Evaluating User Experience in Smart Home Contexts: A Methodological Framework

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Abstract. Similar to the concept of 'smart city', the phrase 'smart home' is being adopted by many businesses and stakeholders as a priority which recognizes the growing importance of digital technologies in the home context. However, few targeted methodologies exist that take into account the dynamic and interactive aspects of this environment when studying user experience. To date, the multi-disciplinary field of user experience studies, which investigates individuals perception about using a particular product, system or service, lacks a methodological and conceptual framework to study these smart homes that are connected to the internet and to a rapidly increasing amount of both sensors and actuators.

The goal of this paper is to create a framework to explore how technology enables and constrains agency and engagement in smart homes or spaces. Our methodological framework is grounded in the concepts of interactivity and affordances. We will propose a framework that takes the operational, structural features of a smart home (expressed in structural affordances) into account as well as the functional, subjective perception and usage of these features by people (expressed in functional affordances).

Keywords: Smart home · Affordance · User experience

1 Introduction

Smart Home technologies are increasingly on sale and are forecasted to reach a value of more than 40 billion U.S. dollars by 2020 (Statista 2017), to grow over 50 billion U.S. dollars by 2022 (Zion 2017), or even with 138 billion U.S. dollars by 2023 (M&M 2017). Despite the rising popularity of smart homes, few concepts or frameworks are available that provide guidelines to study and comprehend these smart spaces. Existing research on smart homes has focused on the technological challenges involved in delivering smart domestic environments (Cook 2012) without too much consideration to smart home users at all (Wilson et al. 2015). An user-centric vision is currently missing from a field being overwhelmingly 'pushed' by technology developers. Hence, literature in social sciences and communication studies lacks generic frameworks that enable the investigation of the many ways in which smart spaces have implications for the daily lives of their inhabitants or of the diverse ways people interact and communicate with and within these smart spaces.

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In this paper we propose a theoretical framework that addresses this gap. We illustrates it's applicability by discussing 'interactivity' in smart spaces. We will use the concept affordance as it offers a way to consider smart spaces independently of 'under-socialized' technological-determinist perspectives that argue that technology shapes interactivity or 'over-socialized' (social) constructivist perspectives that argue that technology is a purely cultural construct. Moreover, while most theories on structure and agency, neglect how structure is actually perceived by people, the notion of affordances enables us to take perception connoted aspects into account as well. Also, the concept underlines that affordances are not mere action possibilities but that they can also invite behavior (see e.g. Hogan 2009; Withagen et al. 2012). Our effort tries to broaden the concept of affordances in order to understand human use and interaction in smart spaces or homes.

This paper is structured as follows. First, smart homes are briefly discussed. Next, the concept affordance is theoretically unpacked. We briefly sketch the history of the concept, provide affordance typologies from literature and propose a working definition. Third, we develop a theoretical framework for the study of smart spaces that uses affordances as a central concept and takes a structural perspective (focusing on the object of interactivity) as well as a functional perspective (focusing on the goal of interactivity). Fourth, in the last part of this paper we discuss and review the value and usefulness of the developed framework.

2 Smart Spaces and Homes

Smart spaces support services that actively involve surrounding digital devices and Internet services (Korzun et al. 2015). As such, a smart home is a physical embodiment of such a system in which software uses sensors to perceive and reason about the state of the home and its residents (Cook et al. 2013). These smart home technologies comprise sensors, monitors, interfaces, appliances and devices networked together to enable automation as well as localized and remote control of the home (Cook 2012).

While a smart space is usually thought of as a meeting place where people come together to collaborate, to share knowledge, and engage in shared activities (Frey et al. 2013), the primary objectives of a smart home are to increase home automation, facilitate energy management, and reduce environmental emissions. (Saad al-sumaiti et al. 2014).

As the term 'smart homes' is often used as a generic descriptor for the introduction of enhanced monitoring and control functionality into homes (Hargreaves and Wilson 2017), we will adopt in this paper the definition provided by Aldrich (2003, p. 17): "(…) a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond".

In the literature on smart homes, the domestic environment is often simply the 'taken for granted' backdrop within which technology will be used (Richardson 2009). However, ethnographic and sociological research on the use of ICTs in homes shows these domestic environments are important as they are actively divided by their

occupants into functionally and interpretively distinct places (Hargreaves and Wilson 2017). Domestic environments are shared and contested places in which different occupants have sometimes different understandings, preferences, responsibilities and emotional associations (Nyborg 2015).

