Exploring Acceptance and Consequences of the Internet of Things in the Home

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***Abstract*— The Internet of Things (IoT) presents huge potential for designing new technologies. However it is not yet clear which of these technologies will actually be accepted as a part of our everyday lives. Alongside the development of prototypes and exploratory evaluations, other research methods could be useful in eliciting responses to future visions, and developing implications that can inform design. In this paper we explore factors that could affect the acceptance of IoT technologies in the home. We present a review of relevant literature from human factors, HCI, sociology and psychology, and analyse the results of a survey in which participants were presented with scenarios of near-future IoT systems in use in the home. Based on this, we develop an initial set of design principles for IoT technologies in the home.**

Keywords- internet of things; home; family; technology acceptance; human factors;human-computer interaction

I. Introduction

The concept of embedding computation, sensors, actuators and networking into all kinds of objects has provoked a vast amount of creative design and development. This has led to Internet of Things (IoT) systems and infrastructures at varying levels of maturity. In the near future we can expect an abundance of new products and services to emerge. However, the human aspects of interactions with IoT technologies are currently under-explored. Not only will the perceptions of the general public be key to the acceptance of IoT technologies, but the potential consequences to individuals, families and societies could be enormous.

At the heart of many IoT visions is the collection and sharing of data that will provide new insights into our activities. Guo et al note that IoT *"leaves digital traces that can be compiled into comprehensive pictures of human daily facets, with the potential to transform our understanding of our lives"* [1]. Characteristics of IoT technologies and infrastructures will affect how much data is collected, by whom and how it is shared or personally identifiable. Privacy and data protection frameworks will need to adapt to new challenges.

Visions of the Internet of Things expect an increase in smart or autonomous computing, often working without human intervention [2,3]. However, people and social structures cannot be seen as passive actors in this process. As well as accepting or avoiding specific technologies, we appropriate or subvert them as they become part of our lives.

The introduction of IoT in the home is of particular interest due to the complex social dynamics of domestic spaces, in which residents share multiple resources whilst maintaining varying levels of individual, group (e.g. family) and subgroup (e.g. parents) autonomy. The home is an intensely personal space, in which privacy, ownership and control are important factors. In the IoT home, data which is not generally publicly available will likely be shared between occupants. Data about the home may not be 'owned' by or attached to any single person and yet reveal personally-identifiable information. The consequences of this will be bound up in the specific contexts of our dwellings, which could be a nuclear family home, a shared bedsit, or one of many other configurations, all with particular social structures and dynamics. The networking of mundane items could radically relationships between home occupiers and home objects. In this paper we explore these socio-technical interactions and their implications for the acceptance of technologies.

II. Literature Review

In this section we review a range of literature that provides concepts and issues through which to understand the acceptance and consequences of the IoT in the home.

A. *Acceptance of IoT Technologies in the Home*

Technology Acceptance Modelling (TAM) has attempted to build models that reflect people's willingness to accept a given technology. In general, if people perceive a technology to be useful and easy to use, they are more likely to accept it, however TAMs show further complexities and variations across domains and user types [4]. Bagozzi – though strongly involved in TAM development – has criticised the neglect of group, social and cultural aspects of decision-making in current models. He also notes a lack of deep understanding of affect, emotion or self-regulating processes of feedback [5].

The uptake of new technologies can alternatively be conceptualised both socially and individually using Rogers's 'Diffusion of Innovations' model [6]. This model suggests that decisions to accept or reject a technology will take place after the individual is made knowledgeable of the innovation, and attempts are made to persuade them to accept it. After an initial, tentative acceptance, individuals experiment with the use of the innovation to ultimately determine its utility and whether to continue using it.

Reviewing literature in ubiquitous monitoring, Moran and Nakata found that intrusion, awareness, control, boundaries, trust, context and justification are factors perceived to impact behaviour in relation to being monitored. Relating these factors to technologies such as CCTV or loyalty card schemes, They propose that the obtrusion, coverage and control are among characteristics that should be considered in designing systems, along with the frequency of data collection, the ability to integrate data across sources, and how users are informed about the system's purpose [7].

