al. where authors record the natural interplay between users and a prototype for designers to review. Contrastingly to this, Ross et al. [38] implicitly perform this step as they start from the functionalities of a well-known object, i.e. a lamp.

Personality Profile Definition The notion of personality is essential for the creation of consistent and understandable behavior to facilitate interaction [25]. Therefore, with the outlines for the interaction determined, personality profiles are defined during the *personality profile definition* phase. Recent studies express personality profiles or stereotypes of personalities using the Big-Five personality traits [24]. Currently the

Table 2 Big-Five personality dimensions by [24], contrasted by opposite poles from [44]

Personality dimension	Facets	Opposites
Openness to experience	Imaginative, independent, interested in variety	Practical, conforming, interested in routine
Conscientiousness	Organized, careful, disciplined	disorganized, careless, impulsive
Agreeableness	Softhearted, trusting, helpful	Ruthless, suspicious, uncooperative
Extraversion	Sociable, fun-loving, affectionate	Retiring, somber, reserved
Neuroticism	Calm, secure, self-satisfied	Anxious, insecure, self-pitying

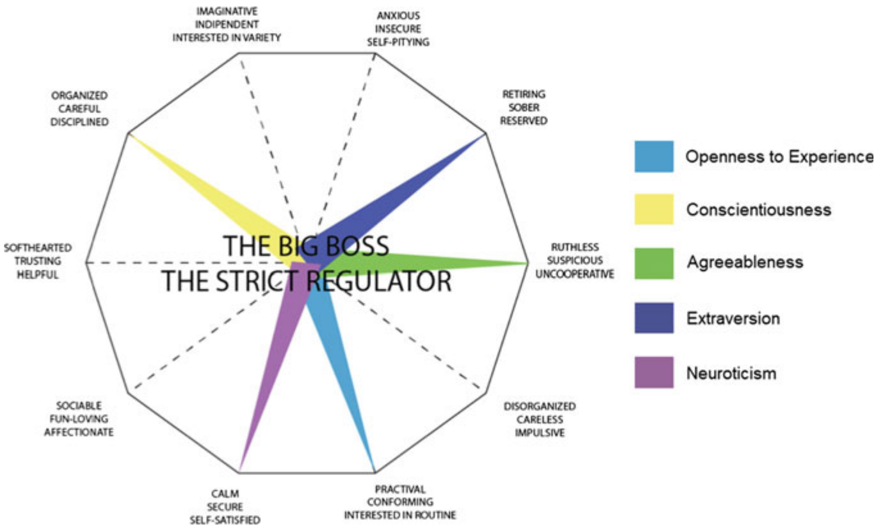

Fig. 4 The *Big Boss* stereotype visualized in the wheel of personality. (From [44] © 2016 Association for Computing Machinery, Inc. Reprinted by permission.)

theory that is supported by most empirical evidence, the Big-Five describes personality in 5 dimensions, i.e. *Openness to Experience*, *Conscientiousness*, *Agreeableness*, *Extraversion*, and *Neuroticism*. Spadafora et al. [44] contrast each trait with its opposite poles, seen in Table 2. The personality stereotypes can be visualized in a wheel of personality to easily identify duplicates, as can be seen in Fig. 4. As a starting point to define personality profiles, literature often refers to stereotypical emotional states from either human behavior [44] or from character behavior from storytelling folklore [9]. In other work, characteristics are created during a brainstorming session with users in regard to the objects of interest [25].

Interaction Improvisation Stereotypical interactions based on the personality traits are improvised, acted out and recorded during this phase, often by professional

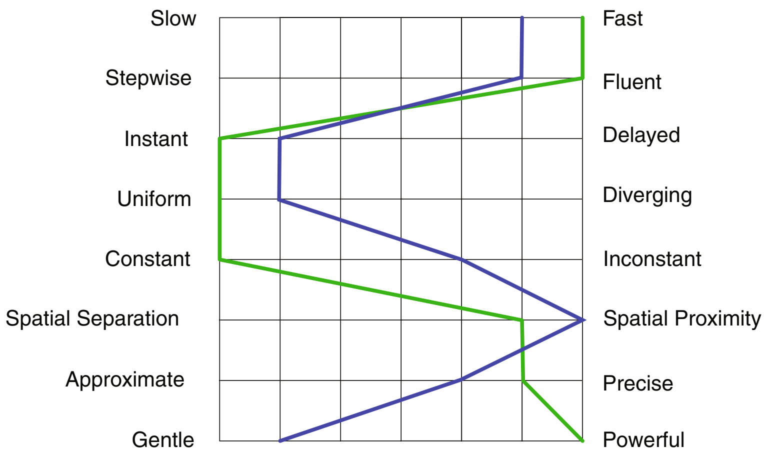

Fig. 5 Interaction profiles for emotional states *Happy* (blue line) and *Brave* (green line) plotted in the Interaction Vocabulary

dancers or actors. When regarding interaction related to tangible objects using physical interaction attributes, interaction profiles can be defined using the *Interaction Vocabulary* [23]. In the Aesthetics of Interaction, this vocabulary helps to address the *How*-level of interaction through a set of eleven dimensions of descriptive, non-judgmental, non-technology bound attributes of interaction. An example of this can be seen in Fig. 5.

Synthesis The personalities generated during the *Personality Profile Definition* are in this phase combined with the results from the *Interaction Improvisation*. This output serves as the material for generating exact behavior.

Behavior Implementation and Evaluation Using the combined results from the *Synthesis*, the exact behavior of every personality can be mapped to the specifics of every device. As the mapping from the results of the *Synthesis* to the device intrinsics could lead to inconsistencies due to a loss in resolution, it is important that the resulting behavior is accurately reviewed.

Implementations

Authors in [44] present *Personalities*, a process showcased by defining the behavior of a social Sofabot which interacts with users in its environment. The defined behaviors are tested in a user study using a Wizard of Oz approach to exact the interactions. A similar approach was taken in [43] in order to investigate the social behavior models of a robotic trash barrel. The aim was to study the recognition of the varying stereotypes of behavior of the robot and compare how personality influences social status.

Ross et al. [38] focus on the Aesthetics of Interaction to utilize the design for interaction in creating various prototypes of lamps. As a result, their experiential prototypes showcase behavior in interaction through abstract expression by dancers.

In order to define personalities in domestic robots, Meerbeeck et al. [25] concentrate on improvisation to support an iterative design process for behavior. Their expressions were visualized using a 3D animation approach, which served a think-out-loud evaluation by users.

Aiming at emotion encoding in drone interaction, authors in [9] start from anthropomorphized emotional states using folklore to create personality in the flight pattern of a drone. User feedback concluded that the behavior in a drone's flight pattern was easily recognized.

Design for SIoT

Although authors in [33] did not approach personalities from a design perspective, their autonomous socialization using *mascots* and benches implemented static behavior based on inter-device proximity. When considering the design process in the context of autonomous socializing things within a SIoT environment, bringing personality to the behavior of social things has the power to positively influence the interaction between the user and its environment. If we consider behavior as an indicator for intentional actions, an in-depth study could analyze how autonomous behavior can be predicted using to personality. A user being able to configure a personality on its SIoT environment and the social things within, will gain awareness of future events, making the system more intelligible.

5 Discussion

Social things autonomously establish relationships, provide services and compose novel interfaces inside the SIoT environment. While benefiting network navigability and service discovery, the increase in complexity does not have the user in mind. While SIoT systems can greatly improve by taking the user's context into account, the perception of the context remains fallible or might not even be possible. Therefore, we must warrant the user's awareness by explicitly visualizing what the system thinks and how it has come to this understanding.

By designing for intelligibility and control, developers of social things can utilize the space to analyze, devise and implement different techniques to warrant better awareness and enable richer interaction for the user. Given a specific problem, designers can generate and iterate over design alternatives for supporting intelligibility and control. We envision extensions of the design space for empowering end-users of SIoT systems to utilize the dimensions in order to configure the behavior of its environment based on the active relationships between social things. For example, a user set on privacy might configure his social things to provide live embedded notifications before the creation of new relationships, while others might want after the fact notifications in a more general manner such as via email summaries. Using these dimensions to pro-actively configure social things within the environment, the system is able to ensure consistent behavior even while the composition of devices and services remains dynamic.

When considering the design process in the context of autonomous socializing things within a SIoT environment, bringing personality to the behavior of social things has the power to positively influence the interaction between the user and its environment. If we consider behavior as an indicator for intentional actions, an in-depth study could analyze how autonomous behavior can be predicted using personalities. A user being able to configure a personality on its SIoT environment and the social things within, will gain awareness of future events, making the system more intelligible.

6 Conclusion

In the Social Internet of Things (SIoT), social networking paradigms are considered for the Internet of Things (IoT). Things are able to benefit from social capital through autonomously creating relationships between each other and building novel services through service composition. The dynamic aspect of socialization aims to improve network navigability and service availability, while ensuring scalability. However, the addition in complexity comes at the cost of the user's awareness. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. Therefore it is important to investigate techniques that could mitigate the gap between the system's understanding of the context and the user's mental model.

In this chapter, we started by providing an overview of the SIoT by looking at the motivation for supporting socialization, the history of social things, system architecture and basic relationships for things. To determine and understand the interaction challenges that arise, we framed interaction in the world and the need for contextual awareness and considered the role of the human in the SIoT. Building on this, we have regarded existing techniques that aim to provide richer interaction and better awareness to the user by investigating the design for intelligibility and control and the design for behavior of interactive objects. Although further research is needed to extend these techniques, both considering intelligibility or defining personalities show great potential in aiding the user to gain a better awareness of a social system's functionality.

Acknowledgements This work is part of the DISTRO project which is funded from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 642841. http://www.distro-itn.eu/.

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Designing Places for Reflection

An Examination of Social IoT as a Relational Approach in Designing Spaces for Reflective Thinking

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Abstract Sherry Turkle points out in her book, *Evocative Objects*, that we often consider objects as useful or aesthetic, but rarely count them as our companions or as provocations to our thoughts (2007). Indeed, according to distributed cognition theory, our cognitive activities are considerably influenced by and also a product of our interactions with external stimuli, such as everyday objects. Within this vast category of external stimuli, we can also include our indoor places: the architectural three-dimensional space, where we spend a large part of our days, doing various activities, using numerous objects, and interacting with people. With the advent of "smarter" homes and the Internet of Things (IoT), *space* becomes a crucial factor that, together with all other objects, influence peoples' thinking. We are particularly interested in the kind of thinking that can be labeled as "reflective thinking" as a conceptual way of thinking that enables the re-consideration of experiences and actions. Reflective thinking also as a distributed cognitive process depends not only to the individual mental process, but also it is closely related to the external stimuli (e.g. Hutchins, Cognition in the wild. MIT Press, 1995, [1], Dewey, How we think: A restatement of the relation of reflective thinking to the educative process. D.C. Heath & Co Publishers, USA, 1933, [2]). In this book chapter, we present a relational approach to the design of such places considering the *social* IoT (SIoT) as a technical enabler. We do this by specifically focusing on "reflective thinking" and how it is situated in relation to computer-enhanced and smart places. We will describe how reflective thinking is related to people's activities and smart objects within that place. Further, we provide models intended to clarify the relationships between the external factors that influence reflective thinking in a space, and how those relationships make a space a Place (Cresswell, International encyclopedia of human geography, 8, 169–177. Elsevier, Oxford, 2009, [3]). Finally, we provide an example in the form

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_6

of a narrative, to show how might an SIoT-enabled place look like in prototyping lab of a design school as a very specific place. In short, the aim of our work as presented in this chapter is to spark a conversation and discussion about how HCI/Interaction Design can engage in designing of places that supports reflection using Social IoT. In doing so, we suggest that a central dimension in design of such places should be based on the study of *relationships* among involved components: people, their activities, and objects. We also suggest, as a theoretical contribution, that Social IoT is not only a technical platform, but rather should be understood as a relational technology that enables new kinds of places for reflection.

1 Introduction

The diffusion of Internet connectivity across devices and social networks brought new possibilities of designing smart, and connected objects and places, it has also brought new challenges to the design community. This new category of devices (commonly also called IoT devices, [4]) 'forces' designers to not only think about the design of functionalities, experiences and ease of usage, but also to think about the network and social interactions of these computational and smart artifacts as a whole ([5, 6, 7]).

Furthermore, the continuous development of social media platforms, in combination with the growing interest in the Internet of Things (IoT) suggest a technological development towards a Social Internet of Things (SIoT), wherein, smart and connected devices can participate in their own social network, and wherein the IoT devices can have their own social connections [7, 8]. For this development, we see an opportunity to develop an understanding for how such networks do and can support user's thoughts and reflection.

Our thinking is influenced to a large extent by our interactions with objects and things. Further on, the things we are surrounded with, are increasingly computational, smart, networked and interconnected. Accordingly, our "thinking" is increasingly influenced by interactions with such computing and interactive objects and spaces, as well as with the people we are connected to [9]. Therefore, our thoughts and reflections are increasingly part of larger interconnected systems—appropriately referred to as the Social Internet of Things (SIoT) (e.g. [7]).

In Human-Computer Interaction (HCI) research, "reflection" often refers to the action of thinking about the information provided by computing artifacts to be informed about an action or behavior and take course of actions to modify or change it in the future [10]. Social interactions play a relevant role, since they create that possibility of talking with other people about experience. Talking with other people about experiences, help to recall memories and reflecting not only about the action, but also about the objects and places, where the action has taken place [11].

But how can places serve as scaffolds for thinking? And how do we design with the Social Internet of Things as an enabler of places for reflection? And how do places stand in relation to us, to our activities and to our everyday objects in these networks of things? For sure, the Internet of Things (IoT) comes with the promise of a nearby future filled with networked smart objects and environments. But how can we align one such technology-driven agenda with a vision of how smart objects can not only bring computation to the environments they are part to, but also be designed in relation to the places that constitute our everyday environment, and to our everyday reflective thinking?

Designing for reflective thinking, is complex, mostly because, reflection as a distributed cognitive activity is in relationships with many external things such as our everyday objects, spaces, people and it is also interrelated with our daily activities.

Here the theory of distributed cognition provides us with some theoretical ground as it deals with the *relationships* between humans, objects and places, in cognitive activities [12, 13]. This framework extends the boundary of cognition beyond the individual brain and mind (in specific terms—distributed problem solving with the use of objects) and it enables us to address questions related to how we think together, and the role of objects in reflective processes. Hence, distributed cognition framework, can guide us to develop a relational approach for designing places for reflection.

Having introduced our main notion and its theoretical grounding we then provide a couple of models and figures that we have developed to illustrate and clarify the relations among thinking and the external factors that influence them. We conclude this chapter discussing about examination of SIoT as a relational approach for designing places for reflective thinking, by providing an example of a specific SIoT-enabled place for reflection, the prototyping laboratory of a design school.

2 Reflective Thinking and Distributed Cognition

The theory of distributed cognition—like any other theory of cognition—seeks to describe how cognitive processes work. However, unlike other traditional cognitive theories, it considers cognitive process as a series of interactions between the individual, other people, objects and the environments in which the cognitive process takes place. It can also be applied to reflective thinking as a cognitive process, which is not only individual, but also collective and distributed. Reflection depends on many external factors such as people acting as mentors, social interaction, objects that hold memories and emotions, environments which are stimulating for reflection and so on. Reflective reasoning is a deep, slow and effortful process and it requires moments of quiet, but also the aid of external support, such as writing, computing tools, books and the aid of other people. Unlike the experiential thinking, reflective thinking is not autonomous or reactive, it is about concepts, reconsideration, planning and decision making [2]. It is not about the elaboration of the information structure already existed in our brain.

Further, as we have described above, in HCI research, “reflection” refers to the action of thinking about the information provided by computing devices, in order to capture awareness about an action. As Hollan et al. highlight, distributed cognition is built up of a system of functional *relationships* among its elements and mechanisms. It is a system that dynamically configures itself, in order to co-ordinate the elements to achieve a functional goal.

One of the crucial factors that influences human cognition in Distributed Cognition, is the external physical structure or the material world. Such structures, in distributed cognition theory are called *boundaries of the unit of analysis* for cognition and are the natural or artificial spaces, which also contain objects and people [11, pp. 175, 14, pp. 31]. In the theory of Embodied Cognition, also the important relationship between mind's internal processes and external material structures has been emphasized (e.g. [15]).

Accordingly, the value of a good design emerges, as long as places and the objects within, are part of our cognitive processes, so a well-designed built environment, can improve, influence or change our way of thinking [11].

3 Designing Places for Reflection

The emergence of personal computers brought computers to the new environments such as the home environment and it defined new usages for information technologies (e.g. [16]). This was early on envisioned by Mark Weiser at Xerox Parc, who also introduced the idea of Ubiquitous Computing [17]. Since then many researchers have adopted his vision for designing new computer-enhanced and interactive artifacts and environments (e.g. [8]). Consequently, designers have explored design of simple, intuitive and calm interactions with such computational artifacts [18].

The interest in applying traditional architectural studies in designing computer enhanced spaces or so called smart spaces (e.g. Smart Home) is increasing. It has been suggested to use interaction design and user experiences design methods, but explore interactivity at the scale of architecture (e.g. [8, 19–21]). It helps to design user experience in a built environment as a whole, going beyond of utilitarian views, by understanding the relationship between interactive objects, users, built environment and user activities. The idea of considering the architectural settings as an active participant in the interaction is not new. Either in the HCI and architectural design researches, the understanding of interrelation and interaction between users, the built space and the pattern of activities, has been long the subject of study (e.g. [8, 22, 23]).

Further on, ways of articulating the relation between people acting in a particular space with the use of smart and wearable objects and how such objects and tools enable us to take action in the world has been extensively explored from the viewpoint of Embodied Interaction [24]. Embodied interaction is the phenomenological study of such interactions. It views tangibility as a key mean of interaction, but it takes a broader stance by envisioning meaningful interaction with technology inspired not only by physical objects but also social and spatial phenomena of everyday life. It examines engaging human body and social context with materials of digital artifacts (e.g. [4, 24, 25]).

As it has also been described in the previous section, a distributed cognitive process can be defined as a system of functional relationships among the elements that participate in it [11]. The elements are for instance, user, user's activity, other people, objects and also the architectural tridimensional space. The particular interactions among these elements, give meaning to an architectural space, which has been also the subject of many studies. For instance, the emphasizing role of the "place" over "space"—e.g. "home" over "house"—and the way an architectural space can become meaningful, personal and characterized through its objects, people, activities, memories and etc. that inhabit within (e.g. [26]). In addition, "Place", in humanist geographical studies is a location with a set of meanings and attachments, it is where we can find a combination of materiality, meanings and practices [2, 27]. Place has been seen also as a "process", where it is produced through actions and iterations, through material continuity of people and objects that participate in time-space practices of the locale [28, pp. 280].

Therefore, we suggest to shift the focus from the notion of "space" towards the notion of "place" for designing smart and computational built environments for reflection. This is relevant, considering that (1) Places, similar to objects, can evoke thoughts in user, because they hold memories and cultural expectations and meanings, they structure people's behaviors and enable certain activities, using related objects; (2) Social Internet of Things (SIoT) as a technical enabler can augment this property of places.

3.1 Places and Situated Reflections

Reflection recalls memories, actions and experiences and supports people to understand and frame a situation ([29, 2, 30]). Reflection demands continuity, which is a process of making sense of one experience, based on the meaning derived from past experiences [2]. It helps to guide people to understand a situation deeply, in order to take careful and informed courses of actions for change. Nevertheless, a technologically enhanced place, in order to be of support for reflection, needs to help inhabitants to build a longish and constant process of engagement within it. To this aim a place should create slow and thoughtful interactions with user instead of merely and passively representing the information [31].

On the other hand, people usually use and interact with objects in order to do a task. Also, according to the Activity Theory, which is a well-grounded theory in HCI and Interaction Design arena, the user forms an activity-oriented relation with the artefact ([32–34]). Activity in this framework, is a purposeful action that is directed to accomplish a specific user's goal or need through using computers or interacting with computing objects. Places play also crucial roles in this activity-oriented relation with objects. The place where an activity is usually being carried out is the built environment where we design also for reflection on such activity.

As Suchman puts, all human actions are situated—actions depend on the circumstances and the context of the activity. For *Situated Actions* she referrers to that interrelationships between actors, activity and the context [35].

Putting this in a simple way: For instance, if we consider designing for reflection on prototyping as an activity, then the place is the laboratory. What makes a laboratory a place are the situated activities and materials that can be found only there. For instance, cutting materials in this context, is situated in laboratory, because it is usually being carried out in a laboratory, which is a built environment with its specific materials, tools, appliances and etc.

Referring again to the distributed cognition theory, we are *spatially located creatures*. We must use directions, reconfigure objects according to the space in order to enhance our performance. The way we manage our spaces are also part of our way of thinking [14]. Further the environments in which people are culturally embedded, provide the space and resources for learning, thinking and problem solving [1, 11, 14].

3.2 Interactive Artifacts and Reflection

What we mean by an Interactive Artifact, is a physical, computational and human-made thing, that is involved in an interaction process—*action and influence*—with humans and other things. Sherry Turkle defines an interactive artifact as such that reacts immediately to each action performed by human [36] and as Suchman describes we view artifacts as interactive because of their linguistic and reactive properties [35]. Further she defines an interactive artifact as a social object:

> The greater reactivity of current computers, combined with the fact that, like any machine, the computer's reactions are not random but by design, suggest the character of the computer as a purposeful and, by association, as a social object. [35, pp. 38]

There are a large number of projects that demonstrate how tangible and Smart Objects can be designed to support user's activities in everyday life—stretching from simple functional tools to social, networked and connected objects that can support reflections and capture awareness about a behavior ([4, 25, 37, 38] (e.g. ambient devices such as Home Joule).

Given that, we suggest, that if we are increasingly surrounded by interactive and smart objects in our built spaces, and if those artifacts are not only functional tools, but also objects that influences our thinking and behaviors, then why do not we take on one such approach to the design and development of Social IoT system? If we really are going in the direction of "smart objects" we suggest that we can find a solid ground here for thinking about a design space for SIoT systems that do not only focuses on the design of smart objects, but rather on the relations between people, objects, activities and places (Fig. 1).