This paper will present a framework that provides guidelines to study and comprehend such domestic environments taking a user-centric as well as functional viewpoint that considers the home as an informant allowing active control or automation.

3 Affordances

3.1 History of the Phrase Affordance

The term affordance captures relationships between an organism and its environment that allows or inhibits certain actions (Koles and Nagy 2014; Ziglari 2008). Affordances point to the relationship between properties of the environment and the possibilities for action it allows. They highlight the fact that social and cultural artifacts and actions are situated, that they take place using technologies that can be designed, that are controlled and owned. Today, many interpretations of the concept 'affordance' exists and the exact meaning of the term continues to be subject of ongoing debate.

The term affordance was originally proposed in the field of ecological psychology by Gibson (1977). Gibson argues that animals and people initially do not perceive the (physical) properties of objects, but rather what objects offer or afford them: "what we perceive when we look at objects are their affordances, not their qualities" (1986, p. 134). In this sense, the affordances of a home or space refer to those objective and subjective entities that this particular setting can offer its users and surrounding systems (Gibson 1986). They are "what [a tool] offers … what it provides or furnishes, either for good or ill" (Gibson 1986, p. 127). Scholars from other disciplines have used the term to refer to certain ''actionable properties between an object and an actor'' (Zhang 2008).

Another view on technology affordances was created by Norman (1988), who focused on the perceived and actual properties of the thing that determine just how the thing could possibly be used. Norman, who applied the concept to everyday artifacts, illustrates the latter with the example of vertical door handles that afford pulling, while flat horizontal door plates afford pushing. Norman adds an important caveat, arguing that affordances are the result of a mental (cognitive) interpretation based on the knowledge and experience of the individual applied to his/her perception. Perceived affordances tell the user what actions are possible and how they should be implemented (Norman 1988).

For Gaver (1991), affordances are independent of perception; they exist whether the perceiver cares about them or not, whether they are perceived or not, whether there is perceptual information available for them or not. Thus it is useful to distinguish affordances from the perceptual information about them. Most examples of affordances refer to perceptible affordances in which there is perceptual information available for an existing affordance. When no information is available, the affordance is hidden (and needs to be inferred from other evidence). When information suggests an affordance that

actually is not there; a false affordance exists on which people may mistakenly try to act. When no information about an affordance can be perceived and the affordance does not exist, people will usually not think of a given action.

3.2 Typologies of Affordances

Various typologies of affordances have been created in literature. Creating typologies is a useful approach to better understand a concept as it is a research strategy that raises the level of abstraction and highlights similarities and differences while at the same time requiring exclusivity; i.e. an affordance will be classified in the best fitting category even if it has some features of other affordance types as well. Some of the most interesting typologies include those created by Trepte (2015), Reid and Reid (2010), Hartson (2003), Hogan (2009) and Kaptelinin and Nardi (2012).

Cold and Warm Affordances
Trepte (2015) distinguishes two kinds of social media affordances: 'warm' affordances that invite us to comment, upload, tag and 'cold' affordances that imply agreements about privacy, terms and conditions of use (legal architecture), data ownership, … Communicating in social media spaces thus means experiencing warm affordances (e.g. sharing content) under conditions of cold affordances and as such accepting that all is shared with an (unknown) company that sells or exploits personal information.

Interpersonal and Conversational Affordances
In their study of SMS-culture, Reid and Reid (2010) distinguish between 'interpersonal' en 'conversational' affordances. Interpersonal affordances link up to Goffman's notion of expressive control (1959) and enable self-conscious impression management during a 'social action' (performance). Most online platforms feature different interpersonal affordances that allow such 'expressive control'. The second type distinguished by Reid and Reid (2010) are conversational affordances that determine the extent to which extended interactive exchange of information is possible.

Cognitive, Physical, Sensory, and Functional Affordances
Hartson (2003) describes four complementary types of affordance. Cognitive affordances are design features that help, aid, support, facilitate or enable thinking about something while physical affordances enable doing something. Functional affordances stress the goal a physical affordance can realize and help the user in doing something while sensory affordances provide design features that help, support or enable the user in sensing something.