Complex social dynamics mean that the home presents particular issues as a space into which technologies can be introduced. As a counterpoint to the reductionist modelling seen in TAM or Diffusion of Innovations, Domestication of Technology studies take a rich, qualitative approach to understanding how technologies move from the public realm to the private space of the home. Ward describes this process as a transformation *"from cold and meaningless product into a desirable part of the home… consumers enter a struggle for control and the artefact becomes a site for the negotiation of meanings. For example, when a television is located in the home, rules and routines are applied, to allow the household to sustain routine and rearticulate its values"*. [8] Richardson argues that Domestication research has been particularly neglected in smart home development [9].

A reliance on extensive infrastructures means that individual, household, commercial and governmental agreement and cooperation will be needed for many IoT technologies to function. The advantages to organisations and societies can be incentivised such that benefits are passed to the individual, and we should not forget the role of fun and leisure in prompting the acceptance of technologies. At the same time, the acceptance and consequences of IoT technologies will rely on, and result in, a range of social and psychological issues, some of which are highlighted in the following section.

B. Consequences of Living with the Internet of Things

Many envisioned and existing Internet of Things technologies have a presence in the home. These include commercially available systems such as networked Energy Monitors, Smart Fridges, and systems to track activities by tagging objects, such as Greengoose [10]. These systems collect detailed information about activities both within our homes, and about the wider activities of people who live together and may share access to this information.

While technologies that capture data about us may become less visible, the outcomes of data collection could make visible new forms of information about our activities to those around us. New information appliances, visualisations and alerts are part of an IoT vision, and smart behaviours in homes will be based on collected data and human actions, which may highlight and define elements of these actions that were previously ambiguous, or entirely unknown.

In reviewing the dissonance between privacy guidelines and the kinds of data collection that occurs in IoT systems, Soppera and Burbridge argue that the notion of 'personal' data is disrupted, as systems collect volumes of data that is not directly related to any one person, but from which personal information can be ascertained through collation or contextual information. They also argue that people will be less aware of when data is being collected, or how data may be used [11].

In technologies such as energy monitors and smart fridges, we are already seeing a new kind of information appliance through which information is displayed at the household level, with various degrees of detail that can be used to understand personal activity. Within these data there are potential to understand both overall household behaviours – how much energy did we use today, or how much milk did we drink – but also individual family members behaviour – how much energy was used in the sockets in Sarah's bedroom, or how many times did Geoff do the shopping?

Increasing awareness and monitoring of children is an obvious use of IoT technologies and data. While parents may be happy to invest in this, research suggests that surveillance is a point of evolving tension in child-parent relationships. For example Toscos et al studied blood-glucose monitoring in diabetic children by their parents, finding that particular tensions arose in later adolescence. Children wanted to take control and increase their privacy, while parents remain anxious about their welfare, seeking to maintain access to data. Lies and breakdowns in trust often occur during this period, but through a prototype design and evaluation study, the authors show that technologies can be designed to take this evolution of relationships into account [12]. More generally, adolescence is a period of tension, as shifts in control occur [13], so this is an area where IoT technologies could be particularly disruptive.

IoT technologies could also have potential in the care of the elderly. For example Dohr et al describe IoT technologies to support telemonitoring and assistance [14]. However it is important to consider universal needs for privacy, and relationships with family and care givers, within these designs. For example, research studying attitudes to GPS tracking technologies found complex issues, such as how family and care givers felt obligated to spend a great deal of time monitoring data to ensure a person's safety, to finding that they preferred restrictions on the technology based on respect for a persons' right to autonomy [15].