With this as our point of departure we would now like to illustrate the relations and then focus on one central element at a time. In doing so we would like to suggest to start from places, as they are physical surroundings that people, their

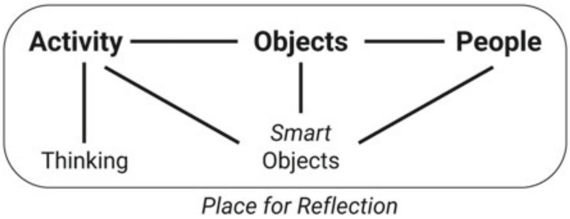

Fig. 1 Elements of a place for reflective thinking. "Thinking" in this model is considered as an activity that can be supported by using objects, in particular smart objects that people use

activities and objects are usually situated within it. They prescribe to contain specific types of objects and specific types of social interactions according to their functions. Accordingly, there are activities that belong to that specific space—i.e. kitchen, pans, family members, cooking. With this in place we will then illustrate other elements and relations around it.

So, if materials and objects are part of our cognitive processes, then well-designed things and places can influence and enhance our way of thinking [11] so a good design approach to reflection using SIoT systems as technical enabler is needed. As an attempt to address this need in the following sections we will suggest to use SIoT as a relational approach in designing places for reflection.

4 Social Internet of Things as a Relational Approach

The Social Internet of Things (SIoT) is a concept that combines social networking with physical computing in the IoT or smart devices [8]. So, if we consider to use this technology –SIoT– for supporting people's reflective thinking, we need to take into account two main principles. Smart objects and IoT device (1) are able to socialize with each other and with built spaces to create their own social network for dialogue and exchanging information; (2) they can also help users to connect to each other, so they mediate the communication between users [9]. These two principles resonate well with two important drivers of reflective thinking, which are first, having *interactions with objects* that are meaningful in a situation and that can recall memories and experiences [16]. This can be more effective, if the objects of the same experience, memory and activity are connected and can provide feedback not only to the user but also to each other. The second important driver of reflection is having conversation and the possibility *to talk about experiences with other people*. This driver of reflective thinking is also supported and augmented in SIoT, simply because people can talk and dialogue to each other through smart objects and social networks.

Considering SIoT, as a technical enabler of the two drivers of reflection, we have explored the properties that make a built space, a "place" for reflection. In this regard, we draw on relationships that a built space creates with other components within it, namely (1) objects, (2) user activities and (3) people. Furthermore, to frame the built space as a "place", we consider it as a product of the relationship it has with other components (Fig. 2). So, we analyze them as: (1) *Place of the Activity*, whereas

Fig. 2 Relations between a "place" and other components within it. (An architectural space definition and meanings are closely related to the activities that take place in that built environment (left), if in it we can find the objects, which support the activities we need to carry out (centre), and when it has been configured and shaped according to one person's daily activities, things, and thoughts (right))

we model the relationship between a built space and the specific activities carried out within; (2) *Place of the Object*, whereas we model the relationship between a built space and the objects specifically used within and (3) *Place of the People*, for modelling the relationship between a built environment and people whom the place belong to. Although we analyze these relationships one by one, they are dynamic and each relationship is constructed through relationships with other elements. We suggest that there is an opportunity for designing for reflection considering these dynamic relationships and interrelations (Fig. 2).

4.1 Place of the Activity

In any given built space, people are usually engaged in many different daily activities. Most of these activities are often associated with and belong to that particular architectural and spatial setting. The activity brings particular meanings, cultural expectations and definitions for the built environment, so the relationship between activities and a built space, creates a "place" of that activity. For example, a "laboratory" in a design school is an architectural space, where students, are engaged with making and learning as two main activities. The main activity of students in a lab is related to many other subordinated activities, such as measuring, cutting, gluing, testing, reading, writing, participating in discussions and etc. So, the system of these activities in their interdependency, give specific meanings and expectations to a built environment that we call it a "laboratory".

Thus, an architectural space definition and meanings are closely related to the activities that take place in that built environment.

4.2 *Place of the Object*

People carry out different activities using appropriate objects, which are generally presented in a specific built space. Using the same example as we used above, in a "laboratory" of a design school for instance, we find cutters, screwdrivers, band saws, tables, etc., which are used for prototyping and can be found usually in a laboratory. Their presence in a built space, gives meaning and create expectations for that place.

Then we can for instance categorizing these objects according to the main or subordinate activities. For example, for the activity of cutting we use, cutters or band saws in a "laboratory". So, a built environment can be defined as a "laboratory" if in it we can find the objects, which support the activities we need to carry out in a "laboratory". In this situation, a built space becomes a place, conforming to the particular objects within it.

4.3 *Place of the People*

Place has been defined as a dynamic space, which is constantly turning into a human product [2]. In this regard, a home is for instance a place, because belongs to specific people and it contains and is being created by emotions, memories and experiences. A home in contrast to a house, which works only as a built space for dwelling. But how about subordinate and smaller areas within home environment –e.g. bedroom, kitchen, etc.? can they also be considered places, with a lower and more personalized layer of cultural and behavioral expectations? As an attempt to consider this opportunity as another level of place-ness we call it *Places of People*, as they belong to a specific individual even though is located within a bigger place. For doing so, we use the same example as we used for describing other relationships with place, the "laboratory".

In a place like a "laboratory" of a design school, there exist other smaller places or so-called corners. Those smaller and subordinated places, belong to a specific person, or to a specific group of people for social interaction. They are not physically divided from the rest of the space, they are fluid and flexible in size as they can change form and spatial configurations. For instance, when students call a specific place in "laboratory", "her/his place", this actually means that place is defined and it has been configured and shaped according to her/his daily activities, things, and thoughts. We often spend our times and do our daily activities, within those personal places, even though we are often located in bigger and social places such as a "laboratory". One of the characteristics of these places is that when other people interact with it, they may not fully recognize its whole structure, meanings and configurations. As the opposite of a social places in the same location, which structures and the configurations do not belong to a specific person.

5 Discussions

In this chapter, we have used the example of a "laboratory" in a design school to illustrate our relational approach that we proposed for designing places that support reflective thinking. We have discussed the relationships between this place, its objects and tools (e.g. cutters, rulers, papers, pens, etc.), activities (e.g. measuring, cutting, etc.) and people. We argue that all these relationships have to be considered when designing places that support reflective thinking as enabling relationships. For sure, there can also be reflective thinking about something outside of a place (e.g. to think about a place, but not physically being there, as a source of inspiration), and we can do logical problem solving mentally, without using pen and paper. However, being in a particular place, using particular objects, might spark creative thinking, and might be helpful for complex reflective and critical thinking, especially in educational context. Furthermore, we should also acknowledge the additional enabling dimensions that the SIoT adds to this spectrum of thinking with objects. Networked computational objects can do things for us, connect us to other people and places, and transmit data from our local setting, and our current activities to remote places, persons, representations and algorithms.

As these new forms of objects in SIoT enable new connections and relationships we need a *relational approach* to interaction design and in particular to the design for the SIoT [39]. To address such design concerns, we need approaches that acknowledge the relational aspects. This paper is an attempt and suggests one such approach for designing places that stimulate reflective and critical thinking.

So, here we refer again to the example of laboratory as a place for reflection that we provided in this book chapter, how can one such "laboratory" or corner in a design school be re-imagined as an SIoT place? As a future scenario we speculative a little bit from the perspective of how the things, people and their activities might be connected to each-other and how will this evoke reflective thinking and improve the quality of prototyping and prototypes of design students. From the viewpoint of a SIoT one such space can for sure be enhanced with built-in sensors and data sharing, for instance through near field communication technologies and internet connectivity as to support communication, collaboration and information exchange—through computers and through smart internet connected objects.

For the design "laboratory", we can imagine a place augmented with computing and data, where things, the laboratory and the students are in a meaningful relationship to each other, thanks to the internet connectivity that SIoT technologies provide. Here we consider corners, these smaller places that serve as gathering points for teamwork of a specific group of people or for individuals, as the "hubs" of these relationships. There are usually plenty of those fluid places in a laboratory inhabited by students, their prototype projects, materials and tools. In these "hubs", design students need to communicate with each other, in order to exchange their experiences and comment on or critique each other's prototypes. Here the "hub" itself can offer this opportunity. It can become itself a piece of technology, as smart mobile unit of space, equipped with sensors, actuators, microphone, photo camera and video

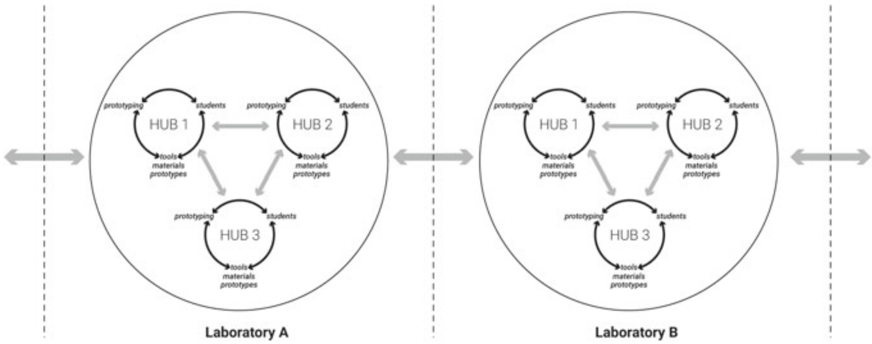

Fig. 3 A scheme of relationships between hubs and laboratories

projectors, that can move freely in the space, meet other "hubs", observe, think and talk.

Furthermore, students might need to communicate with materials, whereas the material itself can provide information to the students about suitable and possible applications considering the prototyping activity. Communication with laboratory "tools" is also needed in order to ask these augmented tools about how to use them, concerning both safety issues and craft techniques. These SIoT tools might also store information regarding all the aspects of prototyping process, time, using various techniques for different materials, creating variegated forms and assemblages. And finally, these "hubs" can communicate with other "hubs" in other laboratories in other universities in other places (Fig. 3). As this network of connections grows into larger structures it might also offer a better service to students, who will benefit from experiences of other students and share their own. This information can be provided to students in a real-time fashion, so enabling collective reflections in action.

6 Conclusion

In this chapter, we have explored the relationships between places, people, activities and objects as a way to create a better understanding for designing places that support reflective thinking. We have done this using the notion of the "Social Internet of Things" (SIoT). As a complement to the SIoT agenda, we have in this chapter suggested that there is a need to explore the relationships between objects, places, user and user activity in order to design supportive places for reflection. We have grounded this position in established theories of activity theory, distributed cognition and situated actions.

We suggest that our work can contribute to the design of better places for reflection by considering reflection as a key concept in design outcome [40]. In addressing this aim we have proposed an approach for design of computing places for reflection that considers the *relationships* among elements in a place where objects and people are interconnected in SIoT systems.

To conclude, this chapter we suggested that a central dimension in design of places for reflection is the study and implementation of *relationships* among the components within it: people, their activities, and objects. We also suggested that a central theoretical contribution from our work is to further develop the notion of the social IoT not only as a technical platform, but also as a relational concern that enables new places for reflections. Finally, we provided an example of such a place, applying to a laboratory space in a design school as an educational context, and we sought to see how this might look like if it becomes a place for reflection considering our *relational approach*.

A Social Internet of Things (SIoT) is about the things we bring into relations—with other things and other people. Computing can enable or restrict these relations, so the design challenge is to see how this web of people and things can be designed as to make the transition from designing things, to making places for not only connections, but also for shared reflections.

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Part III
Social IoT Applications

Sensing Home: Participatory Exploration of Smart Sensors in the Home

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Abstract More and more things in the home are sensor equipped and connected to an all encompassing Internet of Things (IoT). These »smart« things may offer novel ways to interact but also raise questions around their social implications. While participatory research on IoT for the smart city has shown that technically functioning IoT toolkits are valuable research tools, surprisingly few such toolkits exist for participatory research on the smart home. Thus, we have developed the toolkit »Sensing Home« to involve people into designing and understanding use and context of IoT in the home. We will report on the design, development, and subsequent field studies of Sensing Home. Three use cases will be presented, to discuss how Sensing Home enabled several modes of participatory exploration. The first use case reports on people developing custom sensor applications within their homes. The second use case describes how students appropriated Sensing Home for empirical in-the-wild studies of smart sensing in the home. For the third use case, Sensing Home was deployed in households to explore and to make sense of collected sensor data together with inhabitants.

Keywords Internet of things · IoT · Smart home · Networked sensing systems
Sensor data · Personal data · Privacy · In-the-wild · User study

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_7

1 Introduction

The Internet of Things (IoT) has arrived in the home. More and more everyday objects are sensor equipped and connected to the Internet at large. These smart devices are meant to offer novel interactions and possibilities in the home, e.g. more comfort, more security, more safety, or more efficiency. For example, the market for the »smart home« proposes a plethora of seemingly smart thermostats, door locks, or other remote assistants. Still, sensors are getting smaller and less expensive and are increasingly used to make the most mundane objects such as trash cans »smart«. Energy-efficient, networked sensors with a size of a few cm^3 are already in development since some time [1], making the vision of microscopic small, cheap, and ubiquitous sensors that resemble »smart dust« [2] not a distant utopia. It comes to no surprise that HCI and design research on IoT for the home has seen an upturn in recent years. There is, for example a flourishing discourse around aspects of user integration and improved usability of smart home products [3]. With the wave of mass market IoT products ahead, HCI and design scholars are seeking to understand the social implications of IoT in the home and to develop frameworks to value privacy, data security, trust, and agency in such socio-technical systems [4].

While participatory design has a proven record of contributing to understanding use and context of future interactive systems together with potential users, comparably little is collectively known about how to involve people into *actively* designing IoT for the smart home. Still, HCI and design research explore a variety of novel ways to involve potential users in designing and understanding IoT in the context of the home. A number of analogue design card games exist to foster ideation and scenario building for IoT in the smart home [5, 6]. Also, digital tools to quickly prototype smart things and services for the home certainly exist: Yet, they either require smart home products to begin with. For example, the popular IFTTT platform allows to automate sequences of triggers and connected functions [7]. Yet, most of these tools only allow to prototype technological breadboard constructions without much possibility to actually test them in the home together with users.

This comes as a surprise, because IoT technology bears the potential to manufacture small, cheap, and ubiquitous sensor and actuator tools with relatively ease. Research on IoT for the smart city has shown that IoT toolkits are valuable research tools, not least because they are technically functioning and thus can be used to investigate use and context together with participants. Such research devices usually consist of simple sensors that are wirelessly connected, some form of local or cloud computing and displays or actuators as output device [8, 9]. We will review related work in Sect. 2.

As we have been dissatisfied with the scope and functionality of toolkits for participatory research in the smart home, we developed a toolkit to involve people into designing and understanding use and context of IoT in the home. We call this combination of an explorative device and methods of user involvement »Sensing Home«. The main goal of the toolkit is to work »out of the box«. We wanted it to run on simple sensors that resemble the principle of the IoT paradigm of »small, cheap, everywhere« at its core. We rely on the TI SensorTag, which we heavily modified both in firmware and exterior. The toolkit is also ready to use, as it contains a tablet computer for providing visualizations of sensor data, internet connectivity out-of-the-box and computing on our own hardware. The design rationale and technology of this toolkit will be described in Sect. 3. The toolkit allowed us to engage people in a range of participatory workshops and studies. The several modes of participatory exploration enabled by »Sensing Home« will be illustrated by three use cases, which we present in Sect. 4. The first use case reports how people used our toolkit to explore usage scenarios and to develop custom sensor applications within their homes. The second use case describes an interdisciplinary class, where students appropriated Sensing Home to develop and conduct empirical in-the-wild studies of smart sensing in the home. In the third use case our Toolkit was deployed in households to explore and to make sense of collected sensor data together with inhabitants. With a subsequent reflection in Sect. 5 on using Sensing Home we draw out themes for improving such toolkits as research artifacts and methods for future studies on the IoT in the smart home.

2 Related Work

The IoT for the home is a particularly challenging topic for design. It combines the tangible materiality of the home with the intangible materiality of data, services and networks. Also, the home is a particular sensible private area, which is loaded with personal meanings and values. As we see new forms of interaction emerging between these (im-)material configurations, questions around configurations of future use and context arise. Because of this, the design space of IoT in the home may be best explored in close participation with those affected by it [10]. HCI and design research have thus proposed plentiful design research artifacts and methods to involve people into exploring the design space of IoT in the home. These research artifacts and methods include analogue design card games, digital prototyping platforms and working prototypes deployed and evaluated in context.

Analog IoT cards are a common research device to quickly ideate and prototype design scenarios. Clustered in categories and equipped with simple rules, such cards have a proven record in nourishing creativity in participants [11]. KnowCards are a prime example of such design cards for the IoT. They present the technological elements of IoT products in four categories (power, connection, sensors and actuators) which then can be expanded with sets of actors and interactions. Thus, knowCards can support ideation for multisensory interactions and environments [5]. Another example, Tiles Cards consist of »primitive cards« for the basic concepts of inputs and outputs, and »game cards« that define the dynamic and rules how to use the »primitive cards« [6]. The advantage of these analog design cards is that they do not bind the imagination of designers, because they abstract complicated technological components like sensors or actuators and other properties like places, things, situations or dynamics to simple cards. However, these cards do not enforce rules nor point out invalid combinations. Thus, physically impossible combinations may go unnoticed. This calls for high abstraction abilities and background knowledge from involved participants. Lastly, they are by their nature non-functional and require subsequent prototyping. **Digital IoT tools** provide actual functionality and allow users to experience how sensors and actuators behave. By this, they require much less abstraction abilities. The »littleBits« tool is a good example of such a kit. It consists of electronic functional components for power, sensors, outputs and additional connectors [12]. These components can be easily combined by a magnetic connection system and allow a relatively easy way to design working IoT prototypes. A plethora of similar tools exist. ConnectUs [13], WoTKit [14], or Cube-in [15] are designed to teach connecting and programing sensor and actuator combinations. While these tools teach creative and functional combination of input and output they either need some technical or programming skills or come—in the case of littleBits—with predefined and thus limited functionality.

The abundance of ideation tools for the IoT in the home may be one of the reasons, why even the most mundane thing in the home—like a trashcan—has been smartified [16]. In contrast to this, the lack of toolkits for participatory design work together with people is rather surprising. Especially, because a lot of such sensor toolkits exist for participatory exploration, appropriation, and evaluation of sensor data in the smart city. **Sensor toolkits for the smart city** provide the means for citizens to explore their urban surroundings with the help of IoT sensors. For example, Smart Citizen Kit [8] enables users to collect data and to measure, understand, and compare sensory qualities of their city. It consists of sensors to measure air composition, temperature, humidity, light, and sound, as well as data-processing, data-transfer, and battery. Users can place it within the city to explore issues like sound pollution or air quality. Data from all users is accrued and displayed together with its anonymized on a website. As such, users can connect and reflect on such issues. Another toolkit for the smart city is the Air Quality Egg. It also contains sensors to measure the air quality and to display accrued data on a website [9]. These sensor toolkits for the smart city tend to focus on critical issues by combining the data from a large number of sensors to a given context like air quality. Yet, they also provide the freedom to explore several more issues in combining both data from the included sensors and from those sensors employed by other users.

3 Conceptualizing »Sensing Home«

Inspired by this gap in research on sensor toolkits for the home and the availability of sensor toolkits for the smart city, we wanted to create a similar toolkit for use in the home. This toolkit should allow participants to independently collect sensor data in different locations in their home, to observe the collected data, and to further process and annotate it. We wanted to focus especially on the data of simple sensors that are typically small and cheap, e.g. for light, temperature or humidity. Complex and a priori critical sensors, e.g. cameras or microphones, should not be used. Our goal was involving people in the examination of sensor data from their homes. Our system should work without prior experience with smart technology in the home. Therefore, we designed our toolkit as a self-contained system without the need for additional infrastructure, easy to set up and easy to use. Our toolkit does not rely on participants' internet connectivity nor on 3rd party cloud storage or computing services.

We chose a sensor platform that corresponds to the IoT paradigm of being small, cheap and versatile. Our devices represent the most common functions of IoT products for the home: (simple) sensors/actuators, power, computing and communication. We explicitly chose a device with several simple sensors on-board. That gives us a high number of possibilities how to use the devices. Also, in contrast to most commercial smart home products available, we chose a platform that allows us complete control over data flows. The toolkit contains several wireless sensors that are connected to the internet via a gateway. We explicitly designed our whole system to handle all data only on our own hardware and software. Thus, the sensor data is transmitted to a server of our research group. The toolkit is also equipped with a pre-configured WiFi hotspot for instant use without configuration. We modified the outer shell of the sensor platform in order for it to be un-specific and non-descript, in order for participants to question the inside. As such we iterated with a variety of shells before settling on a final enclosure. In order to gather feedback on the initial iteration of Sensing Home, we used various outer shells for the sensors that do not reveal what they entail. Further, we presented this first prototype and a somewhat fuzzy notion that it contains sensors for the home to various people, from peers at CHI workshops to potential participants. This open ended narrative helped to engage with people to inform us on potential use cases: What would people like to sense in their homes? Where would they hide, attach, connect different sensors? Based on this feedback we settled on a 3D-printed color coded shells that reveal the front of the sensor platform and that simultaneously allows for easy attachment to a variety of things. The development of our technology was done in a process of field trials and learning. With each field use we evolved our probe pack from a working minimal version up to the preliminary final setup. We optimized in this process the technical functionality as well as the visualizations that the participants use to analyze their data.

3.1 Technology

We chose as a suitable base for our sensing devices the TI SensorTag [17]. These devices represent the IoT paradigms simple, cheap, small, and everywhere (mountable) at its core. The SensorTag offers battery operation, energy efficient communication via Bluetooth Low Energy (BLE) and a large number of different simple sensors at a low price (USD 30). We utilize the following on-board sensors: (IR) thermometer, luxmeter, hygrometer, barometer, accelerometer, gyroscope, magnetometer, reed switch and manual switches. In contrast to consumer products the openness in hard-

Fig. 1 Sensing Home Toolkit consisting of components for collection, processing, transmission and viewing of sensor data (3 SensorTags, Raspberry Pi, WiFi hotspot, tablet pc, etc.) with material for documentation and data work

ware and software of the SensorTag, intended as a developer product, allows us to adapt the functionality to our needs while keeping the data flows within our control. We modified the SensorTag to make them more practical and more usable for our intended use cases. Our devices are small (45 × 35 × 3 mm) and lightweight enough (15 g) to attach them nearly everywhere. We modified and 3D-printed custom housings to offer a variety of mounting options. It it possible to attach a sensor e.g. via glue pad, rubber bands or cable strips to an object, to hang it somewhere or to just put it down. A consistent color coding supports easy distinction and intuitive association from the sensor housings to the data visualizations (Fig. 1).