Informational, Relational, Temporal and Spatial Affordances
Neil Hogan (2009) proposes a typology of social affordances with four specific groups: the social affordances of time, space, relations, and information. Informational social affordances help users to grasp the social setting; they are the socially relevant content of the interaction, and are most closely aligned with cultural signs, values and symbols. Relational social affordances also provide information but are oriented towards other participants rather than the content of the interaction or context. Temporal social

affordances provide perceptual cues about temporality while spatial social affordances convey the properties of space or distance in online spaces that permit or inhibit social interaction.

Instrumental Technology and Auxiliary Technological Affordances
Kaptelinin and Nardi (2012) distinguish between instrumental technology and auxiliary technological affordances. Auxiliary affordances include for example aggregation affordances or maintenance affordances, enabling carrying out maintenance routines and troubleshooting. Instrumental affordances comprise two components; the handling affordance (possibilities for interacting with the technology) and the effecter affordance (possibilities to make an effect on an object using the technology).

3.3 Affordances Working Definition

As our brief literature review shows, the exact meaning of the term affordance continues to be a subject of ongoing debate and many of the interpretations of the concept are incompatible with the original vision of Gibson (Kaptelinin and Nardi 2012). While we can question the use of affordances because of the ambiguity between the absolute 'real' affordances and 'perceived' affordances described in Norman's definition, from a middle ground perspective, affordances can provide a useful lens for studying technologies and the many ways in which smart spaces have implications for interacting and communicating within these digital spaces.

In order to examine the 'physics' of such spaces the properties of the home can be directly related to the actions it affords. Moreover, affordances are defined to both the environment and the interacting organism (the smart home 'user') and in such a way provide or complement insight in computer mediated spaces. As we understand affordances as contextualized in ongoing activities and arising out of interaction between actor and environment or system, we define an affordance as 'what one system provides to another system', in specific, as 'what a smart home provides to its inhabitants or its visitors'. An affordance thus also encompasses the perceived functional significance certain smart home technology for an individual.

4 Towards a Two Folded Affordance Framework

4.1 Structural Approach: User, Media and Home Affordances

In order to transcend the particularities of any technology or its features we first take a structural approach, defining smart contexts by enumerating its affordances and by considering its infrastructure or architecture. As such, we focus on the object of interactivity, describing the home in objective, structural terms as a space that affords (inter)action towards users, documents or media, and the smart home itself.

In general terms, the phrase 'interactivity' describes an active relationship between two things. Three traditions of interactivity research are identified: human-to-human, human-to-documents and human-to-system interaction (McMillan 2006), focusing respectively on human communication, on how people interact with content or media

and, on how people interact with the system, computer or any type of technology. From within these traditions, interactivity refers to the features of a medium or technology (its potential for interaction in general) and to the extent that people will use these features or affordances.

Smart spaces assemble a cohesive set of structural affordances, providing us with knowledge about the performative infrastructure that smart spaces supply to inhabitants or visitors. Based on the aforementioned distinction we posit three types of structural affordances; (i) user affordances encompass smart home features that are targeted at other smart home users or people, enabling communication, collaboration or networking, (ii) document or media affordances refer to features that enable smart home users to interact with content, (iii) home affordances provide features for interaction between users and the smart home. Taking into account this last type of structural affordance acknowledges that smart homes as intelligent and context-aware learning systems, do not remove the need for any active user involvement despite the fact that they (try to) automate functions according to users' revealed habits. As smart homes offer integrated affordances and boundaries for their inhabitants or visitors, insight in how these structural affordances are used is essential to analyze how agency and engagement is expressed.

Clearly, structural affordances point well beyond their technical functions to the values and goals of the designers and owners of the home. They envision a certain set of relations and hence externalize the 'politics' of the platform (Gillespie 2010) or home, spelling out and proposing - more or less forcefully - certain sets of relations. As affordances are the things that we recognize rather than the technological smart home components that we infer, they offer a key and under recognized link in a theory of structure and agency (Hogan 2009). Thus, insight in the structural affordances present in a smart home, provides us with knowledge about the performative infrastructure that the home supplies to its users, visitors or inhabitants. Some examples of these structural affordances of smart homes include e.g. technology such as an in-house phone and communication system enabling communication (user affordance), technology to play, stop etc. media content (document or media affordance), or technologies that enable smart home users to raise the temperature, dim the lights etc. (home affordances).

4.2 Implementing the Structural Research Approach

In order to analyze a specific smart home or space from a perspective that takes these structural affordances into account two methods could be applied.