A further theme has been increasing awareness and control to encourage positive behaviour change. The success of arguments around this can be seen in initiatives such as the intention of the UK government to install smart energy monitoring to every home by 2020 [16]. Systems aiming at behaviour change face a complex design space of stakeholders, including energy suppliers, consumers, governments and appliance manufacturers. Smart energy meters are expected to share information within and outside the home, as research suggests social influence is key to encouraging behaviour change [17], and also for incentivising and decision-making.

Increasing the available information in areas such as energy use can cause new tensions to emerge in the pursuit of behaviour change. An analysis of interventions aimed at making Swedish households more aware of their energy use found that some participants became uncomfortably over-conscious of home energy usage, causing disagreements about behaviour, and leading to disagreeable changes in family roles, such as feeling obliged to do domestic chores late in the night, when energy was cheaper [18]. It is therefore clear that positive intentions for behaviour change in design can lead to the emergence of negative social outcomes in some cases.

III. A Scenario-Based Survey Study

We have yet to see how many IoT technologies will be domesticated, as these have yet to reach a maturity where longitudinal studies in realistic household settings are possible. Here we use a scenario-based survey approach to explore initial perceptions of these technologies.

Scenarios can guide the user-centred design of near-future technologies, by providing insights into issues that people expect to find in relation to these technologies [19]. These methods can also be used in tandem with prototyping, requiring less resources to explore a range of designs, and can be used quickly with a broad audience.

A. Scenarios

Three scenarios were developed by combining popular and contentious IoT technologies with home-based situations that could reflect issues raised in the research discussed above. Each scenario depicts a feasible near-future IoT technology in the home. In order to communicate visualisations of data, the scenarios are presented using visual storyboards. Following guidelines developed by Truong et al, the scenarios are kept to four storyboard frames with simple text explanations, and contextual details are reduced to a minimum [20].

1) Smart Fridge

The first scenario describes a smart fridge that detects what food is bought and used in the house (figure 1). The Smart Fridge uses this information to alert family members to unusual patterns of food purchase and consumption. In the storyboard example, an alert that fruit purchase has risen drastically in the last week was used.

2) Energy Monitor

The second scenario explores energy monitoring. The storyboard shows a new system being installed that individually monitors each appliance in the house (figure 2). In the final frame it is revealed that 'Jane's TV' has been using much more power than every other appliance in the house. To explore issues with children and the elderly, participants were randomly presented with one of two versions of descriptive text to identify Jane: One described Jane as the daughter in the household and the other describes her as the Grandmother.

3) Proximity Portrait

The final scenario describes a more conceptual technology called the 'Proximity Portrait', that provides a live display of objects that are currently close to members of the household (which could be detected using RFID or NFC tags and a mobile receiver such as a smart phone). The storyboard describes the technology, gives an example of it in action and finally presents example data, in the form of a snapshot of the portrait display (figure 3). Again, participants were randomly shown one of two versions of this scenario, this time both the image and text were altered, swapping the objects between a young boy, adult woman and elderly man, in order to explore the impact of gender and age on interpretations of data.

B. Method

The survey was delivered online. A mixed methods design was used with each participant being presented with one version of each of the three scenarios. After viewing each scenario, participants were asked to respond to 18 closed and three open-ended questions. Table 1 presents the full set of closed questions, answered with a five-point Likert-type response (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree). These included questions on perceived usefulness and ease of use, as described in relation to the TAM. Scenarios were presented in a random order to counterbalance any order effects.

The open-ended questions asked respondents to interpret the information presented in the last frame of the scenario, asked them to describe how they would respond (if at all) and finally, asked why they would, or would not, like to have this technology in their home.