We advanced the SensorTag firmware and central host side software to make them more versatile and more usable for our field studies. This includes first of all improvements for higher reliability, availability, and battery runtime. With the initial stock setup we reached 1.5 days of runtime with all sensors enabled and reasonable sensor intervals. This might be enough for some usage formats like an ideation workshop but it is not enough for using the devices in a field study. Therefore, we had to implement some energy optimizations that allowed us to use devices in typical smart home scenarios with up to three weeks runtime. We realized more flexible sensor intervals and on device data-preprocessing (static and dynamic thresholding) to let the sensors react as fast as possible while still saving energy. Despite the SensorTag software being open source it is not as easy to use as e.g. Arduino. Even a simple change for a meaningful improvement in the software has a steep learning curve and requires deep understanding of the system internals.

To capture interesting domestic activities, it is necessary not only to use the right measurement metrics but also suitable measurement intervals and sensor position. Based on our own experimentation and other work [18] we preset meaningful sampling intervals. We set the sampling for typically slowly changing measures (ambient and object temperature, barometric pressure, and relative humidity) every 10 s, for faster transient measures (light) every 2 s, and externally triggered events (accelerometer, gyroscope, and magnetometer) every 0.1 s for 10 s once triggered by motion. Nevertheless, it is possible to tune all sensor parameters for certain specific usage scenarios beyond the named limits. For the sensor position we chose different approaches in the individual use cases described later. In general the limited range of the SensorTags must be taken into account. In our experience it is good enough for normal sized flats with a single edge gateway. With the help of additional edge gateways it is possible to cover even large homes/houses. We include a Raspberry Pi 3 (Raspi) as an on-site edge gateway as it offers connectivity via BLE and (W)LAN as default. Each Raspi can connect up to eight SensorTags (limitation of the BLE stack) but normally we provide only three as a compromise of flexibility and reliability. Node-Red serves as an easy to use and powerful IoT mashup software on the Raspi. We implemented advanced software modules to use the SensorTags with new functionality and better energy efficiency. Our Raspi-Portal allows for a quick headless setup. We also included pre-configured mobile WiFi hotspots for Internet connectivity. The Raspi forwards the data to a secure server in our department for storage (InfluxDB) and visualization (Grafana).

InfluxDB stores the data of the sensors in performance optimized time series. Visualizations of the sensor data are generated by Grafana. It offers great flexibility in the creation of sensor dashboards with a variety of visualizations. We decided to show simple line graphs as data visualizations (Fig. 2). We wanted only little preprocessing of the raw data, to prevent biasing by pre-interpretation. Such simple time series graphs are comparable to those used in other works [19–21]. Together with the ability to collect sensor data we wanted to give the users the ability to view live and historic data. A preconfigured tablet computer allows to access visualizations of the data. As the visualization are web based they can be accessed from any web browser. This allows the user to utilize either the included tablet computer or other (own) devices for this purpose.

Besides the storing and processing of the the generated sensor data an additional management on the server side is absolutely necessary when deploying more than just a few devices for a single user. This includes an account and device management. Every field use of the devices requires some kind of reinstanciation of the software on the Raspis as well as on the server side to keep the system safe and secure. This includes all account data and passwords as well as all cryptographic keys for transmitting and storing the generated data.

Fig. 2 Screenshot of data visualization in graphs as seen by the participants on the tablet

4 Sensing Home in Use

We conducted several participatory field studies for exploring sensors in the home together with users from various groups. With a focus on the diversity of goals and outcomes of these studies we will subsequently report on three such use cases. The first use case focuses on the exploration of potentially interesting applications of sensors in the home. Here, computer science students, staff of a computer science department as well as elderly volunteers critically explored possible scenarios of using our Toolkit within their homes. The second use case presents an interdisciplinary teaching project. Here, computer science and social science students collaborated in order to design and subsequently conduct user studies in different social settings. The third use case we report on is about sensemaking and empowering people in understanding the potential and pitfalls of potential sensors in their home. Here, we deployed Sensing Home within nine homes and explored the data together with the inhabitants in order to make sense of sensor data collected in their homes. While all three use cases employed the very same Sensing Home toolkit, they allow us to highlight various themes of participatory exploration. In particular, we will show the versatility of such a toolkit for participatory research on the smart home. It allows for an empirically grounded exploration of IoT in the home and allows for participatory design work with participants of diverging technical literacy and fluency. Participants with some technical expertise came up with highly creative applications for sensors in the home. Participants with a only little technical expertise were significantly empowered in understanding the gains and risks of sensor data on the home. Students in turn were able to independently design and conduct empirical studies in the context of the home. Collectively, the diverging themes of participatory exploration unraveled in the following use cases shed some light on the values of doing research on the smart home together with people.

4.1 Use Case 1—Exploration of Usage Scenarios

Inspired by our own previous work on participatory exploration for the IoT in domestic contexts [22, 23] we wanted to investigate themes and applications emerging from the free and prolonged exploration of simple sensors in peoples' homes. In this use case our participants were free to use the sensors where and how they wanted to. In this free exploration the participants could experiment or simply play around with devices and data. We saw it as important for this use case to happen in the real world context of participants homes. This study needed also to run long enough for participants to really experience the usage of sensors in their daily routine. The actual real sensor usage and data collection in such a context allow a direct validation of scenario ideas in means of feasibility and relevance. Despite different levels of literacy and fluency our toolkit enabled the participants to find some interesting, innovative and unexpected usage scenarios. The participants even gained literacy and fluency in using the sensors and reflecting on their meanings. The findings of context and implications of use helped us to develop and enable other use cases.

The goals of this use case were two-fold. First, we wanted to find out whether participants were able to use the sensors and their data meaningfully at all. Second, we were interested whether and how participants might come up with innovative and unexpected usage for the sensors if we engaged and fostered a free exploration. An instant camera and a booklet complemented the deployment of our sensor pack, as we wanted to focus on the experiential qualities of a cultural probe study [24]. The booklet guided participants through the first steps of the exploration with an example scenario and offered templates for structured notes of their own exploration (similar to [25]). Questions included: What do you want to try out with the sensors? What sensor values revealed certain insights? Where did you place the sensors? What does the collected data actually show? Participants were also asked to annotate graphs and document placement of sensors with photos. We conducted this use case consecutively with three groups of participants. Group A consisted of 3 master students. Group B consisted of 3 computer scientists of our department, not involved in the project but with solid technical background. Group C constituted 4 elderly volunteer users with no special technological knowledge or skills. Groups A and B set up their probe packs at home on their own, for group C this was done by one of our researchers. The participants used the sensors for about two weeks in their homes and documented their work during this time. After this time all parts were returned to us. When an exploration and data collection phase was finished we reviewed the notes of the participants. We invited them groupwise for a closing discussion to talk about their experiences and insights. In this use case the generated sensor data itself was not intended for further analysis by us, especially because the sampling context was quite diverse. We analyzed the usage reports to improve the technical feasibility and setup which also includes usability aspects.

The individual sensor exploration and data work of the participants worked very well. All participants were able to browse their data and to explore data patterns meaningfully by the provided visualizations. As expected, the participants found the visualizations of volatile values easier (e.g. light or acceleration in movement). Participants liked these measures as they associated them with »motion« and easy to distinguish changes. But also slowly changing values (e.g. temperature and humidity) were meaningful. We see some differences in literacy and fluency between the three groups. On the one hand some participants of group C had sometimes problems in understanding and interpreting even simple sensor values, on the other hand we see advanced and innovative approaches to use the sensors. Overall the different sensor functions are usually well understood. However, often movement of the sensor is mixed with the movement within a specific room. The relationship between a measurement and the according generated data is generally understood in a fundamental way.

Most participants found usages for the sensors for own purposes beyond scenarios introduced by us as examples. Some of the created scenarios were obviously and expected while some other were highly creative and even surprising. We want to illustrate this by some selected examples in different categories that we identified. Mould prevention was an ever repeating theme including reflecting on own behavior and seeking for optimizations, e.g. for the drying of laundry in the home. The determination and improvement of air exchange in the home by measuring temperature and humidity was also performed multiple times. One very popular theme was the augmentation of mundane household objects and devices to make them »smart«. One participant tried a sensor on a vacuum cleaner to detect operation and load via motion and temperature during vacuum cleaning. An augmented teapot should notify the right time for drinking the tea by measuring its temperature. The augmentations also involved furniture and home installations. A sensor was attached to a bed to monitor sleep and attached to a door to monitor movements (when someone enters or leaves). A sensor near to the radiator revealed the switch off and on time of the central heating system (landlord owned and controlled) by monitoring falling or raising temperature. Even a toilet lid was made »smart« to measure when and how often the toilet was used. The participants attached the sensors not only to objects. One sensor was even attached to a baby to monitor activities, sleeping times and positions. One participant made own little helpers to use the sensors in different scenarios, e.g. a small Lego stand or a velcro sleeve to attach the sensor to textiles.

Another interesting finding is how the participants explored possible useful scenarios. Some of the unexpected insights reported might be created more by accident, e.g. a sensor on a window in the ground floor facing outwards being able to detect light changes caused by the shadow of a passerby on day and the lights of cars in the night. Other scenarios are the result of a systematic approach. This includes the detection of the water level of an aquarium. One participant systematically tried the different sensor functions until finding a satisfying solution by measuring the

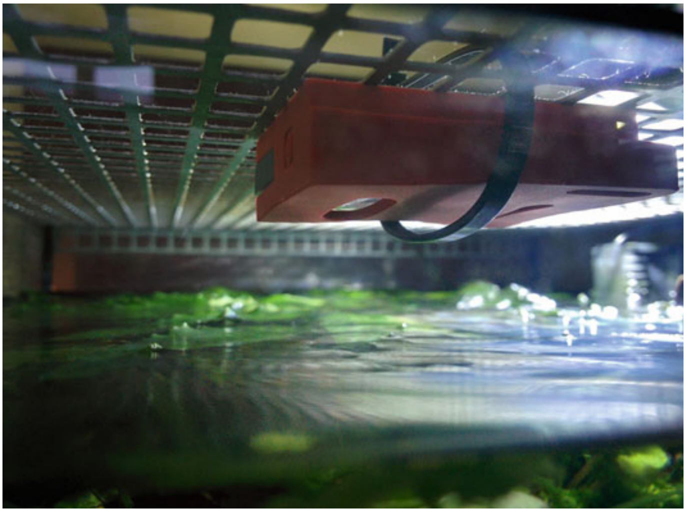

Fig. 3 Sensor mounted on the top lid detecting the filling level of an aquarium by measuring the reflected light

light intensity reflected on the surface of the water as an indicator of the filling level (Fig. 3). One participant set up a sensor in front of a tv set to determine whether it causes characteristic light patterns, e.g. to detect if someone watches tv or even to recognize what is being watched (Fig. 4). The participant even verified whether the pre-set sampling interval of the light sensor was fast enough to capture similar data for a second view of the same content.

A playful exploration of sensors and their data goes beyond the possibilities of an ideation that often only theorizes about what a sensor is useful for or where its limit are. We have seen examples where the exploration allows to experiment with the sensors to verify assumptions as well as examples of serendipity where the playfulness lead to unanticipated results of possible sensor usages. Our toolkit worked very well in means of supporting creativity and satisfying human curiosity by exploring the possibilities of usage. Not only the participants with more knowledge and higher skills ideated and tested interesting scenarios.

No matter how good the initial literacy and fluency on the usage of the sensors and interpretation of their data initially were, the participants gained competences and understanding during the usage. This encouraged us to use the sensors also for other use cases. This comprises e.g. further usages in student projects as well as focussing on the critical reflection of these devices in the home in means of privacy threats and surveillance.

Fig. 4 Sensor on a small stand made of Lego by the participant to bring the sensor in optimal position in front of the tv set

4.2 Use Case 2—Researching and Prototyping in the Wild

We used the toolkit in an interdisciplinary teaching and learning project, which was conducted in two iterations with students of computer science and students of cultural sciences. Based on our toolkit, the students developed their own research interests and empirical case studies for Internet of Things applications in different social contexts, e.g. shared flats, co-working spaces, bars or even horse stables.

»HCI in the Wild« was first held in spring 2017 with 15 students of Chemnitz University of Technology and University of Leipzig and repeated in fall 2017 with 12 students of Leuphana University Lüneburg. The aim of the project was to let students experience both the opportunities and challenges of research and development of IoT » in the wild«. Therefore the students had to form mixed groups to choose a research interest and a method to approach the usage of our toolkit in a self-chosen social environment. The students' projects ranged from cultural probe studies [24] to exploring living worlds like shared-flats, up to the development of own functional prototypes supplementing our toolkit. To enable the students to explore and adapt the toolkit for their own purpose, we provided a range of didactic means. Firstly we established a mutual base of knowledge by reading and discussing research literature on smart homes (e.g. Tolmie et al. [21]), research in the wild (e.g. Kuutti and Bannon [26]) and methods (e.g. Graham et al. [27]). Secondly we ran hands-on workshops with the toolkit and the data visualization by Grafana to empower all students to adapt the technology as well as the data to their research interests. Followingly the student groups started their own research projects which we accompanied through weekly consultations and the students' online » research diaries« . This version of a learning portfolio was structured by milestones that instruct a small-scale research project, e.g. documenting research interest, developing a research question, choosing a method, contacting people in the field, gathering data, etc. Thereby the students' projects could be supervised and mentored by us without determining upfront, what exactly would happen with the toolkit.

In the result, we were awarded with a variety of concrete use cases, explorations of diverging application contexts and even empirical user studies designed and conducted by the students. Before providing examples of this work by the students, we want to highlight the generative quality of the toolkit as proven in this use case of researching and prototyping in the wild. Even undergraduate students with background in humanities were able to use the toolkit as a technological basis for comparatively complex empirical projects within a time frame of just 10 weeks. We were not only impressed by the productivity the toolkit enabled, but also by the quality of inquiry the students conducted with it. Whereas we learned through use case 1 to narrow down specific sensor and data visualizations combinations to enable an explorative use of the toolkit, we learned through »HCI in the Wild« how it proves within different social contexts of use and diverging research perspectives. We will see in the examples that the interdisciplinary student groups did not just apply the toolkit, but came up with own modes of researching the social IoT.

The first of two dominant categories of usage was *monitoring conditions*, as in »Smart Tomato«, where students tried to find an ideal location for a tomato plant in their apartment correlating light and humidity values. The students therefore added an additional sensor to the Raspberry Pi, measuring the humidity of the flower soil through electric resistance. Similar research interests were visible in projects researching the humidity and temperature in the sleeping room (2), or energy consumption of the boiler for central heating. One student group even analyzed the air quality in student clubs and compared it to their popularity. In these projects the sensors were used in their originally citizen science-purpose to enable people to conduct research within their own life-worlds. A surprisingly frequent use case in this sense was the monitoring of pets. Overall three student projects used the toolkit to monitor domestic animals: A cat, a dog, and even a horse were tracked and analyzed by mounting the SensorTags to their collar, resp. mane (Fig. 5).

The monitoring of animals links to the second dominant category of use cases the students came up with, the *monitoring of behavior*. Other than in checking rather passive values like air pressure, the monitoring of movement or action has to deal with meaning and interpretation. This has to be done when data is collected—not only when the students researchers finally analyze the data. An example for such projects is the self-monitoring of a student, to track her productivity over the day by operationalizing different spots in her flat as places of leisure or places of work. The research question as well as the toolkit itself implied that she reflectively explored her everyday routine in a rather ethnographic manner. Another group equipped a co-working space with multiple SensorTags to measure data like light values and humidity in order to correlate it with the co-workers perception of well-being and productivity, which was gathered by a daily questionnaire the participants had to fill out.

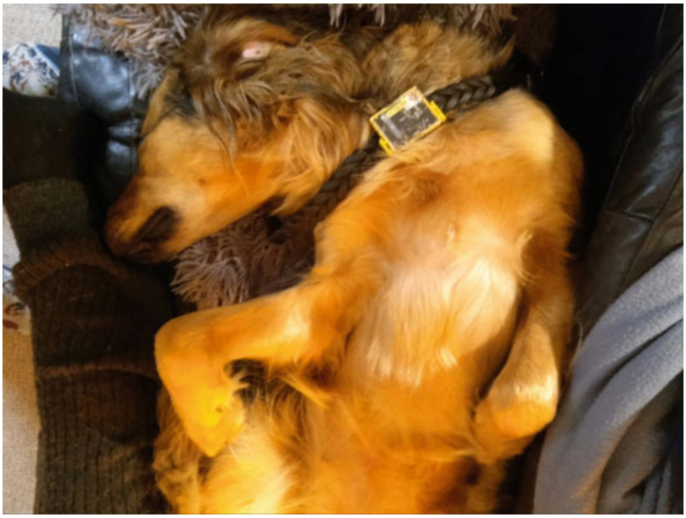

Fig. 5 Sensor equipped dog

Handing the toolkits to students with a rather open-ended narrative, to use them for their own interests, has not only led to interesting use cases. Whereas the basic purposes of the SensorTags as device is to monitor environmental conditions, the students projects showed that the designed toolkit provokes deeper engagement with IoT in social contexts. Firstly, all projects included an explicit analysis and reflection of the »application context«, which was not derived from a given task, but following the criteria and relevances of the researched life-worlds—even if it is due to the relevance of the students themselves. Secondly, all projects included an additional form of (mostly qualitative) data gathering and analysis. Those ranged from ethnographic writing, over questionnaires, up to interview studies, which were in some projects even combined. Even the owner of the tomato plant was interviewed, whether she thinks the monitoring helped her and/or the plant to thrive.

The interdisciplinary teaching project »HCI in the Wild« confirmed two major implications of social IoT we wanted to address with the design rationale of our toolkit. Above all, IoT devices in general and research artifacts in specific have to be *open for appropriation* by the people using it. An IoT product sensitive for and meaningful in social contexts like the home cannot be derived from an upfront defined problem-solution pairing. It should rather provoke and enable people who use it to question such pairings and/or develop their own. Secondly, the student projects highlighted the importance of *data work*. The students experienced that all data can become relevant if put in in a particular context, and that this context needs to be brought up when interpreting IoT data. Especially human behavior and its traces cannot be gathered and understood without knowledge about these practices, their intention and their context. This importance of data work for the social IoT encouraged our third and final use case.

4.3 Use Case 3—Critically Reflecting Implications of Social IoT

Encouraged by the participants' and students' appropriation of the toolkit, we decided to deploy it as a research artifact in homes for longer periods. Within a series of three field phases we conducted studies using the toolkit in nine households in two mid-sized German cities. The main focus thereby was to understand the *social implications of IoT data* and its visualization for the inhabitants and to enable reflection on privacy threats and surveillance through IoT in the home.

For this third use case the toolkit was gradually developed further. Especially the deployments of the students helped us to improve the technical robustness e.g. by enabling secure remote management and recovery from undefined states caused by various influences. Furthermore we had to create a methodical frame to enable the use of the toolkit as a research artifact to evaluate how participants deal with IoT data in their home. Therefore, we narrowed down the participant's instruction to use the toolkit compared to the very free explorations in use case 1 and 2. Mainly, we predetermined the position of the sensors in the homes (on hall door, on fridge door and opposite to tv set) in order to achieve comparability between the cases and to promote the interest in the data. When defining those spots we built on the findings we obtained earlier, especially to generate data, that shows traces of everyday activities, rather than focusing on environmental conditions. When using the toolkit as a research artifact, we thus initially restricted the application by the participants, but simultaneously left open, how the data could be interpreted and encouraged the participants to find their own purposes for it.

Altogether we ran a series of three field phases over the course of eight months in 2017 with participants living in different household-constellations, ranging from a 74 year old living alone to a family with two teenage sons and two dogs. We introduced the toolkit to them as ready-made artifact in the manner of a probe pack [24, 27, 28] The ready to use aspect was very important as we were primarily not interested in usability aspects but the social situatedness of IoT data in the home. The study concept did not only consist of our toolkit and the request to document the data but also of a group discussion format to reflect on the data.

The first part of the field phases was the actual data collection in the homes, which took 10–14 days depending on the participants' individual schedules. In the beginning of a data collection phase, a team of two to three researchers set up the toolkit in the home and explained the data visualization software. During this phase, the participants had full access to the data visualizations and were encouraged to perform »data work«, by browsing and selecting interesting graphs on a daily routine. In a second step we conducted group discussions with the participants from different households. Thereby we would not only be able to gather insights into individual experiences [21] but in the collective dimensions of making sense of data from the home. We hoped for a discussion that benefits from multiple participants' experiences with the probe packs and the individual data work. We also wanted to empower

Fig. 6 Guess the Data—participants discussing the printed data graphs

participants to reflect critically on IoT in the home by choosing such a collective discussion method. We called the format »Guess the Data« .

In preparation of all three sessions we performed data work ourselves. We browsed the data as a researchers' group and looked for interesting patterns, whether recurring (regular activity) or outliers/anomalies (special events). We used our experience on working with the sensors and their data, as well as our everyday knowledge of common activities to interpret the data. Thereby it was inevitable to include knowledge about the context and the situatedness of the data, gained from previous contacts and home visits. We selected 10–12 data sections per discussion session. We printed the selected data sections on large format paper sheets. We used the Grafana graphs format that the participants were already familiar with. We anonymized the graphs by removing all markings that directly hinted at the creatorship of the data.

We started the discussion with open questions on the overall experiences of using the probe pack. While presenting the printed graphs one after another, we encouraged the participants to articulate on what they saw in it and which everyday activities they could identify. We expected the participants to speculate on the data, to »guess the data« . We fostered the evolving discussion with immanent questions when necessary. When the discussion of a print faded away we moved on to the next print. We finished the discussion by asking questions on surveillance and privacy regarding that kind of data. The performed group discussions took an average of 90 min and were recorded and transliterated afterwards. Then, we analyzed the gathered data by following the analytic principles of grounded theory [29] in a two-step process with open coding and axial coding by our research group (Fig. 6).

