Chapter 2
Analytical Framework for Research on Smart Homes and Their Users

Abstract Through a systematic analysis of peer-reviewed literature, this chapter takes stock of the dominant research themes on smart homes and their users, and the linkages and disconnects between these themes. Key findings within each of nine themes are analysed in three groups: (1) views of the smart home—functional, instrumental, socio-technical; (2) users and the use of the smart home—prospective users, interactions and decisions, using technologies in the home; and (3) user-related challenges for realising the smart home—hardware and software, design, domestication. These themes are integrated into an analytical framework that identifies the presence or absence of cross-cutting relationships between different understandings of smart homes and their users. This analytical framework serves to organise, link, and integrate the empirical analysis in Chaps. 3–6 of the book. More broadly, the analytical framework shows how research on smart homes and their users can benefit by exploring and developing cross-cutting relationships between research themes and traditions.

2.1 Introduction and Key Questions

Interest in smart homes has risen rapidly over the past 10 years (Fig. 2.1a). Published research on smart homes and their users is also expanding. Yet analysis of reports, studies, websites, and promotional material produced by smart home technology developers and service providers reveals a notable absence of user-focused research (Hargreaves and Wilson 2013). A clear understanding of who smart home users are and how they might use smart home technologies is missing from a field being strongly pushed by technology developers (Haines et al. 2007).

In this chapter we ask two related questions:

Q1 What are the main themes of scientific research on smart homes and their users?

Q2 What are the linkages and disconnects within research on smart homes and their users?

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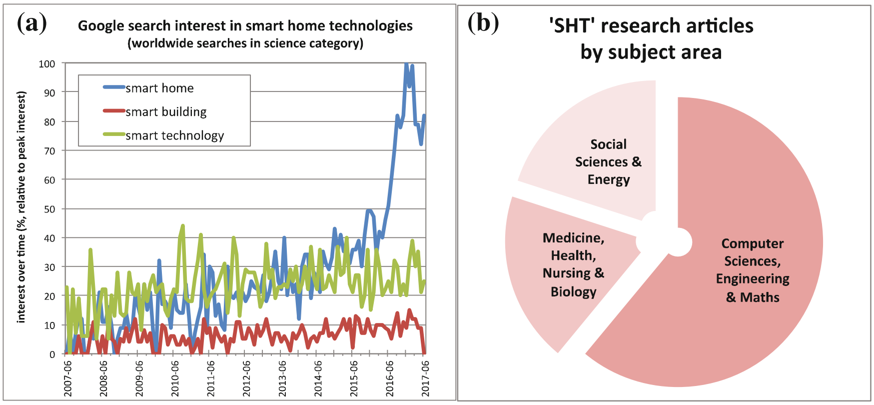

Fig. 2.1 Interest in SHTs over time and peer-reviewed SHTs research (Notes: Left panel shows rising interest in smart homes based on Google search; Right panel shows disciplinary classification of 150 scientific publications on smart home users)

To answer these questions, we analyse peer-reviewed scientific literature to identify the dominant themes, emphases and arguments on the users and use of smart home technologies (SHTs). This enables us to develop an analytical framework for research on smart homes and their users. We then show how the framework helps to identify cross-cutting linkages as well as disconnects between research themes. In subsequent empirical chapters (Chaps. 3–6) we use the framework to organise and inter-link our new data and analysis on smart home users. In this way, we demonstrate the framework's purpose: to bring coherence and comprehensiveness to an important and growing field of research.

2.2 Research Themes

The starting point for our analytical framework was to identify existing themes in research on smart homes and their users. We conducted a systematic literature review and thematic analysis of academic publications that explicitly address "smart homes" and "users". Specifically, we searched the Scopus database using the search string 'Smart' AND 'Home' AND 'User' AND 'Technology' and included a total of 23 synonyms and variants (e.g., 'Residen*' and 'Hous*' in lieu of 'Home', with the *capturing different possible word endings, e.g., 'House', 'Housing'). For further details on the search protocol, see Wilson et al. (2015).

After screening out spurious hits including articles on smart homes that did not focus on users either directly or by inference, we identified a final sample of 150 peer-reviewed articles. These articles either explicitly investigated prospective or actual users of smart homes, or implicitly considered users through inferences on the usability, design, or attractiveness of smart home technologies. Using the Scopus disciplinary classifications, we classified this set of 150 articles by discipline (Fig. 2.1b). Engineering and computer sciences dominated (61%) with the remainder split evenly between health-related disciplines (19%) and the social sciences and energy studies (20%).