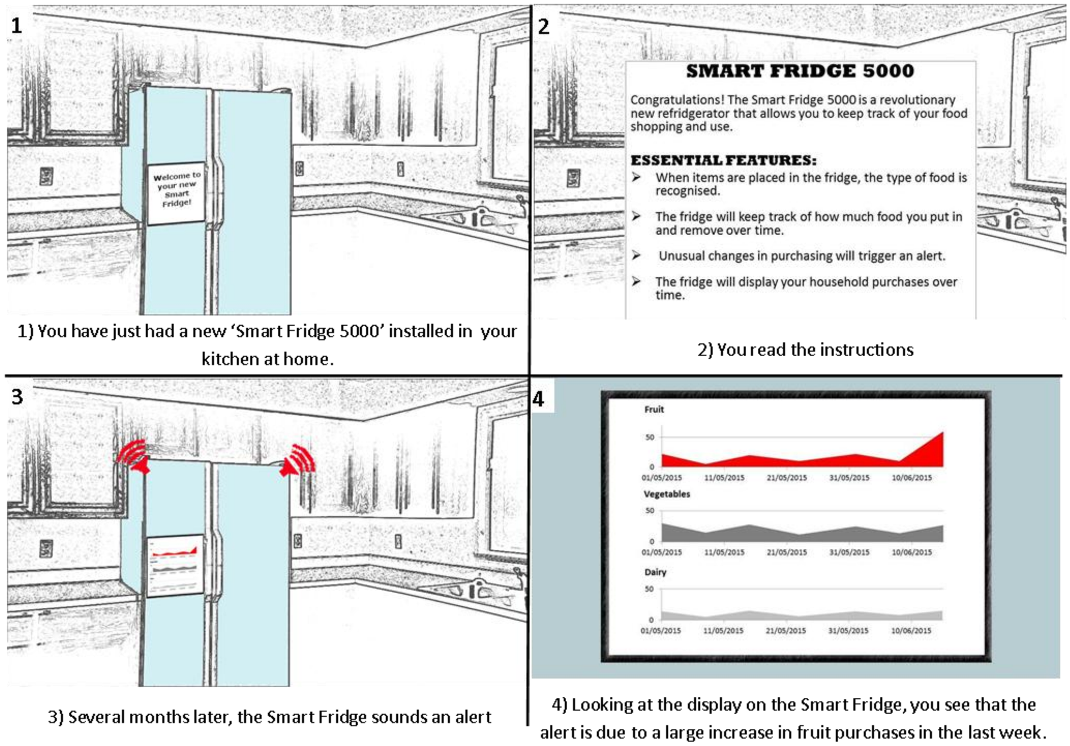

Figure 1: Smart Fridge Scenario

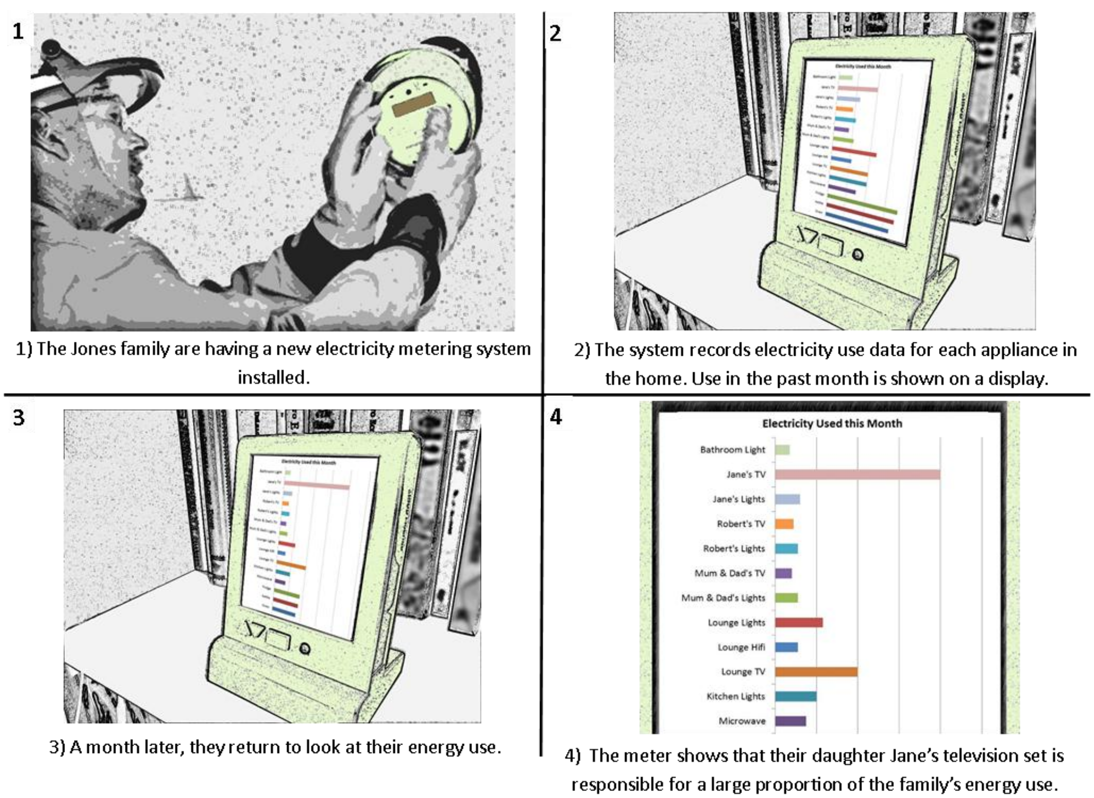

Figure 2: Energy Monitor Scenario

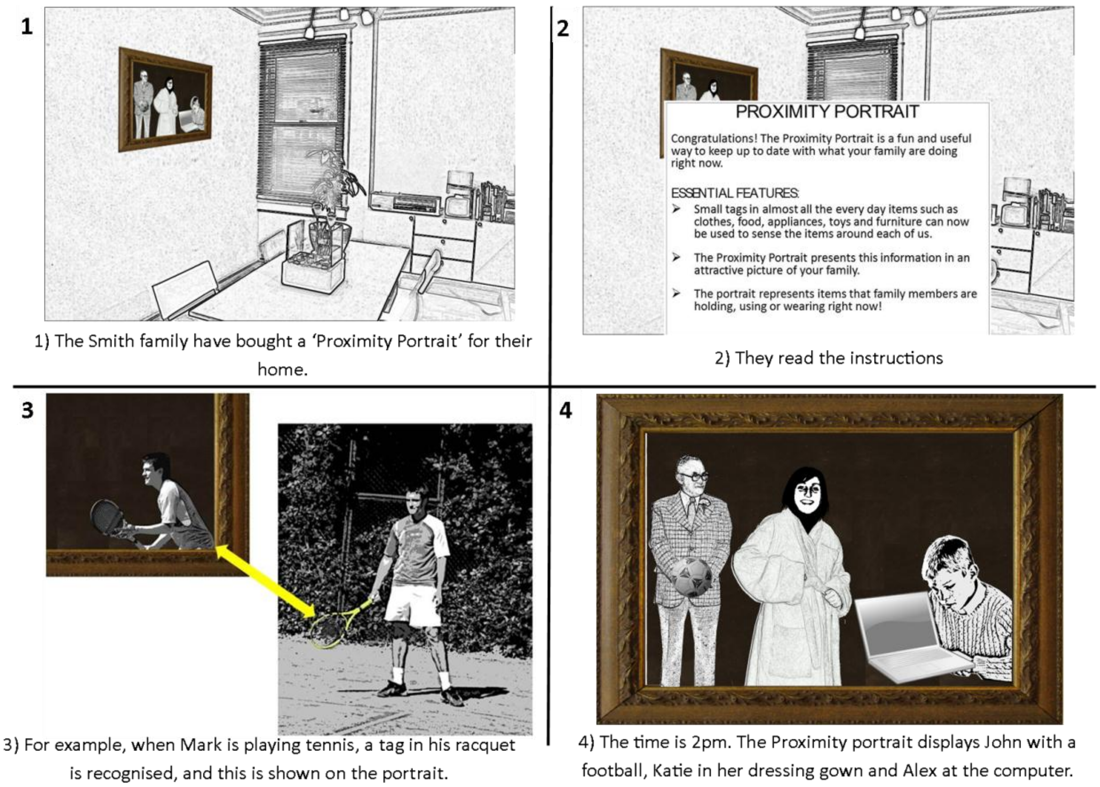

Figure 3: Proximity Portrait Scenario

C. Results and Analysis

35 participants took part in the study, of which 17 were female and 18 male. Ages ranged from 20 to 80 years old, with the majority (26) falling into the 21-40 years age range. Table 1 presents the questions and the mean of results, alongside Friedman tests for statistical significance between the scenarios.

Closed question responses showed the Energy Monitor to be the most popular technology, with the Proximity Portrait the technology respondents would least like to have in their home. In the following sections we explore features in the scenarios and the responses that suggest reasons why technologies are perceived as acceptable, or to be rejected.

1) Usefulness and ease of use

Statistically, the smart fridge and proximity portrait scenarios represent significantly less useful technologies to respondents. However, the simplicity of the chosen scenario does not do justice to all potential functionality, and several respondents suggested ways in which a smart fridge could provide useful functionality, such as highlighting food that was about to pass a use by date, or when they had run out of common purchases.

As TAMs suggest, results on usefulness and ease of use were predictive of accepting the technology in the home. However a more complex picture which emerges through the open responses. Usefulness is related to the type of household, and a person's role within it. For example one respondent noted in relation to the Smart Fridge that *"I do the shopping and the cooking and am…fully aware of what is in the fridge...in a larger household, with many people helping themselves…there may be some call for it"*.