The first is rather straightforward and boils down to listing the different technologies that the smart home provides or affords and logging their usage. As users interacting in contemporary smart homes operate in what could be termed as 'digital enclosures' or as spaces "where every action and transaction generates information about itself" (Andrejevic 2007, p. 2) it is mainly a technological challenge to ensure that everything is captured, mined and instrumentalized.

The second method, the walkthrough method, encompasses an approach that provides insight in the object-oriented character of structural affordances. This design evaluation methodology, initially designed to provide a new tool for assessing the

usability of a system, and assigning causes to usability problems, entails a systematic review process "in which the author of a particular aspect of a design presents his or her proposed design solution to a group of peers" (Polson et al. 1992, p. 742). Implementing the aforementioned structural research approach would thus mean that the smart home architect and the providers of the smart home technologies (or a group of external reviewers) step through the available smart home functions considering the behavior of the interface from an object-oriented perspective and assign the home functions to either one of the three structural affordances categories (user, document or media, and home affordances). This inventory exercise should end up with a detailed and fine-grained list of technologies that are embedded in the house and that facilitate human interaction or interaction with media content or the house itself.

4.3 Functional Approach: Inter-action, Intra-action and Outer-action Affordances

We also need a perspective that describes how smart home inhabitants or visitors engage and interact with the structural affordances mentioned above. Hence, we posit a functional approach or perspective that describes the smart home in subjective, functional terms as a space that affords its user certain (inter)action goals. We suggest to add a set of functional affordances to the methodological framework, namely inter-action, intra-action and outer-action affordances.

Inter-action affordances point to the use of affordances for communication. They reflect the use of structural affordances from a 'process' viewpoint; as a type of information exchange between two or more people. They enable conversations and are thus 'social' affordances. Intra-action affordances enable interaction from a person to himself/herself. As the individual receiving the message is (due to time separation) in a different state from the moment when the message was issued, the message is likely to contain something 'new' and hence, valuable to the receiver. Intra-action does not describe a mental or cognitive process but the process of external representation of a mental process. In that sense, intra-action affordances can also be called 'personal' affordances. Outer-action affordances support communicative processes outside of information exchange, in which people reach out to others in patently social ways to enable information exchange. These affordances enable negotiations about availability, assist in finding ways to establish connections, and support the progress of an interaction. Outer-action affordances scaffold information exchange (Nardi et al. 2000); they are 'context' affordances.

Some examples of these functional affordances of smart homes include e.g. using technology such as an in-house phone and communication system to communicate with other inhabitants (inter-action affordance), using technology to store a memo or the specifics of a future event in a calendar (intra-action affordance), or using technologies that enable smart home users to have insight in the presence or absence of inhabitants (outer-action affordances, see Fig. 1).

Fig. 1. The Eta Clock, a Kickstarter project that works with a smartphone app to show the locations of house members as an example of a technology providing outer-action affordances (https://www.kickstarter.com/projects/2111232964/the-eta-clock-a-community-location-device).

4.4 Implementing the Functional Research Approach

Similar to applying the structural approach two methods could be applied in order to take a functional affordances perspective.

The first uses the aforementioned list of different technologies that the smart home provides and the logs of their usage and provides this as feedback to the smart home users, asking them to consider systematically the mental operations in the use of the smart home, such as goal formation.

As a matter of fact, this could serve as a pre-cursor for a walkthrough approach in which smart home inhabitants or visitors step through the available smart home functions considering the behavior of the interface from an goal-oriented perspective and assign the home functions to either one of the three functional affordances categories (inter-, intra-, and outer-action affordances). This second inventory exercise should then end up with a detailed and fine-grained list that describes the smart home in subjective, functional terms as a space that affords its inhabitants certain (inter)action goals.

4.5 The Framework

The combination of the structural and functional affordances approach sketched above creates a twofold analytical lens or research framework (see Fig. 2) that can be used to describe interactivity in smart homes, in objective, structural terms as well as in subjective, functional terms. Structural affordances help us to describe the home as a space of object-oriented user, document or media and home affordances. The functional affordances describe the home as a space of perceived inter-action (social), intra-action (personal) and outer-action (context) affordances. This twofold framework for interactivity in smart spaces thus takes into account structure and agency, synthesizing both the structural properties of the smart home as well as the ways that inhabitants or visitors perceive and interact with these capabilities.