From the 150 peer-reviewed articles analysed, we identified nine inter-related themes of research and the key findings within each (see Wilson et al. 2015 for details of the thematic analysis). We organised these under three groups or meta-themes: views and visions of the smart home; understandings of users and the use of smart homes; and user-related challenges to the realisation of smart homes.

The first set of research themes describes three views or ‘grand narratives’ of the smart home future. These views provide the context and underlying rationale for industry activity and scientific research. They offer different and at times competing visions or interpretations of what smart homes are and what they are for.

1. Views of the smart home
   (i) functional view
   (ii) instrumental view
   (iii) socio-technical view.

The second set of research themes relate specifically to the users and use of smart homes. They begin with basic questions about who smart home users are, and what specific characteristics they have. They then extend to different views of the form, frequency, and function of user interactions with SHTs.

2. Users and the use of the smart home
   (i) user needs and wants
   (ii) user-technology interactions
   (iii) homes as complex places.

The third set of themes turns to the principal challenges for realising the smart home in the near-term future, distinguishing hardware and software development issues from design and usability challenges. More fundamental questions are also asked about the users of SHTs amidst the complex and irregular rhythms and patterns of everyday life in the home.

3. Challenges for realising the smart home
   (i) hardware and software
   (ii) acceptability and usability
   (iii) domesticating technologies.

In the next sections we explain each of these themes in more detail, drawing out relevant literature which represents the main arguments and findings.

2.3 Views of the Smart Home

The first meta-theme of research on smart homes and their users is concerned with the views, visions or 'grand narratives' of a smart home future. Why is the smart home a growing and potentially important field of research and development? Three broad views are evident in the literature: a functional view, an instrumental view, and a socio-technical view. The *functional* view sees smart homes as a way of better managing the demands of daily living through technology. The *instrumental* view emphasises smart homes' potential for managing and reducing energy demand in households as part of a wider transition to a low carbon future. The *socio-technical* view sees the smart home as the next wave of development in the ongoing electrification and digitalisation of everyday life.

The functional view

Proponents of the functional view argue that extending and integrating the functionality already provided in homes by a range of information and communication technologies (ICTs) will contribute to 'better living' (e.g., Friedewald et al. 2005; Park et al. 2003). Much of the technologically-oriented literature on smart homes presents their benefits for end users as both obvious and manifold: comfort, security, scheduling tasks, convenience through automation, energy management and efficiency; and for specific end-users, health and assisted living (Cook 2012; Rashidi and Cook 2009). Balta-Ozkan et al. (2013) group these benefits in three categories: lifestyle support, energy management, and safety.

User-centric research clearly emphasises the enhancement of existing services not the provision of new ones: "the point of technology is not to replace experiences that we already enjoy today with our families … (but to) support or enhance experiences you already enjoy … but in new ways" (Heath and Bell 2006, p. 258). As examples, smart homes can deliver better-connected workspaces (Chae and Kim 2011), enhance existing televisions through interactivity (Bernhaupt et al. 2008), and even help overcome digital divides by including elderly and other households currently marginalised from the information society (McLean 2011).

The functional view points to a wide variety of tasks and activities that smart homes could help people achieve: remotely controlling specific appliances, improving memory and recall through automated reminders, enhancing security through simulated occupancy when homes are empty, and so on (Cesta et al. 2011; Demiris et al. 2004, 2008; Orpwood et al. 2005; Park et al. 2003). These correspond in broad terms with users' perceived needs for improved comfort, convenience, security, and entertainment (Aldrich 2003).

The most clearly resolved functional view of 'better living' is articulated by researchers in the health and social care domain. Here, smart homes can "contribute to the support of the elderly, people with chronic illness and disabled people living alone at home … (by improving) the quality and variety of information transmitted to the clinician" (Chan et al. 2009, p. 93). This decision-support functionality is centred on monitoring through wearable, implantable, and sensing devices to facilitate preventative care and detect adverse health incidents (Chan et al. 2008). Other health researchers examine specific vulnerabilities, such as individuals living with serious mental illness, emphasising that caregivers rather than individuals are often the direct beneficiaries (Giger and Markward 2011).

The instrumental view

A more clearly instrumental or goal-oriented view of smart homes emphasises their roles as the means towards a defined end of energy demand management, with associated benefits for households, utilities, and policymakers (Darby 2017). The aims of households trying to save money and energy align with the efforts of utilities trying to improve energy system management and the objectives of policymakers pursuing greenhouse gas emission reductions and a secure, affordable, reliable energy supply. The instrumental view sees the smart home as a technological contributor to a low-carbon energy transition (e.g., Lewis 2012; Martiskainen and Coburn 2011) or sustainability more generally (Chetty et al. 2008). As Wilhite and Diamond (2017) argue: “smart homes are grounded in the thinking that efficiency, optimization, standardization and automatization are the keys to reducing residential energy use.” This instrumental purpose of smart homes is consistent with research in the commercial and institutional sectors on smart or ‘intelligent’ buildings with automated energy management systems (BPIE 2017b; Bull et al. 2013; Wong et al. 2005).