Other responses noted that the energy monitor could be useful in dividing bills in shared houses, or that it could incentivise children by rewarding them for reducing their use. While most comments about the proximity portrait were negative, it was considered that the might provide useful awareness of the elderly, or to track criminals.

It is interesting to note that 31 of the respondents said that they would act in some way in response to the information presented by the Energy Monitor (e.g. asking the person to change their behaviour, or buying a more energy efficient appliance). In contrast only 15 responses would act based on the Smart Fridge scenario, and only four suggested they would take action based on the Proximity Portrait scenario. The likelihood that someone will act on information can be seen to parallel their perception that the technology is useful and desirable. Energy Monitor actions were in some cases specific to the age of the character, but generally suggested respondents were concerned about the perceived level of television watching, for example suggesting that they would *"make sure that Jane's getting enough social contact and physical / mental exercise… in a way not to offend or cause unnecessary feelings of guilt"*.

Table 1: Closed questions, mean scores and Friedman tests between scenarios

	Statement	Smart Fridge	Energy Monitor	Proximity Portrait	Friedman Test (X^2)
Q1	I can tell a lot about what people have been doing based on looking at … (the technology).	3.11	3.77	3.37	7.848
Q2	**I would like …(the technology) to provide me with information about people that I live with.**	**2.60**	**3.60**	**2.14**	**39.018**[a]
Q3	**I would be comfortable with the people I live with using … (the technology) if it included information about me.**	**3.17**	**3.80**	**2.23**	**39.631**[a]
Q4	**I would like to see information about the general public collected through … (the technology).**	**2.66**	**3.40**	**2.09**	**31.88**[a]
Q5	**I would be comfortable with the general public viewing anonymised information about me that was collected through (the technology).**	**2.63**	**3.26**	**1.89**	**34.308**[a]
Q6	**I would be comfortable with commercial organisations viewing anonymised information about me collected through (the technology).**	**2.14**	**2.69**	**1.66**	**26.247**[a]
Q7	I understood what (the technology) does.	4.23	4.43	3.89	9.8
Q8	**I understood what was happening in this scenario.**	**3.97**	**4.31**	**3.60**	**17.797**[a]
Q9	… (the technology) is easy to use.	3.94	4.00	3.74	3.155
Q10	**… (the technology) is useful.**	**3.14**	**4.20**	**2.60**	**36.505**[a]
Q11	People under the age of 21 would find … (the **technology**) easy to use.	4.00	4.11	3.83	5.915
Q12	People under the age of 21 would find … (the technology) useful.	3.00	3.29	3.03	3.5
Q13	People aged 22-60 would find … (the technology) easy to use.	3.89	4.09	3.77	3.057
Q14	**People aged 22-60 would find … (the technology) useful.**	**3.29**	**4.06**	**3.09**	**21.121**[a]
Q15	People aged over 60 would find … (the technology) easy to use.	3.54	3.63	3.29	0.711
Q16	**People aged over 60 would find … (the technology) useful.**	**3.00**	**3.77**	**2.80**	**24.065**[a]
Q17	**I would like to have … (the technology) in my home.**	**2.83**	**4.09**	**1.89**	**49.333**[a]