The mechanisms and horizons of participants' sensemaking of their domestic data we observed corresponds with similar studies for individual participants [19, 21]. Daily routine and implicit, situated [30] knowledge become a backdrop for interpreting data from the home. When discussing the individual data work in the group, especially sensitive activities and behaviors became visible. Even simple sensor data can become critical for residents' privacy not only by pointing to possibly sensitive information like sleep rhythm or wasteful behavior. Our study design showed furthermore the critical dimensions of collective sharing and sensemaking of such data. Eventually the participants realized the surveillance potential of gathering data in the home by own practice: The active usage of the sensors and data work led to forms of surveillance of other family members.

Participants for example used the sensor data to confront their housemates with their domestic activity. A female participant corrected her boyfriend's careless behavior regarding the light in the hallway, which he often forgot to turn off. She confronted him with the visualization of the light sensor data, and added *»he was a little bit shocked«* . She used the visualization to problematize his behavior which finally lead to a morally enforced change in behavior habits. But we also observed usages of the sensor data for surveillance as main purpose. One participant reported a situation where she used the data visualization to check, whether her partner was telling the truth about when leaving the home:

> »He said 'I have been in the garden all the time'. And there I laughed and said: 'This cannot be true, because the apartment door only opened at 17:30.' And he said 'Really? […] Were you watching me?'«

It becomes apparent that the participant used the sensor system asymmetrically. During the group discussions it became clear that all of the participants understood that this system could be used to surveil partners or children.

The use of the toolkit in homes shows its generative potential in hindsight to a critical reflection of IoT technology. The participants proved and realized that simple environment sensors can reveal a lot of sensitive and personal information. Combined with situated knowledge about the housing situation this data can be used to identify a certain person and recognize their activities within the household. Combined with the discussion format »Guess the Data« the—sometimes ethically problematic—implications of IoT in the home became tangibly aware to the participants and us as researchers.

5 Results

We built a functional IoT research device for participatory exploration of smart sensors in the context of the home. Using it in three different modes with people encouraged our initial design rationale, to enable an empirically grounded exploration of the design space for IoT in the home. The tangible exploration of usage scenarios proved that participants with diverging technical literacy and fluency were able to use the toolkit in their own means. Furthermore we could observe that the participants gained competences in data interpretation during the usage. This encouraged us to use the sensors also for other use cases. By using the toolkit as a research artifact for student projects, we tested its versatility and robustness for prototyping and appropriation in the wild. This exploration showed that the toolkit enables people who use it to question problem-solution pairings of IoT for the home and to develop their own. Use cases 1 and 2 highlighted importance of data work, while situated knowledge of practices in the home was topic of use case 3. Here the deployment in homes over two weeks sensitized the participants that simple environment sensors can be used to identify a certain person and recognize their activities within the household. We further developed the discussion format »Guess the Data« to gain insight into the participants' evaluation of the social and ethical implications of IoT in the home.

Through these three case studies we have shown that Sensing Home allowed us to adapt the toolkit with relative ease to diverging methods and applications. All these in-the-wild studies could only be conducted because Sensing Home was technically functioning. The toolkit allows for independent studies for longer periods of time without having researchers present. It thus allowed participants to gain first hand expertise through usage and subsequently empowered participants to engage in informed and critical discussion about the potential gains and risk of smart sensors in the home.

Still, some of the ideated scenarios were beyond the technical limits of the current implementation, e.g. due to the limited range of the sensors. Evolved sensors might solve this issue and will allow the usage in the greater context of home in the (semi-)public space of the building and maybe even outside the building without the need of additional gateways. SensorTag are versatile, but sometimes not versatile enough. Sensor dimension and sensor placement are an issue for deployment. Yet, the possibility to add extension modules with more or specialized sensors for specific purposes needs to be explored. As well as longer unmaintained deployment of the sensors could be enabled by slightly larger housings that holds larger batteries for a runtime of several months. This would offer the possibility to make the devices part of the daily life of the participants without any need for attention during long term studies.

Acknowledgements This research was funded by the German Ministry of Education and Research (BMBF) under grant number FKZ 16SV7116.

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Direct End-User Interaction with and Through IoT Devices

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Abstract Research addressing the Internet of Things (IoT) has been predominantly concerned with the interconnection of physical devices. However, increasingly complex application scenarios require us to further investigate the interface between IoT devices and users. In this book chapter, we explore the possibilities of direct end-user interaction with and through IoT devices. We do this by examining the increasing automation of environmental factors, such as temperature and lighting, in open-office environments. Increasing automation offers many benefits around responsiveness of buildings to environmental conditions and improved energy efficiency, but can result in a reduction in office inhabitants' options for manual control of their environment. To inquire into this issue, we designed and evaluated an IoT device called the MiniOrb. The device employs tangible and ambient interaction and feedback mechanisms to support office environment inhabitants in maintaining awareness about environmental conditions. It reports on their subjective perceptions and opinions around comfort levels in the office and receives feedback on how their individual preferences compare with their colleagues'. A mobile-device based version of the application was also created. Employing screen and touch interactions, this version of the interface enables users to access the same information as the tangible device, but with different degrees of input precision and ambient interaction. We describe the design of the system along with the results of a trial of the device with real users, including a post-trial interview. The results shed light on how IoT devices can support direct end-user interaction by combining ambient and tangible interaction approaches. Such devices can mediate the interpretation of sensed data by end-users, as well as help collect crowd-sourced data that directly relate to sensed data.

Keywords End-user interaction · Ambient interface · Tangible interaction Indoor climate · Individual control · Peripheral awareness · Social IoT Crowdsourcing

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_8

1 Introduction

The increasingly widespread application of Internet of Things (IoT) technologies in domains such as medical applications, intelligent transport and smart cities, has led to a greater awareness of the sociotechnical implications of this technology that transcend technical questions of interconnectivity, protocols and device design. For instance, smart city applications touch on different usage contexts, involving people across multiple layers of urban development (e.g. waste, road infrastructure, lighting etc.). While there is increasing awareness of this fact we propose that there still is a disconnect between the design of IoT devices and protocols on the one hand and complex application scenarios in the other hand. One of the pressing questions when considering different application scenarios is how and what level of abstraction IoT devices and networks is needed to support direct interactivity with end-users. In this chapter, we consider the notion of direct end-user interaction with and through IoT technologies. Considering end-user interaction with and through IoT devices offers a number of unique perspectives that are currently under-explored in the literature:

- How can end-users be enabled to directly interact with individual sensors or sensor arrays?
- How can interactive IoT devices help end-users to make sense of data?
- How can we design ways for end-users to qualify sensor results and share that interpretation with other users?

We explore these questions in the context of Home and Office automation, one the most prevalent application scenarios currently being discussed in the context of the IoT. In office environments in particular, the use of embedded smart sensors is well advanced. In order to efficiently control indoor climate in modern office buildings environmental monitoring technologies have been tightly integrated with building control mechanisms. Building management systems (BMS) are commonly used to orchestrate large numbers of sensors to monitor environmental conditions and control temperature, humidity, lights and blinds accordingly.

The aim of such systems is to make buildings more responsive to dynamic environmental conditions and thus more comfortable 'on average' for their inhabitants. However, even if they draw on localised sensor inputs to give a more complete picture of environmental conditions across a building, they still generally rely on centralised control systems. This means that individual inhabitants' preferences are not met, either because those preferences happen to be different from an idealised 'average user' or because relevant local environmental conditions are not available to the system. This is a particular issue for open plan office environments shared by large numbers of inhabitants, each with individual preferences. The resulting lack of inhabitant's control over their environment mirrors common concerns levelled at IoT scenarios, in particular questions around privacy and the locus of control.

In our research we aim to address this problem by contributing to the design of systems which allow people in open-plan office environments to control the conditions of their indoor climate. Additionally, we seek to support inhabitants in communicating their preferences with others so that an overall consensus can be reached around desired indoor climate conditions. It is worth clarifying that we do not seek to take the extra step of using this information on desired environmental conditions to actually change the functioning of environmental control systems. Doing so presents a number of significant integration challenges with both technical and social dimensions. It is a 'wicked problem', consisting of many interconnected challenges and an extended research programme will be required to address these challenges in full. Although we see the work presented here as contributing a valuable first step in this programme of research, the larger challenges of integrating with functioning environmental control systems is beyond the scope of the study.

Our focus in this paper is to explore a range of potential *interaction mechanisms, feedback modalities, and personal input techniques*, that could be employed by such systems. We have designed, implemented and conducted an initial evaluation of a system which explores these principles. The system allows users to provide feedback about their subjective impressions of comfort in an office environment for a several salient environmental factors. It employs both tangible and ambient modes of input and output and also provides for the display of data sensed by the system and an aggregated representation of group preferences.

Our system is made up of the following three parts: (1) a local **Sensor Platform**, which is placed near users' work area and gathers local measurements of humidity, light, temperature, and noise levels; (2) **MiniOrb**: a small tangible and ambient interaction device, which displays the local environmental conditions as sensed by the local sensor platform and allows the user to submit their preferences in relation to these; and (3) **MobiOrb**: a mobile application, which implements an alternative interface for displaying sensor information and allows users to input preferences through touch-screen interactions as more precise values.

The purpose of this chapter is to address two pertinent questions related to end-user interaction with IoT devices. Firstly, how might tangible and ambient interaction techniques be used to support people in reflecting on and recording subjective preferences in relation to comfort levels in an office setting, and secondly how effective are these techniques compared to more conventional screen-based touch-interactions for setting the same information, but with greater numerical precision?

The rest of this chapter is organised as follows. Section 2 discusses related work, specifically in the context of ubiquitous computing, ambient interaction as well as crowdsourcing and participatory sensing. Section 3 outlines the design of the MiniOrb device, its related sensor platform as well as its mobile interface. Section 4 summarises the results of the device's evaluation. Section 5 discusses and interprets these results in the context of end-users interacting with and through IoT devices. Section 6 concludes this chapter and summarises insights gained.

2 Background

2.1 Ubiquitous Computing and Indoor Climate

Within building studies, there has been a move towards 'user-centred' conceptions of how people experience buildings [24]. This raises questions concerning the ways that social relations, people's lived experience, and their day-to-day use of buildings have an effect on how they experience indoor climate. There is an awareness and recognition that far from being simply an engineering problem, the energy efficiency of buildings is as much dependent on the lived practices, use-patterns and social relations between building inhabitants [12]. In order to improve the sustainability of buildings in terms of their energy use, we need to question the models of comfort based on pre-defined steady-state conceptions of indoor climate [23].

Alongside this, there is also increasing use of ubiquitous sensing technologies within buildings. So-called 'smart' sensors distributed throughout a building provide data which is used to intelligently regulate indoor climate systems (Liu and Akinci). In practice, this often is realised as increasingly automated indoor climate systems, however the occupants of buildings have been shown to have lower levels of satisfaction if occupants lack control over their environment [4]. Giving control of the indoor climate to people not only has benefits in terms of improving satisfaction overall [4], it can also prove effective as a way of reducing energy consumption [2].

There are a number of interaction techniques which can be employed to facilitate user engagement in this context, but in this chapter we focus on the way that tangible and ambient interaction mechanisms linked to an IoT sensing platform could be used for this purpose.

2.2 Ambient Interaction

Ambient devices are a type of interaction mechanism, designed to unobtrusively communicate information to users. In one example, Ishii et al. [11] instrumented office environments with a range of devices which could provide ambient feedback as part of their ambientROOM environment. This environment included a range of modalities such as sounds, lights, air flow and visual projections. Ambient feedback approaches have since been studied within a range of other settings (e.g. [3, 19]).

Ambient devices typically employ simple mechanisms for output, such as glowing orbs. However, despite their outward simplicity, ambient devices present several challenges to designers. Designers must consider carefully what information should be displayed by the device, how the appropriate intensity levels for notifications should be classified, and how transitions between various states should be handled by the device [15]. Besides their use as output devices, there is also an increasing interest in finding ways to integrate tangible interaction mechanisms into ambient devices so that both input and output capabilities can be provided for users (e.g.

Hausen et al. [7, 10]). For instance, AuraOrb [1] augmented a "glowing orb" display with touch input and eye contact sensing. This allowed users to trigger functions of the device simply by directing their gaze to it. Other examples in the context of presence awareness and instant messaging have also explored this approach (e.g. [5, 7, 18]).

2.3 Crowdsourcing and Participatory Sensing

The notions of crowdsourcing and participatory sensing are relevant to understanding end-user interaction with IoT devices for gathering and sharing data. Jeff Howe who coined the term [8, 9], defines crowdsourcing succinctly as: "*The application of Open Source principles to fields outside of software.*" Crowdsourcing is an effective approach to collect and analyse information from large numbers of contributors using internet-based services, either implicitly or explicitly. Participatory sensing [13, 17] is a form of crowdsourcing that is applied in an IoT context. Participatory sensing describes the gathering of data through sensors that participants carry or use, without the need for participants to actively interfere. By contrast, the related concept of citizen science [6, 16], implemented through projects such as the *Berkeley Open Infrastructure Network Computing*, not only allows researchers to harness the computing power of many computers worldwide, but also supports the active contribution and analysis of data through volunteers—an approach referred to as civic intelligence [22]. Similar approaches are being employed in non-volunteer setups, including Internet marketplaces such as Amazon's *Mechanical Turk* (mturk.com), using micro-payments to support a broad range of analysis tasks or IBM's *Many Eyes*, to facilitate the distributed creation of visualisations from datasets [25]. These related notions show a spectrum of user engagement when sharing and interpreting data that is of relevance when considering the design of end-user enabled IoT devices.

3 Design Process

The design process was based on an existing embedded sensor platform previously developed by one of the authors [21]. The platform consisted of a range of basic environmental sensors (temperature and humidity, light sensor, and sound sensor) mounted onto a custom-built circuit board. The board was designed to be placed in indoor office environments, and was envisaged to be predominantly mounted on office workers' desks. Sensor platforms communicated wirelessly via a ZigBeee mesh network, relaying sensor reading to a central server for logging.

The purpose of the sensor platform was to sense, monitor indoor climate data for individual desk workstations in order to log differences in environmental conditions and detect potential problems (e.g. increased sun exposure and glare due to the way blinds are being operated, noisier workstation due to the placement of air conditioning ducts). While the sensing process was automated, the platform allowed users to provide simple feedback by means of an on-board "joystick". This small PCB-mounted button was chosen because its very small form-factor integrated well with the overall design of the sensor platform. The placement and shape of the initial button itself made it not particularly suitable as a user feedback mechanism. However, the fact that feedback had been built into the initial platform made us consider expanding on the range of interactions and feedback mechanisms provided by the platform in order to collect user-preference information alongside raw sensor data and to explore to what extent the control of indoor climate could be customised to individual user preferences.

The overall goal for the design of this interactive sensor platforms was to build a series of interaction mechanisms, that integrated directly with the existing sensor platform and would support *tangible and ambient interaction* directly through the device. Directly integrating the interaction with the existing sensor platform introduced a number of design constraints. We decided that the new interaction platform should use the same basic microprocessor computing platform as the sensor platform, in order to be small and unobtrusive enough to fit on people's desks. The feedback and interaction mechanisms the device offered should still be rich enough to be both engaging and useable, so that users would be motivated to contribute their preference data. In addition to these high-level goals, we explored a number of additional design goals:

- The device should be unobtrusive and very easy to interact with
- The device should allow users to understand current sensor readings by showing data using an ambient display mechanism
- The device should enable users to set individual preferences for each of the sensor categories
- The device should allow users to compare between individual and group (average) preferences, enabling them to be aware of other users' preferences
- The device should allow users to provide feedback on their level of "social connectedness"

We introduced the additional parameter of "social connectedness" as a soft measure of the overall social environment in order to complement the sensor readings made by the platform. The purpose of this measure was to allow participants to express their perceived level of office comfort with regards to their social environment in addition to indoor climate preferences. The interpretation of the term "social connectedness" was deliberately left to participants allowing them to *interpret it according to their needs* and the specific context of their office environment. Rather than specifically providing a quantitative measure for social connectedness, we wanted to open up this measure for discussion in our subsequent participant interviews in conjunction with other environmental factors (please see the "study design" section for further discussion).

Basing the design of our interaction device on the existing sensor platform introduced a number of design limitations. One particular limitation was the fact that the sensor platform only possessed a small number of free input/output ports that could be used to communicate with the interaction device. Due to this we did not focus on building an interaction device that had a large or complex set of interactive capabilities. Instead the design of the device focussed on supporting a small but sufficiently complex set of interaction mechanisms that would addressed our design goals, yet allowed us to base our design on the existing sensor-platform infrastructure.

To design the MiniOrb, we carried out an iterative process, which involved building working prototypes that we 'lived with' in our work-spaces so we could experience them directly and use these experiences to drive refinements to functionality, usability and physical form of the devices. An important point here is that the 'behaviour' programmed into the devices could only be fully understood by taking time to personally experience what it was like to interact with the devices. This led to several improvements to the design of the devices. We added audio output to provide additional feedback to the user when preferences were being set and to communicate reminders to users to interact with the device. We also found that it was necessary to support users to be able to compare between the current reading of a sensor and their preferred setting. We also added the ability to 'scroll' through the various sensor readings.

During this process, we discovered the need to consider whether people would need to be able to get precise readings of the data from sensors, relative to the more 'ambient' display of the device. This led us to develop and design a second prototype implemented as a mobile-optimised web app. This replicated the basic functionality of the device and also allowed users to read and enter precise values for sensor readings and preferences. This mobile web-app implementation provides an alternative approach for building an interface based on the same sensor platform. In this case, the sensor platform's functionality is accessed through a screen-based interface. This second interaction approach is more representative of typical methods for exposing and accessing the data of IoT sensing infrastructures. It therefore provided a useful comparison point that could be evaluated alongside the tangible and ambient device design.

3.1 The MiniOrb System

The MiniOrb system is made up of three separate components: a sensor platform; a tangible and ambient interaction device; and a mobile-device delivered web application. Each of these parts plays a different role in the overall system. Each is described in more detail in the following sections (Fig. 1).

3.1.1 Sensor Platform

The MiniOrb *sensor platform* is a sensing device based on an Arduino platform. It can measure light, humidity, temperature and sound levels through a range of onboard analogue and digital sensors (see Fig. 2). There are a number of platforms and

Fig. 1 MiniOrb sensor platform (right) and interaction device prototype (left)

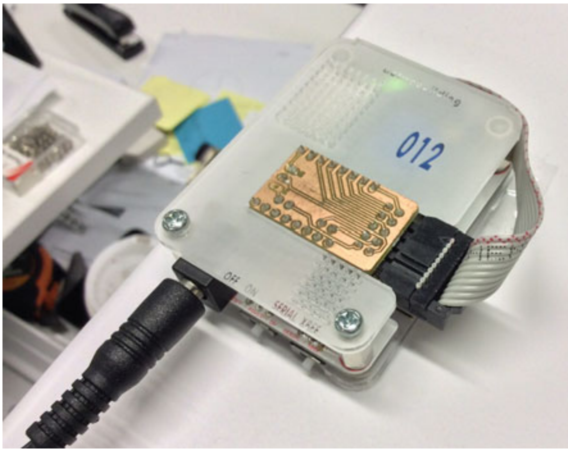

Fig. 2 MiniOrb sensor platform

they can each wirelessly communicate to a central server through a mesh network using the ZigBee protocol. Each sensor platform was deployed above participating users' desks in a similar position, in order for sensor readings to be as comparable as possible. The platforms run autonomously without direct input from users.

3.2 The MiniOrb Interaction Device

The MiniOrb device is a tangible and ambient interaction device. It allows users to record their individual preference values in relation to office comfort levels. Additionally, it displays an average comfort preference based on the inputs of users, as well as readings directly from the attached sensor platform (see Fig. 1, left). The device is equipped with three LED indicator lights, which indicate different device modes,

Fig. 3 MiniOrb breakout diagram

a push-button, a scroll-wheel for user input, a piezo speaker, and a dome-shaped illuminated "orb". This orb, which gives the device its name is made of 3D-printed plastic and acts as a light diffuser for an RGB-LED. The top face of the device is covered with a laser-cut and etched cover, which also acts as a button surface (Fig. 3).

The device's primary output mechanism is the RGB LED within the dome shaped "orb". The device cycles the output of the orb through a series of colours via the RGB LED. Each colour represents a different sensor category as follows: "temperature" is represented by red, "light" by green, "noise" by blue, and "social" by yellow. The choice of colours was constrained by what the RGB LED was capable of producing and also chosen with consideration of sufficient difference between colours for them to be easily distinguishable. The clearest colours from the LED are the primary colours of red, blue and green, which is why these were chosen for the parameters of light, temperature, and noise, which were directly sensed by the device. The social connectedness parameter, which was not sensed directly, but was instead a 'soft' measure based on user input was mapped to yellow, which is created

Fig. 4 MiniOrb ambient interaction device

Fig. 5 MiniOrb interaction

by mixing red and green channels in the LED. Additionally, three small indicator LEDs were mounted beneath laser etched icons for ‘sensor’, ‘user’ and ‘group’ to indicate whether the currently displayed readings relate to sensor values, personal preferences or a group averages. The values of particular parameters were mapped relative to the intensity of colour of the orb display, so that higher values would produce more intense colours (Figs. 4 and 5).

For example, in order to display information related to the light sensor, the device cycles through three separate modes related to this parameter. It first displays the value which the sensor platform has recorded by mapping this to a relative intensity of the colour green. The “sensor” icon is illuminated by the indicator LED to the current state. Next, the device transitions to a display of the last recorded user preference for light levels. Similar to the display of the sensor reading, this is indicated by mapping the value to the colour green on the RGB LED and illuminating the “user” icon indicator LED. The display cycle for the light parameter completes with a display of the value of the average “group” preference for light levels. The duration that each state is shown for is about five seconds. After the light cycle is completed, the device displays a similar cycle related to the “sound” category using blue as the output colour, and so on continually cycling through all the sensor categories and colours.

The fourth “social” category is different to the categories described above in that it is not directly linked to sensor values accessed from the sensor platform. Instead, it is calculated based on overall user feedback for the category. As described in the design section above around the notion of “social connectedness” category, the intention of including this category was to trigger subsequent discussion with participants about their interpretations of this. Therefore, because of the way the values are calculated for this category, the “sensor” and “group” values are identical. To assist users in learning the mappings between colours, sensors and the available interactions, a “cheat sheet” was prepared to accompany each device.