The SHTs most relevant to the instrumental view are smart meters, smart energy-using appliances, and energy management functionality to enable user control and programmed optimisation of appliance use and micro-generation (Paetz et al. 2012; Tiefenbeck 2017). Energy smart homes thus encourage a transformation of passive end users into ‘micro-resource managers’ (Strengers 2011, p. 227; see also Geelen et al. 2013) and a transformation of homes into ‘dynamic micro-energy hubs’ (BPIE 2017a). Personalised, tailored and real-time information and feedback on energy use (and tariffs) via smart meters and in-home displays helps to ‘make energy visible’ (Hargreaves et al. 2010; Wallenborn et al. 2011). Smart technologies also open up a suite of options for household energy management that were not possible under previous ‘dumb’ systems of monthly feedback via energy bills. Smart homes, this view suggests, will enable energy to be cut, trimmed, switched, upgraded, or shifted (Pierce et al. 2010).

However, demonstrated energy savings from the use of SHTs in studies or field trials are relatively small. Large-scale trials of smart meters and in-home displays in the UK demonstrated around 3% energy reductions on average (AECOM and OFGEM 2011). Potential savings (or ‘shaving’) during peak times can be more pronounced (Darby 2006; Davis et al. 2013; Wood and Newborough 2003). But households’ appetite or capacity for reducing energy bills in response to information feedback and price incentives appears limited, and interest in information and price signals rapidly wears off (Hargreaves et al. 2013; van Dam et al. 2010).

Energy utilities are key proponents of the instrumental view but are interested less in household-level energy savings and more in the rollout of smart meters. These will provide utilities with real-time information on both supply and demand distributed across the millions of nodes of the distribution network (Palensky and Kupzog 2013). Linked in-home displays communicating usage and cost information to end users enable utilities to charge for electricity at its marginal cost, providing a price signal to shift or curtail demand when supply is expensive or in short supply (Allcott 2011; Herter et al. 2007). Individual homes are thus integrated into wider 'smart grids', with considerably improved energy management functionality for utilities, and potential efficiency gains with associated financial and environmental benefits (Paetz et al. 2012). This utility-driven instrumental view is already strong in the US (e.g., Davis et al. 2013; Enright and Faruqui 2012) and is also a central part of the rationale behind smart meter rollouts and smart grid development in the EU (e.g., Christensen et al. 2013; Darby 2010).

The socio-technical view

The functional and instrumental views dominated the literature reviewed, but a third 'socio-technical' perspective on smart homes was also evident. Rather than focussing on the specific functions smart homes can offer or seeing smart homes as useful tools to realise broader energy objectives, the socio-technical view sees smart homes as simply the latest episode in the coevolving relationship between technology and society. The socio-technical view emphasises how the use and meaning of technologies will be socially constructed and iteratively negotiated, rather than being the inevitable outcome of assumed functional benefits (Axsen and Kurani 2012; Strengers 2013).

Røpke and colleagues contextualise "the pervasive integration of ICT into everyday practices" (Røpke et al. 2010, p. 1771) as part of what they call the 'third round of household electrification'. Building on Schwartz-Cowan's (1983) seminal work on the 'industrialisation of the home', they see the electrification and digitalisation of the home as the latest round of socio-technical change. Previous rounds involved lighting (early 1890s) and power and heating (1940s–1970s). The core technology of the current round is the micro-chip, which has enabled the creeping digitalisation of almost all aspects of everyday life.

Technology developers' visions nourish this socio-technical interpretation. Park et al. (2003), for example, sketch out working prototypes for smart pens, pillows, dressing tables, doormats, picture frames, sofas, walls, windows and so on, with a correspondingly broad array of services, from remembering, reminding, smelling, lighting, recognising, sounding, connecting and reinvigorating. Taylor et al. (2007) emphasise the potential for almost all 'surfaces' (doors, walls, bowls) to become 'smart' digital displays in an 'ecology of surfaces' with and through which users interact. Even in the health domain with its more overt surveillance and monitoring function over vulnerable household members, SHTs are to be "embedded seamlessly in the everyday objects of our lives" (Hussain et al. 2009, p. 539).