[a] = significant at df=2, p≤0.05 with Bonferroni Correction

2) Privacy, Interpretations and Consequences

Privacy is an important issue, raised in at least 24 responses in relation to the Proximity Portrait. Rather than just being concerned with the type of data being shared, privacy has a complex relationship with usefulness. One respondent noted that the Proximity Portrait: *"would be uninteresting if (it) did not know about enough activities and could be uncomfortable if it was too precise."*. Another noted that *"I would have to be convinced that it had a useful purpose which outweighed the 'Big Brother' scenario"*. While the Energy Monitor appears to share a greater amount of personally identifiable information than the Smart Fridge, it is considered to be less invasive across the responses. This suggests that invasiveness is a complex quality, and higher perceived usefulness can make a design seem less invasive.

A reluctance of respondents to share their data with commercial organisations is consistently seen across the scenarios, which suggests a more general concern than one tied to a specific technology. Even in relation to the most popular technology – the energy monitor – one participant states that *"I don't want electricity companies to have this information… they'll be able to exert more pressure to influence my behaviour"*. It is intriguing to note that respondents were more willing to share information publically than with commercial organisations. However, the scenarios did not provide any incentives for commercial information sharing, which is something that has proved effective (e.g. through loyalty cards and discounts).

Again, there are different concerns based on the type of household and the situations that may occur, with comments suggesting respondents would like to share different amounts of information in a household where they lived with strangers, rather than a family. Others wondered how the technologies could adapt to visitors.

The unconstrained data sharing in the Proximity Portrait scenario leads to particularly negative responses, with several respondents considering it "*creepy*". This is the only scenario presenting specific data about activities in real time. Some of the positive comments around the Proximity Portrait suggest that respondents assume there is the ability to opt out of providing information at certain times, or for certain items.

3) Knowledge and acceptance of novel technologies

In showing a preference for the Energy Monitor, respondents selected a technology that currently exists in a reduced form. In contrast the Proximity Portrait shows few similarities to existing technologies. In the open questions, respondents commonly related the scenarios to technologies they were aware of. Several participants compared their current use of energy monitors to having the advanced version in their home. In the case of the Proximity Portrait, one respondent noted an analogue in fiction: the 'Weasley's Clock' in the Harry Potter stories. Others compared this uncontrolled passive information sharing unfavourably to actively choosing to share a status on social media sites.

IV. Discussion

As the IoT concept matures, more attention needs to be paid to understanding how the sharing of information can be perceived as having positive consequences in the social dynamics of the home. As a starting point for this process, we offer initial design principles, based on the research described above.

1) *Focus on balancing privacy with useful information that provokes action.*

Privacy concerns will present a challenge in the acceptance of IoT technologies. People will accept data sharing that is seen to produce useful, actionable results. While the energy monitor could be seen to share personal data, the information was something that could be acted upon purposefully, so this was not considered invasive. To be accepted, systems should avoid designs which share detailed, personal information, without a clear purpose.