There are three interaction methods provided the device through a combination of the scroll wheel and push button inputs: (1) **scroll wheel**: users can move the wheel to choose between the various sensor categories manually. For example, a user could scroll the wheel cycle through to the sound category immediately instead of having to wait for it to finish the remaining cycles. (2) **push button**: pushing the button triggers the display of the user’s preference for the sensor category that is currently being displayed. When the user releases the button, the associated value read from the sensor platform is displayed on the device. This allows users to easily compare the currently sensed value against their preference in order to help them think about whether they would like the preference set slightly higher or lower. (3) **scroll wheel and push button**: when the scroll wheel and push button are used together, users are able to set their preference value for a the currently selected sensor category. To do this, they simply keep the button pressed down and set the desired value by scrolling. The intensity of the orb adjusts continuously as they scroll the wheel. As soon as they release the button the preference setting is recorded. The design of the device is such that this interaction can be easily achieved with one hand (i.e. by pressing down the button with the index finger and simultaneously using the thumb to scroll the wheel).

A small set of audio cues are also employed by the device to improve the interaction. As the scroll wheel is turned, subtle “clicks” are produced to provide users a sense that they are selecting discrete values. When the wheel scrolled into the “middle” position, a slightly more pronounced click is produced to provide an audible locator for the middle of the input range. To notify the user of when a preference has been successfully recorded and transmitted to the server, a separate “chirp” sound is

Fig. 6 MobiOrb mobile interface (right)

made. Finally, once a day each device emits a short "buzz" sound to act as a reminder to users and encourage them to record their preferences at least once for the day. This sound has been carefully chosen to be noticeable to users, but not to be too annoying.

3.3 The MobiOrb Mobile Application

The MobiOrb mobile application is an alternative interface for interacting with the system. This provides an identical set of functions as the MiniOrb device, is built around a different set of interaction mechanisms (see Fig. 6). Besides the differences in approaches to interaction between the two interfaces, the main difference between them is that users are able to see and set more precise and specific sensor values in the MobiOrb interface (e.g. Light 88 lx).

All of the sensor readings, user preferences and group average preferences are displayed on a single screen in the mobile interface. The screen is divided up into four separate sections, each of which displays information for a single sensor. The four sections all follow a similar graphical layout. Each has a colour-coded slider corresponding to the colour categories used in the MiniOrb (described above). These sliders allow users to record their preferences by sliding left and right. The numerical value of the preference is also displayed in a textbox within the slider. Values of the sensor readings taken from the sensor platform are shown in units relevant to that sensor (e.g. Celsius, lux, decibels) at the bottom of each section. In the middle of each section is another textbox which displays the average group preference for that sensor. Despite the differences in how the information is displayed, the values for sensors and preferences shown in the two interfaces are exactly the same. The most significant difference in terms of the users' experience of the interfaces is that the mobile interface allows more accurate assessment and setting of sensor and preference values, but does not provide the same level of ambient accessibility afforded by the MiniOrb devices placed on users' desks.

4 MiniOrb Evaluation

We evaluated the MiniOrb system through a number of user studies. This book chapter summarises outcomes from a two week long trial of the MiniOrb system carried out in situ with users in their actual work environment along with the outcomes of a number of post-trial semi-structured interviews, which were carried out with participating users. A comprehensive account of the study results has been published in Rittenbruch et al. [20].

4.1 Study Design and Setup

The participants for the study were recruited from inhabitants of the Queensland University of Technology's Science and Engineering Centre (SEC), Australia. This is a recently established research centre, situated across two newly constructed buildings. The buildings host general staff, academics as well as postgraduate students from a variety of disciplines. To recruit participants, an email was distributed to all SEC inhabitants inviting them to take part in the study. The study was planned in three parts, as follows: (1) a questionnaire which assessed existing participant attitudes and preferences in relation to indoor climate factors; (2) an in situ trial of the working MiniOrb system over two weeks; and (3) a post-trial semi-structured interview which aimed to investigate participants' experience of using the device and interpretations of the sensor categories.

Participants' involvement of the different stages was entirely voluntary and participation was obtained via informed consent. Participants were free to withdraw from the study. The overall study design was run twice, once in each of the buildings of the SEC. In total 11 participants across the two trials participated all the way through to the post-trial interview stage. To categorise the interview results we conducted open coding through a grounded theory approach.

4.2 Study Results

This section presents and discusses results from the MiniOrb trial and post-trial interviews.

4.2.1 Post-trial Interviews

The post-trial interviews were organised around three sections: (1) participants' attitude toward office comfort, (2) experiences interacting with the MiniOrb ambient device and (3) experiences interacting with the MobiOrb mobile application. The intention of the first section was twofold: first, enrich the data on attitudes to office comfort levels collected in the earlier round of questionnaires; to provide greater detail on participants' working context; and second uncover attitudinal differences between individual participants. The remaining two sections inquired into how and when people made use of the devices on their desk, and what their perceptions of usability and user experience were. The results from each of these sections of the interviews are discussed in turn below.

4.2.2 Attitudes with Regards to Office Comfort

Although many of the participants reported that they appreciated their office environments over, we identified several concerns from participants regarding office comfort factors. The most commonly raised issues were around temperature. Several of the participants were of the opinion that the target temperature of the air-conditioning system for the building was set "a little bit" too cold. Participants also reported noticing the cold more during certain times of the day (e.g. in the afternoon). It is important to note here that due to the fact that the study was carried out in a subtropical environment. Therefore, issues around the building being too cold did not imply that insufficient energy was being used to warm the building, but the opposite, that energy was being wasted by cooling it more than necessary. The next most frequently raised set of issues were concerned with noise in the building. The notion of "noise" could relate to several different sources of sound, such as building noise, environmental noise, etc. In the context of the interviews, noise was almost exclusively discussed in terms of the noise resulting from conversations within the workspace. Several participants described being disturbed when nearby people chatted or carried on conversations on the telephone. Approximately half of the participants reported that they used headphones to cope with this kind of disruption. Strategies reported by other participants were to move to a quieter desk, to use a separate meeting room, or to work in the university library. Noise issues were reported exclusively by participants situated in an open office workspace. Sources of noise not related to conversation, such as general background noise, were not perceived as a problem. Some participants reported issues around lighting, particularly in relation to how window blinds were set. Participants' response to light as an issue was dependent on the location of their desk in relation to the windows and the direction of sunlight. Participants either perceived that that their work environment was too dark and that they could not clearly see the outside environment, or the opposite, that they received too much light, which caused reflection and glare on their computer screens. Overall however, complaints about lighting levels were fewer and less intense compared to issues raised around noise and temperature. The notion of privacy within an open office setting was also raised as an issue several times. Some participants expressed a desire for more secluded cubicles or offices so that they could carry out their work with more privacy. When we asked about the level to which participants perceived a level of control over their current environments, the majority expressed feelings of very low or even non-existent levels of control. The control factor most requested by participants was to be able to adjust the temperature, followed by the ability to control the setting of the automatic window blinds. Some participants also mentioned a desire for control of privacy and noise aspects, but also reflected that this would probably require changes to be made to the physical layout of the office environment.

4.2.3 Experience Using the MiniOrb

All participants who were interviewed reported that they had used the MiniOrb device. The interviews revealed a number of common patterns participants followed when recording their comfort preferences. The first pattern indicated that many study participants used the interaction device when they first arrived at their desk in the morning, and again at other times when they returned to the desk after a temporary absence (e.g. e meeting or a break). Participants reported that the reason for this was that they perceived the interaction device had a very ambient quality and blended into the background so that they "forgot" that it was there after a period of time. When they returned to their desk from a break however, they commonly noticed the orb displaying sensor readings using different colours and "remembered" that the device was there. The second pattern was that participants would use the interaction device specifically to specify preferences, either when they perceived the environmental conditions as uncomfortable, or when aspects of their local environment changed (e.g. a change in light levels due to the automatic blind control). The third pattern that emerged was that participants commonly provided feedback on comfort levels when the interaction device played a specific sound that had been created to periodically "prompt" participants. A large majority of participants made positive comments about this interaction mechanism. Participants felt that the mechanism prompted them to provide input and cases where they otherwise would have forgotten to do so. Participants reported that they did not perceive the interaction to be distracting or intrusive. One of the participant further reported that they were encouraged to provide feedback by hearing that other people were sending feedback from their own devices (the device issues an audible "feedback submitted" sound that could be overheard by other users who were close enough). Once they heard the sound that remembered the device "existed" and use it themselves to provide feedback.

A large majority of study participants reported that they enjoyed having the interaction device sitting on their desk and felt that it was both easy to use as well as very unobtrusive. Not all aspects of the device were used out the same rate however, and some functionalities were interpreted and applied differently. One aspect that was significantly different between participants was the way that participants recorded their climate preferences. One group of participants frequently used the push button in order to compare the current sensor reading with their own preference setting for a specific category. These participants would commonly set the preference value a "little bit higher" or "a little bit lower" than the status that was currently displayed in order to indicate a gradual change in preferences. Another group of participants, instead turned their preference values to the maximum or minimum setting possible in order to indicate their strong desire for this value to change respectively. When asked, these participants said that they did not think that they were trying to set a specific value, but instead felt that the interaction was more like "casting a vote". They further reported that they were most likely to use the device in this way if they felt strongly about their choice or wanted to express their discontentment (e.g. if they felt that the environment was too hot, or to cold, or that aspects of the environment were too noisy for them to concentrate).

The social category was different from other categories in that it did not directly relate to a reading from the sensor platform. Instead the "social value" was directly defined through the participants' input. Out of our group of participants only a number of users reported having used the "social" category. As described earlier, our intention with adding this category was to trigger discussion in study interviews of what our users' interpretations of such a category were. While some participants reported that they were not sure how to use and interpret this category, others gave unanticipated examples for how they used the social category and how its use resulted in unexpected social interactions. For instance, some participants who belonged to the same department group set their social preference value to the maximum setting at the end of their working day in order to signal to other co-workers that they were available to socialise. These examples show that such a category could be used twofold. First, to act as a measure of "social atmosphere" within the group and second as a way for co-worker to show social availability.

The aspect of the device that was used the least out of all features was the display of "group averages". A number of participants explained that they used the group functionality after submitting their preference via the interaction device in order to compare their own preference with that of other users. Many other participants however stated that they either were not sure what the purpose of the group functionality was or that the group setting was not relevant to them and that they subsequently did not pay attention to it.

Some participants highlighted the fact that providing feedback via the system made them feel like "somebody cared". These participants were well aware that the system only collected feedback values but did not affect actual change. They nonetheless valued the opportunity to share their opinion. One participant stated: "*(…) it just gave me the feeling that somebody maybe cares somewhere*".

The interviews showed some other, less prevalent, issues related to the system's design and functionality. One participant thought that the "press button" function would enable them to compare individual preferences with group average values, rather than sensor values. A single participant mentioned that the light emitting from the device's orb was somewhat distracting and subsequently positioned it out of sight. However, this attitude was not shared by other participants who did not find the device distracting.

4.2.4 MobiOrb Application Experience

Seven out of eleven participants that were interviewed had used the mobile application at least once. The most commonly made observation amongst that group was that the mobile application was less generally noticed or in people's mind. Most participants felt that they used the ambient interaction device more because it was placed on their desk and because it actively reminded and encouraged them to use it. The mobile application, by contrast, was not always turned on and visible. Participants had to remember it was there, access their phone and use it on purpose. This behaviour required more effort and was further removed from the immediacy of directly interacting with a dedicated physical device placed on the desktop.

However, once participants actually used the mobile application they said that they appreciated the ease with which feedback values could be set and found it generally easy to use. One participant commented that the process of setting multiple values was quicker and easier to achieve on the mobile device. The fact that all readings and settings on the mobile device were displayed as numeric values rather than relative colour hues marked an obvious difference between the mobile and the ambient interface. On average, our participants did not seem to prefer one way of presenting values over the other. Some participants voiced that seeing the concrete numerical values, as well as the actual range within which these values could be changed, enhanced their experience: "*It just felt like I knew more what I was saying with the range*". However, another participant mentioned that he liked being able to focus on setting their perceived comfort levels in relation to the current sensed value (e.g. "I would like the lighting to be a bit less bright"), without having to think about absolute numbers.

5 Discussion of Results

5.1 Reflection of Interview Results

The post-trial interviews gave us a nuanced insight into participants' attitudes about office comfort and provided an overview of how they used the various parts of the system. In the discussion that follows, we highlight five areas in particular, which warrant further discussion.

5.1.1 "Protest" Vote Versus Gradual Vote

The MiniOrb device displayed values of sensor readings as well user input about preferred comfort levels via changing colour intensity. This meant that what feedback values actually meant could be interpreted differently by different users. Two different ways in which participants employed the feedback mechanisms stood out as notable.

In one approach, participants would submit *gradual changes* relative to the current sensor reading to indicate preferences in comfort levels compared to the current level. In another approach participants would use the feedback to make submit more *radical change* by giving feedback at the most extreme available minimum maximum settings.

We refer to the latter approach (b) as casting a *"protest vote"*. Participants took this approach when they wanted to express strong disapproval or discomfort. In this sense, it was more similar to a yes/no voting approach than the continuous preference-setting approach we had imagined. This was in contrast to the gradual changes approach (a), which aimed to convey accurate readings of desired comfort levels. Protest votes only occurred in the context of discomfort as they allowed users to express feedback by selecting the maximum or minimum opposite value. For instance, a user who found the office environment too cold would set the temperature preference to maximum in order to express their desire to be warmer. Both approaches constitute a valid use of platform, however in comparison, the mobile application was generally less suited to the protest vote style of interaction. This was because users were already presented with the precise numeric value of their preference. Participants who actually saw how a "protest vote" mapped to particular numerical values on the MobiOrb application, reported that it became clear to them the recorded value was either very high or a very low. In most cases this extreme setting did not reflect what their actual preference would be. For instance, a "protest vote" might record the desired temperate of 30 degree Celsius, which did not match their actual preference, but only their desire to "be warmer". We believe that both are valid approaches for users to provide comfort level feedback and are worth supporting as separate interactions in future systems.

5.1.2 The Trade-off of Minimal Design

The MiniOrb device only provided limited number of input and output mechanisms. This minimal design was consciously chosen by us when we decided to design within the constraints of the existing sensor platform. This presented us with a challenge around how to design a minimal interaction device based on a limited set of tangible interaction mechanisms with suitable ambient output modalities. It was still necessary for the device to support a sufficient level of functionality while at the same time not over-burdening the user complexity. Based on our findings from the post-trial interviews, we are confident that this goal was achieved. Nevertheless, there are aspects of the design that could be reworked in future. Some redesign of elements of the sensor platform do seem warranted in order to expand the interaction possibilities for the device, while also retaining a simple and minimal implementation overall.

The device's "ambient quality" was well perceived and appreciated by almost all of our participants. They felt that the device quickly faded into the background when it was not being used, but that is was equally as quickly available whenever they wanted to interact with it. However, not all of the functionality built into the device was utilised to the same extent. A salient example was the display of the group average, which was used by a limited number of the participants. The relative lack of use of this feature might have been influenced by our decision to allow users to compare their own feedback to the value of the respective sensor reading rather than to the group average. It became clear from the interviews that this functional design decision was significant due to how it supported users to feel that their preferences were aligned with those of the group. This further emphasises the point as much as indoor comfort is a measurable physical phenomenon, it is also a social phenomenon. By making the comparison with sensor values in our design instead of with the values of the group preference, we de-emphasised a "social" view of indoor climate in favour of a "physical" one.

Building a small device with limited interactive capabilities always requires a trade-off. With regard to the design of the MiniOrb device, we suggest that instead of attempting to combine the comparison of group averages and sensor values in a single device, a better design approach is to extract less frequently used areas of functionality, such as the group average readings, and instantiate this functionality in a separate interface dedicated to that task. For example, we imagine complementing our system with a separate "MaxiOrb" device that designed solely for the purpose of publicly displaying group averages to group of users, such as clusters of users in an open plan office belonging to the same work group.

5.1.3 Subjective Perceptions of Being Listened to

Our findings emphasise that how people experience office comfort depends on more than measurable factors. People care about things like "being appreciated" as well as measurable parameters like temperature. An important consideration for the design of systems like this is how to design such systems so they give users the feeling that they will be listened to. It further raises questions about how such mechanisms can help share office comfort attitudes with other inhabitants and help to affect change. For instance, with regards to the "MaxiOrb" public display idea described above, we could consider how such an interface would allow users to indicate to their colleagues that the office is becoming too noisy, thus raising awareness across a wider section of the office population.

5.1.4 Encouraging Interaction

The "remember me" buzz that the device periodically issued to encourage and remind users input their preferences had a stronger than e3xpected influence on users' pattern of use. Somewhat surprisingly, users did not report that they found these notifications distracting. Instead, they reported perceiving them as welcome reminders to use the system. Conceptually, this notification can be thought of as an interaction which moves the device out of an ambient "background" mode of interaction into the foreground of the user's attention. Compared to a more conventional notification, which indicates a change to the system's state, the "remember me" function acts as a form of *reverse notification*, that encourages the user to interact with the device.

5.1.5 Ambient Versus Mobile Interaction

The interview results indicate that the ambient and the mobile interfaces each fulfil different and complementary roles. A key characteristic of the MiniOrb device was its ambient quality. Because it was physically located at users' desks, it was able to act as a constant reminder, while only requiring a minimal interactive effort. This is a highly useful characteristic for an interface to have if the aim is to eleicit user input over an extended time period. In comparison, the mobile device "MobiOrb" was appreciated for its clean user interface, that was better suited to interpret the numerical values and range of the sensor categories and allow users to give more accurate feedback. Interestingly, several users expressed a preference for this interface to be installed as an application on their desktop computer, rather than on their mobile device. These users felt that such an application would better integrate with their desktop working environment and their overall work routines. In general, users felt that the MobiOrb mobile interface was providing additional functionality and saw it as a complementary rather than a replacement interface to the ambient MiniOrb interaction device.

6 Conclusions

The purpose of this book chapter was to explore the notion of direct end-user interaction with and through IoT devices. To this end we described the design, use and evaluation of MiniOrb, a system that combined a sensor platform with an interaction device. The device combines ambient output with a tangible input approach to allow users to share their subjective perceptions of the comfort of their office environments, in particular relating to temperature, lighting and noise. One specific attraction of a tangible interaction approach in this context is that it gives physical presence to a phenomenon that is normally not visible or in peoples' foreground experience. The work reported here addresses two related questions. First, to what extent can ambient and tangible interaction mechanisms make it easier for office inhabitants to reflect on their subjective office comfort levels and record their preferences, and second how do these mechanisms compare to other more traditional approaches that enable users to see sensor information relevant to office environments and record their preferences?

The results show that is feasible to build minimal interaction devices that use non-screen-based interaction approaches such as ambient and tangible interaction mechanisms and that these mechanisms are well suited to engage users in the process providing preferences. Indeed, even with the rather minimal interactive elements that could be supported by our constrained IoT sensor platform, surprisingly rich user interactions and behaviours emerged. This process can be further aided by providing complementary interfaces to provide additional options for the input and reading of accurate sensor and reference values. In our case this was achieved by the provision of a mobile user interface in addition to an ambient interaction device. What is particularly notable is that the system we tested with users did not actually affect the lighting, temperature or any other physical aspects of their indoor environment, but simply recorded what their preferences were in relation to comfort. One would expect that this lack of actual physical control would result in a significantly reduced incentive to use the system. Nevertheless, users still made frequent use of our system. The fact that users reported that they felt they were being "listened to" underlines the need for exploring alternative interaction approaches that allow individual control for users within these environments. While overall, the evaluation points to the success of the system from a user-experience perspective, the results of our study identified many further nuances with regards to the process of how users provide feedback, which functionality should or could be integrated in a minimal interaction device, how to prompt for specific feedback and interactions and insights into how users interpret and handle the display of vague versus accurate sensor readings.

The results show that questions around how to design specific interaction elements that enable direct end-user interaction with IoT sensing platforms are an interesting and valid line of inquiry. End-user enabled interaction devices offer an additional dimension, not normally offered by standard IoT devices. First, they allow for the meaningful interpretation of sensed data through end-users. This approach specifically make sense if the data is directly relevant to end-users, as was the case in our case study on office comfort levels. Second, they allow for crowdsourced end-user feedback to be collected directly at the IoT device level, rather than being collected through different devices (e.g. mobile phones). This approach allows for immediate feedback that ties together the interpretation of sensed data with subjective user feedback. We believe that the study we described here is a first step to gain insights into the tighter integration of direct interactive capabilities in the context of IoT and will help to inform future research in this context.

7 Key Terms and Definitions

Ambient display/interface—Displays meant to minimise the mental effort required to perceive information

BMS—Building Management System

IoT—The Internet of Things

MiniOrb—A custom built sensing and interaction platform for indoor climate preferences

Peripheral awareness—Ability to perceive object or actions not in the direct line of vision

Tangible interaction—Supporting interaction through direct manipulation of physical interfaces

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Engaging Children with Neurodevelopmental Disorder Through Multisensory Interactive Experiences in a Smart Space

Franca Garzotto, Mirko Gelsomini, Mattia Gianotti and Fabiano Riccardi

Abstract Our research explores the potential of IoT (Internet of Things) for children with Neurodevelopmental Disorder (NDD), such as Intellectual Disability, Autism Spectrum Disorder, Down Syndrome, Attention-Deficit Hyperactivity Disorder. The paper describes an IoT empowered physical space called "Magic Room" that supports interaction with "smart" objects and the entire space through body motion and objet manipulation, provides different combination of stimuli. The Magic Room has been designed in collaboration with NDD experts from a local care centre and and, providing an open set of multimodal multisensory activities for children with NDD that stimulate the visual, aural, tactile, olfactory and motor system, may pave the ground towards new forms of intervention for this target group. The technology beneath the Magic Room is an extensible multi-layered software and hardware platform to connect and manage different devices. Activities executed into this Multisensory Environment (MSE) are completely customizable for each child by the therapist.

Keywords Children · Disability · Neurodevelopmental disorder (NDD)
Multi-sensory environment (MSE) · Snoezelen · Full-body interaction
Smart space · Smart object · Smart light · IoT

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_9

1 Introduction

Internet of Things (IOT) is a general term often used to describe digitally enhanced physical objects or spaces enriched with sensors and actuators, connected through a network, digitally controlled, and enable to exchange data. As the power and popularity of IoT technologies and applications increase, researchers face the challenge of making them accessible to and useful for people with disabilities. The focus of our research is to exploit IoT technology for children with Neurodevelopmental Disorder (NDD).