The socio-technical view of smart homes is distinctive in arguing that such technological developments always, and necessarily, co-evolve with broader and longer-term societal changes that may include indirect and unintended consequences. Smart homes are important and interesting precisely because of these potentially transformative but as yet unknown effects (Strengers 2013). The activities constituting everyday life at home may be combined or scheduled in new ways (Nyborg and Røpke 2013). Differentiated identities and gender roles associated with activities such as housework and leisure may be reinforced or destabilised (Berg 1994; Richardson 2009). SHTs may also change how householders understand, experience, and construct meaning around their homes and domestic life more generally (Baillie and Benyon 2008; Davidoff et al. 2006; Strengers and Nicholls 2017).

2.4 Users and the Use of Smart Homes

The second meta-theme of research on smart homes and their users is concerned with understanding who the users are, and how they use SHTs. User-oriented studies in smart home environments are notable exceptions rather than the rule (e.g., Paetz et al. 2012). Current understanding and representation of *actual* smart home users is based largely on inference from research with *prospective* smart home users. Within this body of research, there are three important themes: (i) who prospective users of smart homes might be; (ii) how these users might interact with and make decisions about SHTs; and (iii) how broader conceptualisations of the home as the adoption environment for SHTs conditions both users and use.

The needs and wants of smart home users

There are few specific and differentiating characteristics of smart home users identified in the literature. The major exception is in smart homes for assisted living which emphasises active ageing and independence, self-determination and freedom of choice, and changing and inter-dependent needs of an ageing population (Friedewald et al. 2005; McLean 2011). Specific needs of elderly smart home users include easily accessible contact with emergency help, assistance with hearing or visual impairments, and automatic systems to detect and prevent falls (Beringer et al. 2011; Cesta et al. 2011; Demiris et al. 2004, 2008; Hoof et al. 2011). Vulnerable users in assisted living smart homes comprise more than just the elderly. Chan et al. (2008), for example, highlight the potential for smart homes to incorporate wearable and implantable devices that can monitor various physiological parameters of patients. Giger and Markward (2011) focus on those with serious mental illness. Orpwood et al. (2005) highlight the specific user-interface requirements of dementia sufferers.

Beyond these specific characteristics of health-related users, the identities of prospective smart home users have to be inferred. In the functional view of SHTs, technophile users are attracted to an ICT-enhanced lifestyle, and the potential for control and automation offered by the smart home (e.g., Cook 2012; Park et al. 2003). According to the instrumental view, users are information and price-responsive, and broadly rational in seeking to manage domestic energy use (e.g., Darby 2010; Lewis 2012). A small number of articles imply another type of user: the incremental home improver. The development of modular, affordable and accessible SHTs enables their incorporation into existing as well as new-build homes. Potential users may therefore include low and middle income households, as well as high income technophiles (e.g., Martiskainen and Coburn 2011). A final type of prospective user, prevalent in the more socio-technical studies reviewed, identifies women, children and families rather than unitary households or individual users (Davidoff et al. 2006). Richardson (2009) and Berg (1994), for example, emphasise that women and children will be smart home users as well as men and therefore that distinct gender roles and identities should be recognised during technological design and development.

These types of prospective smart home user—elderly or vulnerable householders, rational energy users, technophiles, home improvers, and differentiated families—are not exclusive. Whether collectively they constitute a strong market potential for SHTs is an open question which we address more fully in Chap. 3. Some researchers are circumspect: "If the history of research into this area attests to anything, it is the narrowness of the appeal of smart homes to a wider population" (Taylor et al. 2007, p. 383).

User interactions with smart home technologies

Users must interact or interface with SHTs in some way. These interactions can be more or less frequent, and more or less active (e.g., Herczeg 2010). In an influential depiction of the smart home, Cook (2012) reduces user interactions with smart home systems to one-off goal-setting: "computer software playing the role of an intelligent agent perceives the state of the physical environment and residents using sensors, reasons about this state using artificial intelligence techniques, and then takes actions to achieve specified goals, such as maximizing comfort of the residents" (Cook 2012, p 1579). Users are interpreted as having fixed and stable needs and preferences that homes, rather than the users themselves, can manage optimally. Smart homes as intelligent and context-aware learning systems remove the need for any active user involvement by automating functions according to users' revealed habits (e.g., Das et al. 2002; Ma et al. 2005; Saizmaa and Kim 2008).