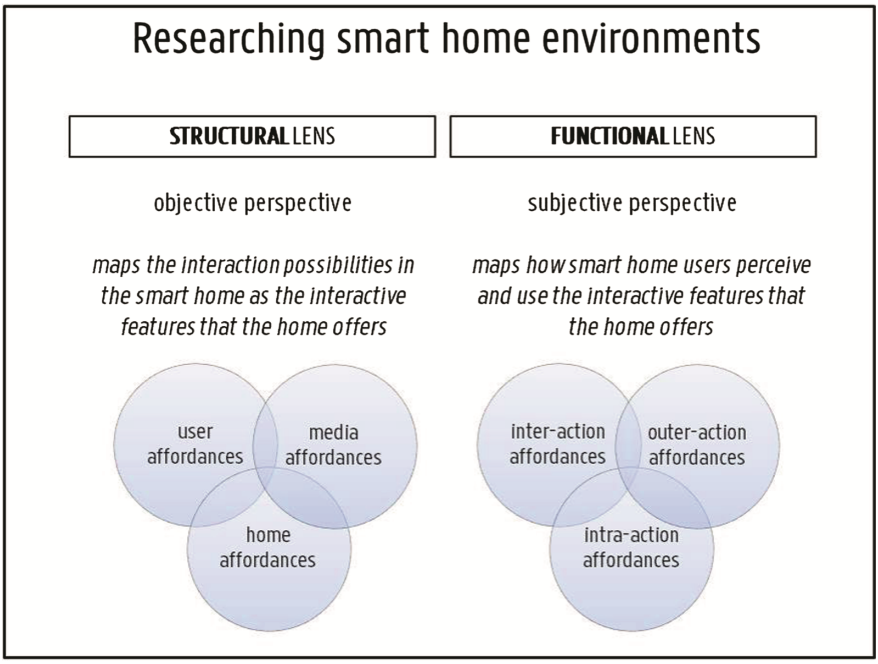

Fig. 2. A methodological framework for researching user experience in smart home contexts

People will often resort to user affordances (as social affordances) to setup conversations with others, they will use media affordances (as personal affordances) to interact with the available content (e.g. in smart home media systems), and they will often use home affordances (as context affordances) to interact with the smart home. Juxtaposing structural and functional affordances shows that structural user affordances can be linked to functional inter-action or 'social' affordances; structural document or media affordances to functional intra-action or 'personal' affordances; and structural home affordances to functional outer-action or 'context' affordances. Figure 2 summarizes the components of our twofold research framework for the analysis of interactivity in smart homes.

Positioning these two perspectives next to each other provides insight in the domestication process of technology (Silverstone and Haddon 1996) and in the appropriation phase in specific as it provides a language to describe how a technology is welcomed into the household and is granted a physical and discursive place, while its use is given a place within existing routines.

5 Discussion and Conclusion

In this paper we considered a smart home's structural affordances, in user, document or media and home affordances. Our analytic framework also made it possible to talk about

the home in subjective, functional terms, describing it as a space of perceived inter-action, intra-action and outer-action affordances. Our affordance lens forced us to consider the symbiotic relationship between the action to be taken in the context and the capability of the technology. By treating the entanglement between the human action and the technological capability as a unit of analysis, the two-folded affordance perspective provides us with a language to examine smart home technologies that avoids privileging any single component of a sociotechnical system over any other component in explaining behavior.

Our proposed framework has two important merits. Firstly, using the framework one can interpret a smart home as a medium 'through' which people can communicate, as well as a medium 'with' which people can communicate and interact. As such, it positions the smart home as a social actor with whom one communicates and interacts, challenging long standing assumptions about the role and function of technology. Secondly, with our twofold framework, we can integrate both the smart home structural properties and the ways that people interact with these capabilities; the framework takes into account human agency as well as the technological tools and components of the home.

The conceptual framework we developed in this paper can be criticized for its vagueness in differentiating user, document or media and home affordances. Indeed, it is often difficult to distinguish them based solely on the involved information or interaction patterns. Also, given the explorative nature of our framework and proposed research approach, a path towards validating the framework should be further explored in order to unearth conceptual, methodological and procedural shortcomings.

Despite these limitations, we believe that the developed framework can function as a steppingstone for more extensive and qualitative research into the many ways in which smart spaces have implications for the creation, use, and experience of digital media content and into the diverse ways people and communities interact and communicate within these spaces.

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