Neurodevelopmental Disorder is an umbrella term, used to identify different pathologies arising during the development period and characterised by the co-occurring deficits in cognitive, social and motor sphere [26]. Intellectual disabilities, Attention Deficit and Hyperactivity Disorders (ADHD), Autistic Spectrum Disorders (ASD) are the most frequent examples of NDD. These deficits affect deeply the life of these people and of their families, since patients can be unable to complete even simple daily tasks, which makes them strongly dependent on others to live [12].

NDD is chronic and patient's improvements are generally very small and very slow. Still, it is acknowledged that intensive support from the childhood can help to alleviate the symptoms. Some therapies have been developed, but they must be deeply customized and constantly adjusted on the patient's needs. Many therapeutic interventions have the goal of teaching some basic skills so that the patient can acquire a sort of, even minimum, autonomy in his/her daily life, e.g., through practices that promotes gross and fine motor coordination, attention and social interaction.

Among the many possible approaches to help these children *multisensory interventions* have a special role. These practices are grounded on two main concepts. First, the theory of sensory integration posits that the learning process depends on the ability of processing and integrating sensory information process and integrate them in order to plan and organize behaviour [9]. Second, most of the impairments associated to NDD are thought to originate from a sensory dysfunction, i.e., the fact that the sensory stimuli are badly processed and integrated. The result of this incomplete or distort process is the creation of an abnormal mental representation of the external world. This in turn may produce motor impairments and deficits in cognitive skills, like generalization, space awareness, language usage and social behaviour [13, 20, 24], and induces distress and discomfort, frequent concentration losses, and disengagement from the proposed activities. Multisensory interventions—integrated today in many programs both in therapeutic centres and in schools in US, Canada, Australia, and UK—attempt to improve the sensory discrimination, i.e., the ability to focus on and discriminate between different simultaneous stimuli, and sensory integration, i.e., the ability to interpret properly multiple sensory stimuli simultaneously.

Some kinds of multisensory treatments require a suitable space, called Multisensory Environment (MSE), a room intended to stimulate the vestibular, proprioceptive and tactile sense of the user, train the integration and identification of the different stimuli, and engage the user in useful activities.

Fig. 1 Physical environment where the magic room is installed (on the left). Multisensory effects in the magic room (projections, lights, bubbles, smart objects) (on the right)

In our research, multisensory environments meet Internet of Things (IoT) technology to offer a digitally enhanced space where sensory stimuli are originated from digitally enhanced objects ("smart objects") or from the entire "smart environment" through multimedia digital projections, ambient sound, lights embedded in the physical space.

The solution we propose is called "Magic Room" (MR) where children with NDD can be involved in playful multisensory experiences that are specifically designed in order to match their needs and offer a much wider gamut of play opportunities than traditional MSEs [1]. The process of designing both the smart environment, the smart objects, and the activities to be performed inside the MR involved a local care centre and a set of NDD specialists who are experts in the use of traditional MSEs.

MR provides digitally controlled stimuli for the audio-vestibular apparatus, the vision, the touch and the olfactory system, in a coordinated meaningful way and in response various forms of interaction, e.g., object manipulation, gesture, and body movements in the whole space (Fig. 1).

2 Related Work

2.1 Traditional Multisensory Approaches

Multisensory approaches have been largely considered in past years and this has resulted into the adoption of two main approaches: one refers to objects and one refer to spaces.

The usage of toys to stimulate the children's senses especially for children affected by NDD, is exploited in various methodologies [5]. Many of them have been inspired by the Montessori method: exploration through senses is the best motor of learning simply and especially thank to the repetition of tasks at one's own pace. These toys, called Montessori toys, reflect this concept and emphasize it through the usage of

Fig. 2 Examples of Montessori toys and Hasbro's Bop-It!

natural materials (mainly wood) and simple shapes. This simplicity also allows the therapists to be creative in the activities they design for each child. Repetition of tasks can be effective in terms of relaxation, acquaintance with the toy and subsequently additional stimuli like light and sound can be added afterwards to motivate children. Another significant example is Bop-It! from Hasbro, which can be pressed pull or tilt in accordance to the command voiced out form the toy itself (Fig. 2).

However, these toys are not customizable for the children: the set of components is fixed and modifications require the manufacturer to create a new version of the toy. Moreover, these toys have a limited amount of senses that can be stimulated simultaneously, mainly focused on visual. More sophisticated solutions can be achieved by considering the environment in which the child plays.

The expression MSE is often referred as the "snoezelen room", for short "snoezelen". This term is referred to a product present on the market and originally developed in the seventies in Holland; snoezeln is the contraction of two Dutch terms "snuffelen" (meaning "to discover or explore") and "doezelen" (referring to a relaxed state). The goal of a Snoezelen is to offer a soothing, nonthreatening and relaxing environment that promotes a general feeling of restoration and refreshment by engaging people with NDD (with the close support of caregivers) with pleasurable, explorative experiences while keeping controlled the amount, intensity and quality of stimuli proposed.

Studies have been conducted to explore the therapeutic and educational effectiveness of Snoezelens and they report improvements of the ability to adapt to circumstances and the mitigation of some stereotypes during the sessions in the MSE [18, 20, 26].

However, "snoezelens" have limitations since they offer a restrained capability for the user to interact with artefacts producing a "cause" and receiving an appropriate stimulus as an "effect" to establish a case-effect relationship, fundamental in the development of cognitive skills. In addition to this limitation, another issue is linked to the creation of learning scenarios, sequences of combinations of stimuli from different sources, which is time-consuming and potentially risky for the session flow, since the stimuli in the snoezelen can be controlled only by the usage of physical buttons; this is not merely a problem of tiredness of the therapists, but also forces the caregiver to release attention from the user, who can in turn remove attention from his/her current task.

Several authors [2, 11, 21] therefore call for exploring new materials and solutions for MSEs.

2.2 Digitally Enhanced Multisensory Approaches

Researchers in the assistive robotic field have taken the path of designing robots able to sense touch, communicate through sound, movements and, in some cases, lights. Several examples have been realized in past years with specific therapeutic or educational purposes. Most of them are static robots [10, 14], with some notable exceptions that offer children the possibility to explore the physical space while experiencing a controlled multisensory experience. QueBall [25] is a spherical robot able to roll in order to move, sense touches on the surface and communicate with the user through a wide range of visual and sound stimuli. I-BLOCKS [6] offers a set of composable blocks equipped with sensors and actuators that can be connected to create interactive floors or walls. Teo [3] is a soft, huggable, mobile robot that can react to manipulation; it enables joint (child + robot) body movements in the space and joint control of multimedia contents on external displays.

Polipo [27] is an interactive smart toy devoted to training fine motor skills. Activities with this object are completely dependent to the presence of the therapist who provides support and decides which kind of movements the user has to perform. Polipo is equipped with four functions designed to train four different motion (press, pinch, slide and turn) that can be personalized to increase the difficulty of the action. It is also equipped with lights and speakers to play the preferred song of each child, which is directly customizable by the therapists, and is used to give positive reward to the child when completing a task.

Still, the cited works use one or more interactive devices in sedentary contexts, and do not investigate the learning potential of combining full-body interaction [4] and multisensory stimuli in the whole physical ambient.

The legacy of research on MSE has been collected by other researchers, mainly in the field of HCI and Assistive Technology, resulting in new approaches.

MapSense [7] is a multi-sensory interactive map that uses a touch-sensitive surface, tangibles, olfactory and gustatory stimuli, to help visually impaired children improving collaboration and memory skills. MEDIATE [22] is an example of interactive system that implements multisensory full-body interaction in the space, creating a sense of agency in children affected by NDD and to enhance non-repetitive actions in their behaviour. This is achieved through visual, tactile and aural stimuli, letting the user express him/herself through body movements: it contains, for example, an interactive floor able to generate sounds in reaction to the user's footsteps. However MEDIATE does not integrate with smart objects, which is important to focus the attention of the child, to promote multimodal sensory integration and to trigger different possible behaviour of the user during the therapy.

A different approach has been used by Sensorypaint [23], which is a multimodal multisensory system designed to let the player digitally paint using physical objects, body-based interaction and interactive audio.

Authors have compared the use of Sensory Paint with other MSEs through empirical studies, noticing that the combination of aural-visual stimuli and full-body multimodal interaction sustains engagement and helps develop different skills.

2.3 Customizable Technology

Several researchers in Assistive Technology (AT) pinpoint the importance of keeping both the caregivers and the care receivers "in the loop", meaning starting from these stakeholders' needs and defining technologies that can be customized to their specific and evolving needs during the therapeutic program.

A number of studies (e.g. [8, 28, 29]) embrace the concept of "user empowerment", which can be expressed as "the users of the technology are empowered to create and modify it to solve their own problems … and they are involved in all design activities, including the development of prototypes" [19]. As discussed in [17], addressing the "user empowerment" requirement is fundamental in Assistive Technology to increase the success of an adoption process and the adoption rates consequently.

Important paradigms that are emerging in the AT field are the so called "Do it yourself" (DIY), and End User Development (EUD) [16, 28]. Both these approaches claim that it is important to provide forms of customization beyond parameters tuning, making possible for therapists or caregivers to build and personalize the technology they are using. In MapSense [7], for example, the tangibles integrated in the system's interactive map are created by the educators and visually impaired children using 3D printing.

The robotic system reported in [29] provides a Scratch-like interface, letting the therapist to use a basic visual programming tool to design the behaviours of the robotic components according to the need of each care receiver. Now the challenge is to enlarge the power of DIY and EUD tools to smart ambients, instead of the single object present in the environment. An example is presented in [16], where authors describe a preliminary EUD tool for Ambient Assisted Living scenarios allowing the elderly and their caregivers to control and tailor personalized behaviours of different smart appliances in a "smartified" house.

3 The Magic Room

The Magic Room (MR) is an "open" smart environment designed to transform any regular room (which must satisfy only some minimal preconditions dimensions and aeration system) into a magic multisensory play space that offers enjoyable experiences to children with NDD, and helps them in learning and wellbeing.

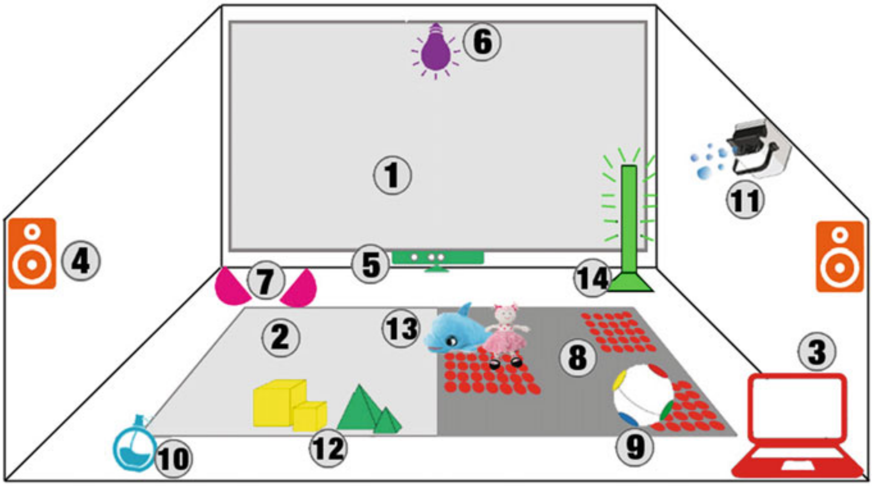

Fig. 3 Schema of full MR's content. (1) front projection, (2) floor projection, (3) computer, (4) audio system, (5) kinect sensor, (6) fed smart lights, (7) portable smart lights, (8) smart carpet, (9) magic ball, (10) olfactory machine, (11) bubble maker machine, (12) smart object, (13) smart dolphin and smart doll, (14) tube lamp

Compared to commercially available solutions of traditional MSEs, the Magic Room is much more affordable, and can be extended easily both in terms of devices present in the smart environment and in terms of available stimuli and activities.

As shown in Fig. 3, the MR is equipped with:

- two projectors, one oriented towards the front wall and one oriented towards the floor
- a Microsoft Kinect™ sensor in order to detect the movements of the children playing in the room, the gesture they are performing and their position
- an audio system composed of 5 speakers appropriately disposed across the room and a personal computer that controls and orchestrates the behaviour of these appliances
- several smart objects: objects of different geometric shapes and materials (a cube, a pyramid, a cylinder, and a ball) and plush toys. These smart objects contain sensors and actuators in order to detect the child's interactions with the smart object and with the smart environment; such sensors may vary from the different smart appliances but can be categorized as accelerometers, gyroscopes, tag readers, touch or pressor sensors, while actuators can be categorized as motors, controllable light actuators, sound emitters and vibration motors. The covering of smart objects is usually made by fluffy soft materials in order to be comfortable at touch and pleasant to the sight.
- smart lights (portable lamps and light bulbs on the walls) that can be remotely controlled and can change both in colour and in brightness; we are currently using

Philips Hue^{TM} lights that are easily retrievable on the market and are distributed with public API's to control them.
- a set of digitally controlled appliances: a bubble maker, to produce soap bubbles that are known to amuse children and tube lamp that illuminates a vortex of bubbles inside with changing colours, and is very attractive for children.

The enabling technology of the MR is based on a multi-layered software and hardware architecture integrating various sensors able to detect the behaviour of the children that are playing into MR and to communicate with smart objects of different nature and to respond with an orchestrated set of stimuli.

4 Children's Activities in the Magic Room

The children's activities in Magic Room consists of simple games that involve movements in the space and interactions with smart objects, smart lights, and multimedia contents [15]. All the activities have been designed in cooperation with therapists for local care centers to adapt both to their educational purpose and to the children's needs.

It is important to notice that, independently of the complexity of the activity and the sensing capabilities of MR, the caregiver can keep the complete control: when the activity is running he/she has a remote control with which he/she can trigger events that are too complex or that MR is not able to sense, or can force the execution of some control "instructions" so to adapt the activity more efficiently to the child's needs.

During the initial design phase, we acknowledged that a predefined fixed set of activities would have made the use of the Magic Room problematic: therapists' goals change very frequently and activities must be constantly tuned for each child. Hence in the initial version of the MR there was no automatic control or orchestration of stimuli: MR was a gigantic "Wizard of Oz" where all the effects were activated or deactivated through buttons or sliders on a visual interface over the PC by an operator according to the children's movements, positions and manipulation of objects. This has been of incredible value in a first exploratory study that has enabled us to simulate a countless number of interactive situations and tasks with the goal of finding the most suitable combination of stimuli.

However, this was not a appropriate solution on the long term: with one caregiver constantly focused on operating on the PC, children with NDD could not be properly controlled, nor they could receive the sufficient support to perform the task. Additionally when children understood that the "magic" was made by the caregiver at the PC, MR lost great part of its appeal.

To fulfil the therapist's need of customization and simplification of the management of the smart environment, we developed a web tool used to empower the caregivers which enables them to define new activities.

Fig. 4 Relaxation activities obtained through soft lights and calm environment and music

Therapists have defined so far over 35 multisensory activities that are characterized by different levels of complexity and cognitive effort.

In the rest of this section we report examples of these activities, organized in groups according to their main learning goals: relaxation, visual-motor coordination (eye-hand coordination), gross motor skills, spatial relationships, shapes, sizes and colours, social reciprocity and turn taking, practical skills, affection and emotional bond, attention, concentration and memory span.

4.1 Relaxation

The deficits induced by NDD create a state of insecurity, uncertainty, and inadequacy, which in turn originates anxiety, psychological rigidity, and resistance to any change in routine. Relaxation is fundamental to help children unlock these states. To help them a set of activities has been designed to relive the stress and are used also to create a trust bond between MR and the children. These activities are basically build with a video of realistic environment on wall and floor, coupled with soft lights of appropriate colour and natural inspired music and can be basically presented with innumerable different variations (Fig. 4).

4.2 Visual-motor Coordination (Eye-Hand Coordination)

To promote an efficient communication between the eyes and the hands, some activity relies on simple manipulation tasks of the Magic Ball (Fig. 5): a light stimulus is activated on the smart object in the position touched or pressed by the child. In a more difficult activity, projected animations suggest a spatial relationship, like “the cat is ON the table”; the ball has some orientation cues and the child is asked to press the ball in the area corresponding to the shown relationship, in this case on the top,

Fig. 5 Visual-motor coordination activities with polipo and the magic ball

so that the area becomes highlighted while a nice music is played, and soap bubbles appear.

Another type of activities relies upon the use of Polipo: the child is asked to perform fine manipulation of the elements present on the border of the toy to train in performing movements similar to the ones needed in the real life: the room projections display the situation in which that motion is needed and give visual feedback to reward the child increasing the motivation for him/her to continue.

4.3 Gross Motor Skills

Gross motor skills, which are larger movements a person makes with his arms, legs, feet, or entire body, are fundamental to perform every day functions, such as walking, running, and are also crucial for self-care operations like dressing.

To enhance gross-motor skills, in the "Pond game" some items like stones or leaves, are projected on the floor on top of an animation of a river or a lake, and the child has to walk or jump on the foreground items only, without touching the background. Another example is the "Catch the Stars": A realistic video showing a galaxy, with stars and planets, is projected on the wall, while the blinking white LEDs on the carpet render the effect of a starred night sky; the children must hit the corresponding areas to make them disappear. Another similar activity is the "Luminous Path" activity. The LEDs in the smart carpet draw sequence of interconnected straight lines (constituting a path) on which children have to walk while the Kinect sensor is tracking their movements (Fig. 6).

4.4 Knowledge Skills (Spatial Relationships, Shapes, Sizes and Colours)

These activities focus on teaching children the differences of objects in shape, size, colour, distance, and the relationships between these objects. For example, a character

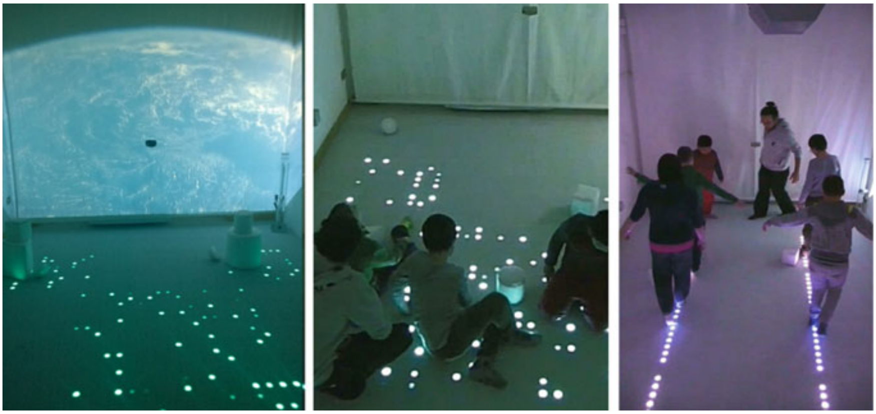

Fig. 6 An example of activities to train gross motion

Fig. 7 Activities to learn the basic geometrical shapes and the colours

on the screen invites the child to pick up an object of a given colour (or of a given shape) and place it in the corresponding shape on the floor lighted up thanks to the smart carpet (Fig. 7).

A more complex activity is "Move to", designed to train children to build associations between objects or shapes, and colours. A grid of images is projected on the floor (the images number depends on the chosen level of difficulty). Initially, each image shows an object with a dominant colour (for example a yellow sun, a red rose, a green tree) while the front projection presents a colour which is associated to one of the images; the child is asked to move to the image shown on the floor that has the projected color. When he or she reaches the right position, the image disappears and the lights in the room turn to the colour of the front projection. In a more difficult versions, the images show colored contours of objects only. Once the player has successfully chosen the correct item, he or she is asked to perform again the same

Fig. 8 Children playing at Piera the frog story

action when the projected colour changes, until all images have been successfully chosen. The child is rewarded for his/her success with a "waterfall" of soap bubbles, while the tube lamp produces bubbles and changes colour, and clapping sounds are played.

4.5 Social Skills (Reciprocity and Turn Taking)

The goal of these kind of activities is teach children respect for the others and appropriate social behaviour, e.g., waiting while others are playing and the turn taking need in social interaction.

These skills are promoted in the story of "Piera the frog and her family". This storytelling activity requires children to pay attention and listen to the animated characters, mimic and interact with them, and act in turns, waiting for a mate to complete an action or playing in groups to solve some tasks of imitation, as shown in Fig. 8.

4.6 Practical Skills

Activities in this category are devoted to promoting the understanding of some basic tasks in life social spaces such as crossing the road, taking a bus, or shopping. The physical room is transformed into an outdoor or indoor social environment, for example crossing the road with a policeman, by effect of sounds and fragments of realistic videos displayed on the walls and on the floor.

The interaction paradigm is the same as in the animated storytelling activities: the video proceeds if the child performs the right movement or gesture, or grasps the right object, according to social cues appearing on the current video scene.

In the "Bus stop" activity (Fig. 9- left), for example, a video of a real bus stop is shown frontally and children have to position near the signal so that the bus arrives,

Fig. 9 Activity to learn to take the bus (on the left) and the smart doll (on the right)

then people are shown to get off the bus; children have to wait until everyone has exited the bus then they are permitted to get up (simulated with the children that move towards the screen as if to enter the bus itself.

Another example is the smart doll (Fig. 9- right), equipped with an RFID reader with which it is possible to identify some card shaped tags. Over this card it is possible to insert in a transparent pocket an image that, for example, it represents foods. Using these images and changing the smart room to simulate a dining room is possible to teach children for example, like the salad is not an appropriate food at breakfast or that you can't eat more than one slice of cake per day.

4.7 Affection and Emotions

To promote the capability of developing and externalizing feelings, various activities with the smart dolphin (inspired to pet therapy methods) help children to build an affective bond towards this toy. The physical room is transformed into a virtual aquarium by effect of virtual sea worlds displayed on the walls and on the floor, soft light effects, and smooth music, and "real" dolphins swim in the room. The child manipulates the smart dolphin and explores its affordances; the dolphin reacts to touch, pressure, vibration, position change with the light of its LEDs strips, soft vibrations, movements of the mouth or the eyes, real dolphin sounds. When it "falls asleep", the lights are soft turned down and the video changes to a quite water space without animals.