2) *Support negotiation and flexibility over the sharing and use of data*

Soppera and Burbridge consider it problematic to protect privacy whilst allowing passive collection of data through a pervasive, decentralised network [11]. One approach to this could be to focus on providing rights over instances where information is used or shared, rather than data capture itself. In the survey, concerns centre around the ways in which information is shared and used, rather than whether data that is collected in a raw form. Systems should be able to support users to make statements to the effect of *"I will let you know x for this purpose, or to do y, but not for other purposes"* in relation to their interactions with people and organisations.

3) *Use ambiguity to maintain social dynamics*

In many cases, the issues raised in the literature review and the survey could be considered as the effects of providing specific information that is seen as unnecessary. In response, it is important that we make appropriate use of ambiguity. Gaver et al pointed out how ambiguity in various forms can be a resource for design [21], and Aoki and Woodruff explore how ambiguity allows us to avoid conflicts when using communications technologies, such as allowing a person to ignore a call without it being clear to the caller whether they could have answered it [22].

In most cases the useful and acceptable information to share is not raw data, but specific data points or aggregates. As part of the IoT design process, differences in the effects of providing levels of ambiguity in the information, from fine-grain detail to broad aggregates, should be tested. If the aim is to integrate technologies without disrupting current social dynamics, then ambiguity should provide only the required information.

Real time or current information appears to be particularly concerning for the survey respondents. Designs could support further negotiation and flexibility in choosing ambiguity preferences such as *"We will see the aggregate of this data on a monthly basis, but not the raw data points."*

4) *Balance the ability of others to interpret data for useful awareness, with the need for personal space and identity*

While information about others may be shared for specific reasons, our survey showed interpretations and actions beyond this original intent. For instance, the energy monitor could result in awareness of excessive television viewing, even though this is not the explicit purpose of the tool.

On the other hand, technologies that share data across the household can limit the ability for others to take control of individual space and identity, strong issues in the family that develop in adolescence and continues into adulthood [12]. Technologies should support negotiation between family members on the use of information such as *"I will let you have the knowledge that I have done x, but not y, and only at time z"*.

5) *Leverage relationships with understood issues and technologies*

Innovation requires value that can be understood by the adopter, particularly in the 'persuasion' phase prior to acceptance [7]. In the survey respondents preferred a technology they perceived as useful, based on their existing understanding of energy monitoring. Information sharing with no obvious relationship to existing tools and activities is difficult for people to accept by default.

6) *Enable development and maintainence of trust in objects*

The integration of the physical and the digital presents issues for predicting and trusting the objects around us. This will be of particular importance in the home where people will expect defined boundaries to acceptable information sharing. One example of enabling trust could be in designing more appropriate legal and data access agreements. In current models software requires users to consent to lengthy terms and conditions, and agree to ambiguous access rules, regularly changed due to software updates. The survey and reviewed literature suggest that users would be uncomfortable with accepting these in relation to data capture in their homes.

7) Employ a range of methods to investigate acceptance and consequences in relation to a new design

It is clear that researchers have approached technology acceptance using different perspectives and methods, from qualitative evolution in the Domestication of Technology, to broad patterns drawn from quantified feedback on perceived usefulness and ease of use in TAM. In our survey, the combination of qualitative and quantitative feedback allowed us to identify significant patterns and to explore the reasons why people felt the way they did.

V. CONCLUSIONS

This paper has explored factors that will influence the acceptance and consequences of IoT technologies, as they become domesticated into our homes. The suggested principles can be considered as a starting point for designing systems, and integration with the surrounding context of their implementation.

More broadly, a user-centred approach is required to map this complex design space, to understand how to avoid negative individual and social consequences, and to support acceptable and useful information sharing. Our future work will develop further methods to elicit perceptions of these types of technologies, and compare the results of these approaches with field trials of IoT prototypes. We will test variations of designs that represent different types of information sharing, for example providing more or less detail about activities, or either current or historical information. Through this we can understand acceptable forms of information sharing, and build a conceptual framework for designing IoT in the home and beyond.

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