Once the children are familiar and emotionally bond with the smart dolphin, they can use it in a more functional way. The smart dolphin becomes a bridge between the physical and the virtual world: a virtual dolphin on display suggests manipulations to do on the smart dolphin, and conversely, the smart dolphin can be used as game controller to trigger behaviours of the virtual dolphins in the sea world (Fig. 10). In this game, for example, a dolphin is swimming into the smart environment, displaying

Fig. 10 Activities with the smart dolphin SAM

a seabed in all its magnificence. Every action that the children do on the smart toy is directly represented on the screen: when the child caresses the head of the smart toy the sensors detect in and transmit information to the environment where the digital dolphin shows itself happy by performing somersaults, or if the pacifier is placed in the mouth of the smart toy the virtual dolphin goes to sleep.

In another game, a digital dolphin is swimming horizontally across the water while some rocks are falling or sliding horizontally moved by the waterflow against it; the child has to make the digital dolphin avoiding the rocks; the game is completely controlled thanks to the orientation of the smart toy: the gyroscope inside it is able to detect which orientation the toy has and consequently move the digital dolphin so that he is able to avoid the dangers to reach it's family.

5 The Magic Authoring Tool

To customize the Magic Room we provide caregivers with a tool able to define combinations of stimuli so that an infinite set of scenarios and activities can be created. This tool is the Magic Authoring Tool (MAT).

To define an activity MAT offers some primitives that are related to two concepts: what has been sensed by MR and what can be performed by its actuators. To define how Magic Room have to behave we offer a Rule Based descriptive language. Rules are used to describe "micro-tasks" and the effects of elementary interactions. To account for more structured situations and scenarios involving multiple interactions, rules are clustered in "Scenes" (sets of mutually exclusive rules). An "Activity" is a (ordered) set of Scenes. A "Session" is a (ordered) set of activities.

As shown in Fig. 11, blocks in yellow represent *rules*; each rule must have a *condition* to verify and *a set of actions* to perform, such that when the first condition characterizing a rule that is met, the associated sequence of stimuli is produced the control is moved to the next scene. Conditions of executions of the blocks (represented by green primitives) is represented by an *event* sensed by MR's sensors; could it be

Fig. 11 MAT interface: (1) stage area, (2) actions and sensing components, (3) multimedia contents, (4) simulation area

an action performed on a smart toy able to sense it, a motion or a position decoded by the Kinect or the caregiver's action on the remote control, when the event is too complex or undetectable by MR. As for the *actions* to be performed, instead, they are represented by the red blocks; they define different stimuli from the actuators present in MR. Once the caregiver has completed the activity description, MAT translates it into a programming language like code, interpretable by the orchestrator of MR.

Another important aspect to take into account is that different activities require different multimedia contents, and these content should be frequently updated along the time to reduce the risk of boredom. To address this issue, MAT includes a multimedia database where the caregivers can upload the multimedia content they need (e.g., retrieving it from the web) and use for an existing or new activity.

As an example, Fig. 12 shows a rule for a scene in an activity with the smart doll. This activity consists of projecting an image on the front screen that highlights a part of the human body (e.g., the left hand) and suggests that the same part should be touched on the smart doll.

In particular, the system waits for two different possibilities: the user can press the touch sensor present in the left hand of the smart doll or the caregiver can signal that the user has pressed the wrong sensor. The latter case has a predetermined behaviour where red light is shown for 3 seconds. In correct cases the light of the room turns to green, an image of a contour of child with the left-hand coloured is shown on the front screen, and a clapping sound is played. After 5 seconds, so that the child can elaborate and process the reward, the clapping sound is stopped, the light turns white and the image of the contour of the same child with the right-hand coloured integrated with an explanatory text saying: "touch the right hand" are shown.

Fig. 12 Example of a rule realized in MAT

6 Conclusions

We performed an exploratory study to investigate strengths and weaknesses of the Magic Room for children with NDD. The study involved 19 children organized in 4 groups attending the care centre. Children are aged 8–13 and have different forms of NDD (Intellectual Disability, ASD, Down Syndrome, Prader-Willi syndrome) at different severity levels: "severe" (IQ = 30–35, 4 children), "moderate" (IQ = 35–50, 9 children), and "mild" (IQ = 50–70, 6 children). They used the MR in group with their 2 therapists for 2 or 3 sessions. Each session lasted for approximately 40 minutes and was video recorded. Our findings, based on the observations reported by the caregivers, the analysis of video-recordings (performed by therapists not participating in the session, and a final interview to the entire therapeutic team, indicate that the MR has a strong potential as learning environment for children with NDD.

The experiences in the MR have elicited functional performances, social behaviours, and emotional responses that either do not occur using traditional MSEs or require much more time to be achieved. For example, the "familiarization" with the new space was surprisingly short. Even if children with NDD are often suspicious and worried about the unknown and any new situation may be a source of distress, the participants to our study were not afraid to enter the MR and were immediately attracted by all its effects: the experience in the room was perceived pleasurable, as a kind of magic. The various stimuli, especially the lights, the projected animations, and the bubbles seemed to trigger interest as well as positive behaviours and emotions. After the first session some children explicitly asked to play again in the room.

Some improvements in the areas addressed by the various activities (communication/socialization, emotion, cognition, and motor) were observed in each child regardless the individual differences in intellectual functioning and adaptive behaviour. According to the therapists, these improvements can be ascribed to the richness of interactions and sensory stimuli offered by the many smart components, the capability of bridging the physical and the virtual world, and the strong role given to dynamic interactive lights. Obviously, these results are very preliminary and further research is needed. Improvements were not consistently present in all children and all sessions, and we have no empirical evidence of long term or generalization effects.

Still, the Magic Room may pave the ground towards new therapeutic interventions for children with NDD that we cannot even imagine now.

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From Social to Civic: Public Engagement with IoT in Places and Communities

Can Liu, Mara Balestrini and Giovanna Nunes Vilaza

Abstract This chapter reviews existing work on public engagement with Internet of Things (IoT) systems from a social perspective. It contributes a taxonomy that categorises the emergent social phenomena around IoT in places and communities. We sample representative work from each category and summarise the identified factors that are positively associated to social and civic engagement. Based on previous work and our own experiences in this field, we discuss possible approaches to scale up citizens' participation and the role of technologies in such public engagement processes.

1 Introduction

With the development of pervasive computing technology, computerized objects blend in the environment in various forms and carry social meanings and functions. Under the lens of Social Internet of Things, things have social properties depending on the service they provide [5] and the relations they establish with humans and among each other. Objects can function as social actors, and social relations with and through objects are emerging [38].

As computerized and connected 'things' can be increasingly deployed in public settings, there is a shift in Human Computer Interaction (HCI) towards aiming to engage with citizens and communities to trigger new social dynamics [7, 21, 41],

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A. Soro et al. (eds.), *Social Internet of Things*, Internet of Things,
https://doi.org/10.1007/978-3-319-94659-7_10

augment everyday activities [46], invite mass public participation [47] and even address matters of concern [8]. The last decade has seen the raise of civic tech or digital civics, which Borhner and DiSalvo [12] have described as a logical step in HCI articulated turns from the cognitive to the social, to the cultural, and now to the civic. Central to the design of civic tech is the notion that researchers should design with citizens rather than for consumers [42], and community-led technologies have the potential to reconfigure power relations between citizens, communities and the state [12, 55].

Researchers are increasingly collaborating with communities to design and deploy new technology infrastructures with the goal to effect positive social change. Various forms of urban displays visualise citizen data in public space to improve awareness of civic matters and encourage behaviour change [52]. Numerous art installations and urban computing projects deploy computerized artefacts in urban spaces with the intention of engaging the public with critical issues and sparking conversation and discourses [29, 47]. Designers work with members of the public to engage with issues in sustainability, healthcare or development. Researchers argue that designing artifacts and systems helps people to re-imagine constraints and parameters surrounding issues [19]. The idea of object-oriented democracy has been posited to refer to the design of systems for grassroots communities.

How can IoT be used to identify, make sense of and address situated matters of concern? How to scale up the engagement within a larger social and societal context? How can technologies be designed to empower people to bound and solve bigger issues together? In this chapter, we give an overview of how IoT is used in public and community spaces in existing work, with a focus on the social aspects. We are interested in the social phenomena and activities that are triggered, performed via, supported by, and developed around IoT deployed at these spaces.

Although the term IoT is broadly used, it does not have a unique definition [4, 31, 59]. While some definitions focus on the telecommunication and some others focus on data collection and automation, they share a vision of pervasive connectivity that encompasses a wide variety of devices including appliances, sensors & actuators, displays, augmented objects, vehicles and so on. As we focus here on the social rather than the technical aspect of IoT, we use it as an umbrella term that covers computerised devices, objects and infrastructures that are connected wirelessly either locally or globally. Thus, we refer to a broad range of literature in urban computing, public display, civic participation and community engagement.

We contribute a taxonomy that categorises the emergent social impact of selected existing IoT projects for public places and communities, and summarise the important factors identified in the design and deployment processes. We provide an overview of how people use and appropriate the technologies as well as the social context and practices they are embedded in. Based on this we discuss the roles of IoT in public and community settings as well as the factors that can sustain and scale up its social impact.

2 Taxonomy of Public Engagement with IoT

While some IoT may trigger fortuitous and ephemeral social behaviours, others can galvanise communities and support them in addressing matters of concern in the longer term. We summarise existing work and propose a taxonomy with five categories of public engagement emerged around IoT technologies: triggering social interactions, raising awareness, inviting citizen participation, building communities, and addressing matters of concern. They are ordered by increasing scale of engagement and potential social impact. This section goes through each category and describes a few representative works, to highlight the observed effects and discuss the identified engagement factors.

2.1 Triggering Social Interactions

Interactive IoT deployed in public spaces are more accessible than QR codes or other technologies that require mobile devices for interaction. Rather than having people focused on their mobile phones, a physical intervention supports walk up and use, and can potentially trigger rich social interactions and discussions.

2.1.1 Attracting and Connecting Passers-by

Extensive research on public installations has shown how members of the public are attracted to engage with interactive technologies [35, 36]. There are known social phenomenon such as *Honeypot effect* [13], which describes how passers-by are attracted to an artifact when it is surrounded by other curious people. *Chains of interaction* are identified in CityWall [44], a large public display, where different turn-taking mechanisms took place among multiple users. The display showed pictures and allowed multiple hands interactions. Groups of friends approached the displays and teamed up in joint activities, or started playing games created by themselves, such as throwing pictures at each other directions. These social interactions happened spontaneously without commands from the researchers.

Fischer and Hornecker [21] demonstrated how *shared encounters* can be triggered in front of technology augmented media facades. They analysed the use of SMSlingshot, a public installation that allowed users to 'shoot' messages with a slingshot-shaped device, onto a media facade with a projected surface at a distance (Fig. 1). This intervention created several spaces that facilitated shared encounters, including a social interaction space, comfort spaces and activation spaces. A social interaction space was defined as the space around the input device, where a performer was 'shooting' a message while mingling with observers. Spontaneous social interactions were observed while a performer typed a message, including suggesting and reviewing messages, holding belongings for the performer to free his/her hands,

Fig. 1 SMSlingshot [21]

Fig. 2 Left: concept illustration and Right: deployment

snatching the devices and so on. Activation spaces were defined as where people could not understand the ongoing activity but might get curious to find out. Comfort spaces were where observers comfortably enjoyed a good view without being in the way of others. People transited across these spaces and created a dynamic social scene centered around the technology.

Another public installation—Jokebox [7], which required coordination between two passers-by to trigger an audible joke, was shown to work as an icebreaker for social encounters even between strangers (Fig. 2). However, although Jokebox was accepted in parks, squares and shopping malls, it was sometimes considered to be an annoyance among people who wanted to enjoy a quiet moment at a bus stop.

Public places are complex; social practices can at times blend or compete. Akpan et al. [2] deployed a public installation—Shadow Wall at ten places with different spatial and social properties and showed that contexts had major influences on how such technologies were perceived and approached. Some highly engaged interactors became *local champions* and played a significant role in drawing others to interact [41].

However, opportunistic local champions could also have a negative impact. For example during the deployments of Jokebox [7], street musicians and food sellers took up strategic places next to the system to display their businesses and invite people to play. This triggered a mixed reaction by passersby: while some were attracted to the interaction space, others preferred to avoid it. Designers for interventions in public should be prepared to solve unpredicted issues and potential opportunistic appropriations and be mindful of the influence of urban interventions in people's routines and activities in a given space (e.g. bus stops).

2.1.2 Connecting Places and People

The Screens in the Wild project [39] presented a network of four urban screens placed at different public locations across two cities (Fig. 3). It allowed people to see video feeds of all the other places on any of the screen and interacted remotely by playing music notes together with a touchscreen. People could also post photos to the displays via social media under particular hashtags, regardless of where they were. During the development phase, the researchers identified tensions in the requirements of the technology between different local communities in terms of the content sourcing, scheduling, moderation, and purposes. The paper highlights a number of challenges associated with designing situated urban interventions for connecting heterogeneous places and communities.

Community displays can be better designed in collaboration with the beneficiary communities. For example, Taylor et al. [49] collaborated with an English rural community in North West England to investigate how public displays could support social interactions at a local level. They adopted a set of user-centric and participatory methods to design and deploy the Wray Photo Display (Fig. 3). Between 2006 and 2010, researchers worked closely with the residents and a 'champion' who acted as an access point, to investigate how the use of the display emerged over time and how real experience with relevant technologies could help community members to engage in participatory design process.

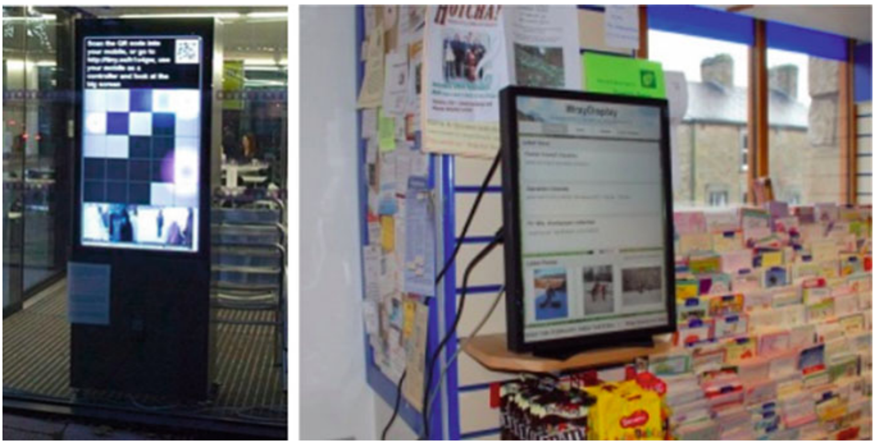

Fig. 3 Left: Screens in the wild [39] and Right: wray photo display [49]

2.2 *Raising Awareness*

Moving forward from triggering social interactions and a joyful moment, researchers have also explored how situated technologies can be used to raise awareness about local issues and enable conversations [29, 52].

2.2.1 Opening Discourses

Urban Probes [43] are provocative interventions that augment everyday objects with sensing technologies, deployed in urban spaces. For instance, Paulos and Jenkins [43] augmented a trashcan with sensors, a camera and a projector, which displayed captured trashcan activities over a timeline on the ground in front of it (Fig. 4). It used an object-oriented approach to reflect citizen behaviors and open discussions around environmental issues.

In fact, many urban interventions do not only attract passers-by to view or interact with readily available content, but also engage them to participate by contributing their own content [29, 33]. Citizen participation can play an essential role in increasing collective awareness. People intrinsically care more once they contribute, leading to increased involvement and engagement [25].

Johnstone et al. [29] reviewed a series of urban art interventions that engaged local communities to create situated content including stories and opinions, with aims of negotiating urban relationships and promoting connectedness. They identified four categories from this body of work: memory collectors, community consultation

Fig. 4 Digital Travelling Suitcases [16] and Visualising Mill Road [30]

devices, communication facilitator and performance generators. The interventions were designed in ways that combined digital and analogue techniques, eg. old telephone, mailbox, etc., to engage a wide range of user groups to create content. Some installations anonymised the content to encourage people to share personal stories. The authors proposed a set of design guidelines for such interventions: facilitate content creation; enhance information representation; support knowledge dissemination and allow content enrichment.

2.2.2 Revealing Heterogeneous Places

Crivellaro et al. [16] introduced an intervention Digital Travelling Suitcases (Fig. 4) into a residential community undergoing an urban regeneration project. Through a participatory approach, the researchers co-designed a walking trail and a technology-augmented suitcase, which comprised an audio system and question cards, for recording and playing place-specific stories. Being passed around among residents, the suitcase played a role in keeping and staging different versions of life in the community. It revealed heterogeneous voices and values bound to a place and triggered discussions about different ways for people to contribute to re-making the place. The ideation process of contributing content shifted the residents' understanding of history. The residents showed engagement and claimed ownership of the intervention as it was seen "for the people". Tension between the housing organisation and the residents became visible and open for discussion.

Another example of collective place-making through people's opinions and public visualisations is the project Visualising Mill Road [30], which studied how technology could encourage citizens living on opposite ends of the same street in Cambridge (UK) to overcome social divisions based in prejudices. The approach taken was to design a set of electronic voting devices to be deployed at shops on both sides of the perceived division to elicit opinions about aspects of the community. The questions on the devices were changed every other day and the data from the previous question was collected. The data was then aggregated and presented as public infographic visualisations that were sprayed onto the pavement outside of the shops.

The project in Mill Road was successful in creating opportunities for reflection, social interactions and conversation. The distribution of multiple devices and visualisations provided multiple entry-points that opened up the range of people participating and triggered localised conversations, which sparked city-wide discourses. The results showed that the divide residents of Mill Road feel between the Petersfield and Romsey areas of the street was not just a perception: the Romsey side of the bridge felt happier, more neighbourly friendly and safer. The findings of the study show the potential of low-tech, low-cost community technology, public visualisations and participatory design approaches to engage community members to reflect on and discuss their perceptions. It also highlights the importance of not thinking about communities as being homogeneous entities [30].

2.3 *Inviting Citizen Participation*

Existing HCI research has investigated how to engage citizens to contribute opinions for decision-making in civic matters. Inviting members of the public or communities to contribute and participate is essential to maximising citizen engagement and technology uptake [47].

2.3.1 Gathering Public Opinions

Public displays are known to suffer from *display blindness* [37]. Overcoming this issue, tangible interfaces are shown to successfully convey interactivity and attract passers-by, thus being used in many public voting interfaces. For instance, Voxbox [24] was a tangible questionnaire designed to collect data about visitors' demographic information and experiences in festival events, as an alternative to traditional paper surveys. By providing a playful and tangible interaction experience, it engaged a large number of participants queuing to answer questions. The collected data was visualised on the back of the box for public viewing.

Another public voting device—Viewpoint [51], allowed government officials to create and post questions for members of local communities to answer (Fig. 5). The device consisted of a physical box with a decorated screen and physical buttons for input. While both parties engaged with the intervention, the residents remained skeptical about its efficacy of actionability—whether actions would be taken based on the results. Furthermore, according to the authors, the low sense of efficacy of Viewpoint [51] partly came from the fact that the questions asked were determined only by the authorities. They identified a need for community members to publish topics that mattered to them.

Fig. 5 Left: ViewPoint [51]. Right: Vote As You Go [27]

PosterVote [54] addressed this problem by introducing a low-cost DIY kit for activists to produce their own physical voting interfaces. It consisted of paper and lightweight hardware, including buttons and LEDs, and could be attached to walls and lampposts (Fig. 5). After deployments in two activist communities, they found value in placing the posters in situ, which triggered local discussions. In terms of the efficacy of the approach, they questioned the representativeness of the results due to the lack of demographic information of voters, and the problem of potential repeated votes. Moreover, different opinions about the ownership of the posters emerged in two communities. While one community fully supported the bottom-up approach, the other had doubts about giving them to anyone in the community and suggested the need for governance protocols. In addition, not being able to see the voting results in real time was perceived as a major drawback by the communities.

2.3.2 Public Data Visualisation

Public data visualisation can fulfill the need identified above, in terms of opening up aggregated data collected from community members. Hespanhol et al. [27] evaluated the engagement effect of visualising voting results on a large display. A public voting system—Vote As You Go, which consisted of an iPad voting device on a stand and a large urban display in the air, was placed in a busy urban precinct (Fig. 6). They found the connection between the public display and the iPad was not obvious, unless the display shows both the video feed of the interaction zone and the visualisation side-by-side. Moreover, after enabling playful full-body gestural interaction for answering the questions, they observed increased awareness and participation. In addition, more collaborative voting was observed with the full body voting interface than with the iPad stand.

Public visualisations have also been used to engage local community members to contribute data and to reflect on it collectively. For instance, Reveal-it! [53] consisted

Fig. 6 PosterVote [54]

of a public display showing dynamic infographic illustrations of individual and community energy consumption data, which was voluntarily entered via a mobile device (Fig. 6). It triggered a playful social comparison of the data and enabled collective interpretation. Part of the engagement also stemmed from the fact that by contributing their own data, the interpretation of the visualisation became particularly meaningful to participants.

2.3.3 Scaling Up Citizen Engagement

Some urban interventions have invited a large amounts of citizens to participate in producing an urban spectacle. SMSlingshot (Fig. 1) described in Sect. 2.1.1 is one example of such project.

Open Burble [47] was a spectacular light structure in the evening sky that was assembled by members of the public (Fig. 7). It was 15 stores high, made of 1000 helium balloons which contained sensors, LEDs and microcontrollers. They were structured and connected through configurable units. Once in the air, it moved with the wind in an organic motion. Citizens could 'paint' this floating 'canvas' by interacting with tablet interfaces held on stands. By inviting citizens to collaborate in creating and flying this urban spectacle, the intervention created a shared experience of collectiveness and a sense of achievement.

While some participatory public installations emerged as spectaculars in urban spaces, some others are enabled by distributed cloud-based infrastructure. For example, Salim and Haque use the term *Public IoT* to describe the mass participation of citizens sensing cities with connected devices. One of their projects, Pachube [47] was a platform for displaying crowdsourced global-wide IoT data that was collected and shared within communities (Fig. 7). During the radiation crisis in Japan, after the nuclear disaster at the Daichii power plants in Fukushima, it was used by a community to aggregate the first citizen-contributed real-time radiation data map. While situated installations demand for physical in situ coordination among people, cloud-based platforms can access to larger groups of people as they enable distributed coordination and contribution.

Fig. 7 Left: open burble [47]. Right: pachube [47]

Scaling up citizen participation requires resources and permissions. Therefore such projects need to collaborative with stakeholders and other partners. Based on the lessons learned from these projects, Salim and Haque [47] summarise the strategies for structuring large-scale participation. They propose five steps: identify needs and dilemmas, identify stakeholders, identify incentives, gather evidence and experience, and provide tools and affordance.

2.4 Building Communities

Benefiting from their attractive and interactive capabilities, public installations can be embedded in community spaces for connecting people and building a sense of community. This can lead to processes of collective place-making, where community members express their voices and affect decision-making in their neighborhood [22].

2.4.1 Facilitating Communication

Community displays have been used to share multimedia stories created by community members [33]. Wray Photo Display, described in Sect. 2.1.2, provided a gallery application for browsing photos uploaded by community members. Through participatory and iterative design, they developed novel features based on the needs of the community, such as *delegated moderation*, where users are given the right and responsibility to moderate the categories they created by, e.g. disabling uploads by other users. A two-year deployment showed high acceptance of the display. The researchers found that historical photos generated the most interest, as they stimulated reminiscing conversations and the historical pictures updated people about community events. Similarly, Beyond YouTube [17] allowed housebound community members to record and share videos via a community display. The researchers highlighted the shared sense of experience emerged among content producers who suffered from similar issues, and the need of verbal or video commentary channels for audiences to convey their sympathy.

OpenWindow [58] investigated a bottom-up approach to using public displays (Fig. 8). Several households were given a display to be placed on their window and a web interface for posting textual content on it. The household members engaged with the display and created hyperlocal content about the neighbourhood, such as a reminder to put trash bags out before sleeping. Social interactions and group discussions were observed around the displays, within households and on online social media. Post-deployment measures showed the potential of strengthening the sense of community cohesion by engaging with the display. However, a general decrease in the frequency of message posting over time showed challenges of sustaining the engagement of content creators. The households also suggested sharing the responsibility of creating content and managing the displays with other community members.

Fig. 8 Left: StreetTalk [57]. Right: OpenWindow [58]

StreetTalk [57] presented a similar type of intervention—public installations on windows of households, which—reportedly achieved satisfactory results (Fig. 8). The researchers took a participatory approach and supported households to design their own intervention for addressing their own concerns. Three households built interactive displays with different modalities for presenting information: a thermal printer printing a message under a button click, an earphone to listen to audio message with two feedback buttons, an LED strip responding to the street noise level. Through deployment, they found that participating in the design of public displays potentially encouraged ownership of the households. The households selectively created content that was likely to be appreciated and understood by a wide range of audiences while keeping it hyperlocal. The acceptance of the technologies showed a positive and creative influence of a participatory design approach for creating interventions within communities—which was also evidenced in the Wray Photo Display project (Sect. 2.1.2).

Another example of how a distributed network of connected devices can support community cohesion and enable new means for communication is VoiceOver [25]. It was an art installation that used networked artefacts to encourage members of communities to speak and connect with each other (Fig. 9). Each participating household

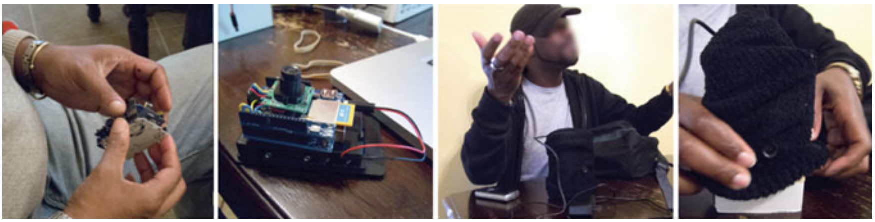

Fig. 9 Community historians [23]

got a visually striking light stick and sound infrastructure installed on their house window. As they spoke to the microphone, the light stick showed animated waves, which bounced across the street by flashing other participants' light sticks, communicating visually their voice reaching the end of the village. This encouraged community members to speak to each other through an augmented communication channel that was both hyper local and hyper public. Community members used it to discuss topics for making decisions and to share life stories. As a result, they collectively formed a "networked cultural infrastructure".

2.4.2 Preserving Community Memories

An important aspect of community building is how to enable the preservation of community memories. As Agostini et al. [1] states, "*Quality of the local community depends on its ability to keep its memories alive through social interaction within the community itself.*" While digital storytelling is considered valuable in community engagement [22], public IoT push it further by associating stories to objects or relevant physical places.

The Community Historians project [23] involved a series of public participatory workshops focused on designing and building low-cost devices with a camera for recording and presenting local community history (Fig. 10). With a critical making approach [45], they aimed to provoke reflection about the technical capabilities of community members. They found that the project cultivated a sense of shared identity within the community by reinforcing four key elements of community building—membership, influence, fulfillment of needs, and shared emotional connection [32].

2.4.3 Sustaining Community Engagement

A major challenge in such community technology projects, like The Community Historians [23] mentioned above, is that they rely on constant content provision. Thus, sustained engagement is hard to achieve. Unlike spectacular interventions where

Fig. 10 Fruit are heavy [18]

people are required to participate spontaneously and for short periods of time, community network projects instead demand that people remain engaged by contributing, moderating content and maybe even maintaining infrastructures. While sustaining engagement with technologies is rather neglected in the broader HCI literature that emphasises novelty, some works have investigated the factors that can contribute to the design of community technologies that achieve sustained engagement.

Taylor [50] and others have identified challenges of sustaining community engagement after a research deployment has ended, including managing expectations and tensions around an experimental technology, creating skills, etc. While many community research projects showed potentials in sustaining the engagement, only a minority of them succeeded in handing over the technology.

As a rare example, CrowdMemo [6] was a community engagement project that aimed to be long-lasting from the beginning. It allowed community members to create micro-documentary films about places and present them to the public by associating them with QR codes embedded in places. The authors identified the important factors in sustaining long-term engagement and handing over the project. Besides echoing existing work about promoting a sense of ownership and social encounters, the authors also highlighted the value of using off-the-shelf technologies in novel ways. They also emphasised the active role the stakeholder groups played in raising funds and organizing events, and the importance of providing values to stakeholders. Furthermore, the public recognition of the project attracted adoption of the approach in other towns and influenced regional education policies. In summary, long-term community engagement and large impact of community intervention require multiple layers of social and organizational effort on top of developing the technology.

2.5 *Addressing Matters of Concern*

In earlier smart city projects, IoT have been used in many application domains in city scale, including the structural health of buildings, waste management, air quality, noise monitoring, traffic congestion, city energy consumption, smart lighting and automation [59]. The IoT here are deployed for data collection purposes, with little direct interaction with humans. Frictions arise during the implementation of top-down approaches for installing pervasive technologies in private buildings and households. Recent research on technologies in communities promotes bottom-up approaches, where IoT are used to empower citizen as a tool to help them to address matters of concern [8].

2.5.1 Participatory Sensing

DiSalvo et al. [20] prompt critical engagement with technology and creative expressions of issues through participatory design activities. They argue that when people use technology to communicate and solicit support with the hope of initiating change, they enact a political action through computing. Through multiple community workshops for designing sensing and robotics technology, they found that the collaborative actions of participants getting the sensors to work and interpreting the readings were seen by the members as shared experiences of exploring and investigating the environment together, with the technology being instrumental to such practices. Furthermore, giving the participants opportunities to present their interventions to a public audience also allowed them to develop arguments and to articulate their concern.

Along similar lines, Fruit are heavy [18] used participatory design to prototype an IoT sensing system for fruit foraging with a community in London (Fig. 10). They encountered safety and privacy concerns when deploying sensing systems in public and identified a lack of policies in this space. The authors questioned the necessity of “smartness” in smart cities by demonstrating a value in systems with low-fidelity and high-latency. On one hand, this community-supported project was operated at the human scale. The added intelligence were generating insights that were possible for any individual human to make. On the other hand, remote sensing and automation might remove the need of some shared activities and knowledge learning, thus hinder community building processes.

On a similar note, an ethnographic fieldwork in an urban agriculture community revealed heavy resistance against technological augmentation of their agricultural practices [40]. Community members valued the reflective sensibility and knowledge building gained through direct interaction with the site. More importantly, they believed sensor technology would have a negative impact on community building by reducing the social interaction between old and new members during informal transfer of tacit knowledge.

2.5.2 Beyond Participation

While a long list of participatory design projects have shown engagement of community members in critical thinking and expression of matters of concern, some researchers note that “participation is not enough” [11]. How to extend such projects to have real impact at the social and political level? From this point on, finding ways to scale up the engagement becomes crucial. Involving external resources or collaborating with existing organisations becomes necessary. How to navigate the social space with increased complexity while ensuring citizens’ goals are being achieved? What roles can IoT have in the process?

There is a need to move on from situated small scale pilot interventions into larger socio-technical systems that connect diverse resources and stakeholders, including their practices and expectations. Balestrini et al. [8] noted a lack of actionable frameworks aimed at scaling up IoT community-based projects. They have developed a city-commons framework that outlines a process and mechanism for co-designing sensing technologies to address citizen concerns. It involves 6 phases: *identification* of matters of concern, *framing* the resulting issues, *design* of the intervention, *deployment* tests in situ, *orchestration* for sustaining and scaling up the engagement, and

Fig. 11 Participants co-designing Dampbuster [8] (top & bottom-left) and the final design (bottom-right)

outcome for reflecting and sharing gained insights with third parties. As a case study of applying the framework, the Dampbusters project (Fig. 11) helped a low-income community in Bristol (UK) to co-design sensing technology in order to address the problem of damp houses. The researchers identified the engagement factors in each phase: face-to-face social interactions, which were fostered by frequent meetings and events, raised awareness and attracted a large number of volunteers. A key aspect was the fact that the participating community had shared purposes and interacted with experts and stakeholders who were also committed to the issue. Moreover, they found that IoT data needed to be governed and managed following a participatory protocol to increase a sense of community ownership. The research also showed that participants often lack the skills to make sense of and operate sensing technologies and that citizen sensing interventions, to scale up, need to provide skills programs and resources to support active participation. Finally, the overall narrative of the city commons—a set of community owned resources that contribute infrastructure to address public matters, fostered engagement by inspiring a shared sense of meaningfulness and solidarity.

This success story showed one possibility of scaling up community engagement and making a real-world impact, by rising large scale awareness and enabling long-term collaboration across communities, organisations and user groups. While the framework is not a recipe, it provides a narrative for a shared vision and a coordination tool to tie multiple partners together. In addition, as stated in [8], the researchers' role is also essential—as a facilitator to import HCI methodology and knowledge, and a firefighter in mending miscommunication and resolving tensions.

The framework was later adapted and used in Making Sense [56], a European a project funded by the European Commission, under the call Collective Awareness Platforms for Sustainable Social Innovation (CAPSSI). It ran for two years (2016 and 2017) and aimed to develop the technical and methodological tools for citizens to engage in citizen science projects particularly urban environmental sensing and monitoring, to create impact and positive social change. To achieve this goal, the project ran nine pilots in Amsterdam, Barcelona, Maastricht and Prishtina where citizens contributed to the design of open source environmental sensing tools and collected data to address matters of concern: air quality, noise pollution and gamma radiation.

Initial pilots in Barcelona and Prishtina were instrumental in creating Community Champions—highly driven, passionate and collaborative communities of interest and practice that later helped to develop further pilots. For example, in Barcelona a group of neighbours from Plaza del Sol, a public square in Gracia, rolled out a pilot to tackle the oppressive noise pollution made by night time public drinking and rowdiness. A co-created approach to sensing was developed, which involved the deployment of 25 open source noise sensors. The data collected over a period of six weeks demonstrated that noise levels in the square were beyond the limits established by the local regulations and were unsafe according to the World Health Organisation. During the orchestration phase, the community organised an open general assembly to co-create solutions to the problem that were later submitted to the City Council. As a result, the square has been refurnished to help alleviate the problem of noise pollution.

In Prishtina, the persistent measuring activities and campaigning by local interest groups and a mobilised, data literate youth, led to a government who previously obfuscated accurate environmental readings, to take steps towards data transparency. As a result, the problem of air quality was finally discussed in parliament in a two-day debate where a resolution was passed. It states that "environmental protection should become a state priority of the government of the Republic of Kosovo" and warns the government that if it does not implement the measures proposed by the parliament, MPs will initiate constitutional changes to enforce their proposals.

What these pilots demonstrated is that it is possible for community IoT interventions to empower people to act on matters of concern by collecting data that can later be used as evidence to promote change. However, this is better said than done, and interventions need to successfully strategise to move beyond the technology and into the complex arena of societal issues. People need to be equipped not only with devices—which have to be designed to be accessible and engaging [10], but also with the skills to use them in meaningful ways. Partnerships with diverse stakeholders, including journalists and politicians, need to be put in place to promote real action. Finally, the project demonstrated how communities that feel empowered and share their success stories can draw others to join in, progressively forming movements that are long lasting. Sustainability is also strengthened by the development of commons, e.g. the Making Sense open technology and methodological toolkit[1], which can be readily appropriated by others therefore lowering the costs and barriers to access for subsequent pilots.

3 Synthesis of Lessons Learned

Figure 12 provides an overview of the public engagement of selected work, categorised by the social impact of the processes of using and developing the technologies. Most of them contribute in multiple categories. What does it take to support social engagement with IoT in public spaces and communities? What can be done to *scale up* and *sustain* citizen engagement? This section synthesises the findings from the described literature and summarises the prominent factors identified during the design and deployment processes.

First, as we can see in Fig. 12, all of the listed projects that deployed interventions at public spaces triggered social interactions or discussions, which in a few cases were scaled up and carried online [30, 58]. To attract interaction or participation, most IoT urban interventions are designed to be visually appealing or striking. Tangible interactive interfaces are shown to help overcome *display blindness* [24]. Having unusual objects in places triggers curiosity and motivates people to approach [28]. To allow for spontaneous social interactions to emerge, the technology shall profit from the affordance of a *social interaction space* around it [21]. Connected devices can also encourage or even require social interactions [7]. Moreover, people interacting with the intervention can also draw other people to join in [13] as they can demonstrate the use of a given technology [21]. Highly engaged participants can play an active role as *champions* to encourage others to participate [41].

Second, situated IoT in places can engage local communities by providing hyperlocal content [17, 49]. This can be achieved by increasing the local relevance of the displayed content or allowing local communities to contribute to the content. They can spark conversations, raise awareness of local issues [29, 43] and reveal local characters who are familiar to the deployment places [16, 30]. The effects can be further enlarged by increasing the entry points of participation at multiple locations [30]. Having public visualisation of data collected from communities members can support collective sensemaking and improve the sense of efficacy [30, 53, 54]

Third, we have shown different degrees of participation of members of the public and communities, ranging from voting and contributing data [51, 53], creating content [16, 17, 49], hosting technologies [25, 58], making and assembling [47, 54], to co-developing the technologies [8, 49, 57]. As shown in Fig. 12, citizen participation appears to be a fundamental activity in most of the listed projects. More involvement seems to correspond to higher level of engagement. Engaging citizens to participate, especially by contributing content or engaging in co-design approaches can create a sense of ownership, which is shown to be an important factor in many community

[1] http://making-sense.eu/publication_categories/toolkit/.

	SMSlingshot	Jokebox	Trashcan	Walk to talk	Visualising Mill Road	ViewPoint PosterVote	Reveal It!	Open Burble	Pachule	Wray Photo Display	Open Window StreetTalk	Community Historian	CrowdMemo	VoiceOver	Fruit are heavy	Dampbuster
Addressing matters of concern									X						X	X
Building communities										X	X	X	X	X		X
Inviting citizen participation	X			X	X	X	X	X	X	X	X	X	X	X	X	X
Rising awareness			X	X	X		X									X
Triggering social interactions	X	X	X		X	X	X	X		X	X		X	X		X

Fig. 12 Fruit are heavy [18]

projects [6, 8, 16, 54]. However, ownership of the work and achievement might be different from the ownership of the technologies. Hosting a technology and being responsible for creating content for it can at times be a burden [58]. The difference might lie in if an intervention addresses peoples' matters of concern or provide them with value.

Fourth, activities that create shared experiences and memories can bound community members together. Examples include expressing common voices, collaboratively exploring and learning sensing technologies, social gathering and networking. Technology-centric smart city approaches tend to remove the necessity of human activities, which may also hinder opportunities for shared encounters and social experiences. This was identified as a major reason of resistance to adoption of sensing technologies in a community [18].

Fifth, developing technologies with participatory methods is shown to be essential in the successful community engagement projects we have reviewed. These methods range from action research [26, 48] to long-term participatory design [34], and often include an ethnographic component [14, 15]. There are many benefits associated to using participatory approaches. On one hand, the researcher becomes embedded in the community, making sense of their culture and practices to identify both collaboration and design opportunities. On the other hand, the community can develop a sense of ownership by setting the goals of the intervention from the outset and developing the mechanisms and skills required to sustain the intervention after the researcher has left. However, while participatory methods can substantially increase the sustainability and appropriation of technologies in hands of the beneficiary communities, this does not always necessarily happen. A hand-over strategy should be deliberatively planned and designed to support these aims [50].

Last but not least, to achieve greater social impact, by either scaling up or sustaining civic engagement, require external resources researchers rarely have. Thus collaborating with stakeholders becomes one way to achieve the goal. In this chapter we described three examples of such approaches. CrowdMemo [6] showed sustained engagement carried on by local governments and policy change after the research project ended. The Bristol Approach [8] and Making Sense [56] made large impact by orchestrating a large scale citizen engagement in using sensors to address environmental issues. Salim and Usman [47] succeeded in conducting mass participative urban installations including Open Burble and Pachube. The lessons learned from these projects suggest common foundations, which are summarised below as themes that are positively associated to greater social impact.

1. Identifying issues or user needs is the primary step to ensure motivation for participation and contribution.
2. Working with external stakeholders and providing them with value. Deploying technologies in urban spaces needs permission and support from owners or managers. Handing over the technologies to stakeholders after the research phase helps sustain the engagement.
3. Providing personal gain to participants. While mass participation urban projects emphasise the importance of incrementally providing incentives to participants,

large scale community engagement projects builds on the sense of ownership and purpose.
4. Creating opportunities for shared experiences and social encounters. Being part of a larger group and addressing shared or public issues is shown to be highly rewarding; building on networks and fostering social interactions is identified as a major factor in strengthening community engagement.
5. Reducing barriers of participation by providing tools or training: while mass participatory urban projects stress the need of providing tools to intended participants, community projects emphasise the importance of providing training programs for participants to gain necessary skills.

4 Perspectives

After discussing the public engagement with IoT in a range from small-scale social contexts to large-scale civic contexts, we end this chapter with a few perspectives on the role of IoT and the choice of particular technologies.

4.1 The Role of IoT

IoT is increasingly being developed by private companies in hopes of delivering new commercial services, such as the case of the Nest[2] and other personal, home and city based IoT systems. They work by extracting data that is often made proprietary, and used to run analytics and optimize service delivery or advertisement. In contrast, we see that IoT, if made open and social, can fulfill community needs, and even foster positive social and political change when its engagement reaches a certain scale.

As Asad and Le Dantec [3] state, Information and Communications Technologies (ICT) support communities' democratic engagement by being instrumental in the situating, codification and scaffolding practices. Technology solely would not have resulted in scaffolding practices, nor orchestrated large-scale engagement. However, the process of co-developing a novel technology that has a single purpose of solving a target problem can mediate an entire network of social practices and galvanise multiple organisations and user groups. What matter the most in the processes are *who* make the design choices, if it provides all parties with *value*, and if there is space and opportunities for *social interactions*. When data is collected through participation, a fundamental issue is who owns that data and under what conditions and for what purposes the data can be used [8].

It is also worth noting that technological breakdowns can become major obstacles for community members with little technical skills to setup IoT systems [10], resulting in disengagement with the project. Researchers shall pay attention to such

[2] https://nest.com/.

issues and help reducing it by designing easy-to-use interfaces, as well as providing clear instructions and maintenance protocols.

4.2 The Choice of Technologies

With a broad take on the definition of IoT, the technologies sampled in this chapter include public displays, QR codes scanned by mobile phones, instrumented objects, projected facades, sensor toolkits and open-source hardware. The choice of technologies is unlimited. In fact there is no obvious correlation between the specific types of technologies and how successful an intervention may be in terms of engagement. However, researchers did observe effects of some properties of technologies.

Balestrini and others [9, 50] stress the tension between *novelty* and social impact with community technologies. While many HCI research promotes novelty contribution, civic technology is not primarily designed for technology enthusiasts but instead for citizens with a need to use it. Novel technologies require that new skills are gained, which may create unnecessary barriers for technology uptake. The lack of stability of a research prototype may cause breakdowns and hinder engagement. An established mechanism to ensure the maintenance of the technology is important for technologies that will be handed over to communities and stakeholders [50]. Nevertheless, off-the-shelf technologies can be used in novel ways, which is shown to be engaging for communities [6].

While social media such as Twitter is widely used by activists in civic engagement with political actions, the use of IoT is less explored outside of the area of citizen science, where choices of technologies are constrained by required functionalities. As a rare example of using physical computerised medium, PosterVote showed the potential of a low-cost voting toolkits as an effective democratising agent for supporting activists [54]. Meanwhile the researchers noted the lack of interactivity it provided. However, although placing physical interactive technologies in situ can increase its local relevance and visibility, expensive technologies may suffer from security issues. Therefore there is a need of making more advanced interactive technologies, e.g. paper electronics, low-power displays, more open and low-cost for being used in pervasive civic activities like voting and storytelling.

Connectivity is an important feature of IoT. However, many of the successful projects we reviewed have limited connectivity. Some have only local connections (SMSLingshot, Jokebox, StreetTalk, Open Burble), some 'connections' are supported by humans (Visualising Mill Road). In fact in Visualising Mill Road [30], the researchers found that the slow analog technique of manually collecting responses from the boxes and painting them every morning in front of the shops created a rhythm for residents to come visit the updates. In Fruit are Heavy [18], although a need for low-power and long-range networking for deploying sensing technologies is identified, the researchers highlighted the value of low connectivity that encourages people to go to the ground and meet others. Therefore, remote access to data is not always helpful, and can even take away the invisible value embedded in places, contexts and social encounters. Community projects tend to be hyperlocal, the narrative and data sets may only be understood together with the knowledge about the local circumstances and social dynamics.

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