These visions of intelligent homes are countered by the complexity, potential inflexibility and poor manageability of fully automated smart homes that are cited as key barriers to their adoption (Balta-Ozkan et al. 2013; Bernheim Brush et al. 2011). A long-standing irony in human-computer interactions is that "the more advanced a control system, the more crucial may be the contribution of the human operator" (Bainbridge 1983, p. 775). End users rate automation as a desirable feature of smart homes, but this is qualified by calls for automation to be strictly limited to chains of functions that users can program or set up themselves: "computers should not make choices for users, but the other way around" (Koskela and Väänänen-Vainio-Mattila 2005, p. 240). An important role of the smart home is to provide useful information to users about various aspects of household functioning (e.g., room temperatures or occupancy, appliance conditions, energy usage) in an effort to help them make more informed choices and decisions.

User interactions with SHTs might therefore range from a one-off input of preferences for the domestic environment ('set-and-forget') to ongoing, repeated, and adaptive decision-making and control. This latter possibility leads to a small strand of research focussed on how users make decisions about SHTs. The instrumental view assumes users respond rationally to improved feedback, information, and price signals (Tiefenbeck 2017; Wood and Newborough 2003). Alternative framings of domestic decision-making have emphasised its emotional, negotiated and pragmatic character. Friedewald et al. (2005), for example, recognise users as being 'emotional' and having moods, as holding cherished ideals, and as valuing communication and interactions with people. Such characteristics orient decisions about the use of SHTs very differently from preferences for minimising energy costs. The domestic environment is also characterised by 'co-presence', meaning one individual's goals and preferences may not be shared by others and so must be pragmatically negotiated (see also Haines et al. 2007; Hargreaves et al. 2010).

Homes as complex places: Characterising the 'home' in smart homes

Within much of the technologically-focussed literature on smart homes, the domestic environment is simply the 'taken for granted' backdrop within which technology will be used (Richardson 2009). In their content analysis of smart home marketing materials, Hargreaves and Wilson (2013) found that most images of smart homes depicted them as sterile, bland and neutral spaces that appeared unlived in. Such depictions are unsurprising given that much of the technological research and testing of SHTs occurs in artificially constructed test homes or living labs (e.g., Chan et al. 2008). These are little more than "a set of walls and enclosed *spaces*" (Taylor et al. 2007, p. 383 our emphasis). A more complex understanding of homes sees them as internally differentiated, emotionally-loaded, shared and contested *places*.

Ethnographic and sociological research on the use of ICTs in domestic contexts finds homes are actively divided by their occupants into functionally and interpretively distinct places. Communication technologies tend to be used and stored in different places within the home for quite different purposes (Crabtree and Rodden 2004). These places may be 'ecological habitats' (where communication media is kept), 'activity centres' (where media is produced, consumed and transformed) or 'coordinate displays' (where media is displayed and made available to others in order to coordinate activities). All these places play significant roles in the flow and communication of information within homes. The spatial layout of specific technologies also actively divides up homes, with certain activities being undertaken in particular places (e.g., Baillie and Benyon 2008; Heath and Bell 2006; Venkatesh et al. 2003). Swan et al. (2008) also note that forms of mess and 'clutter' are an active if idiosyncratic and often ambiguous part of how people organise, construct and generate meaning within the home. Instead of trying to make homes ordered, clean and efficient, therefore, designers might consider how SHTs could help create uncertainty within homes to become part of the perpetual project of organising and constructing homes as distinct and unique places (Swan et al. 2008). These forms of meaning making and internal differentiation within homes matter for how, where, how often, and by whom SHTs are likely to be used.

Domestic environments can also be emotionally charged. Haines et al. (2007) identified the importance of memories and relationships in a study of what end users might value in smart homes. Baillie and Benyon (2008, p. 227) similarly argue that "homes are places loaded with emotion, meaning and memories". SHTs will not serve solely functional purposes, but will be used and understood within broader and pre-existing household 'moral economies'—the unique sets of values, routines and practices that underpin domestic life (Silverstone et al. 1992; Takayama et al. 2012).

Moreover, although households may be a convenient unit of analysis, families are plural (e.g., Davidoff et al. 2006). Homes must be understood as shared and contested places in which different household members may have different understandings, preferences, rights, responsibilities and emotional associations (Nyborg 2015). Richardson (2009), for example, focuses attention on the gendered nature of technology use (see also Berg 1994). She illustrates how technologies are often designed in ways that fail to respond sufficiently to how women as opposed to men and children use domestic spaces. Baillie and Benyon (2008) further distinguish between more active users—who set and enforce the rules for technology use at home—and more passive users who comply with (and at times resist) these rules (see also Mennicken et al. 2014).

2.5 User-Centred Challenges for Realising the Smart Home

The final meta-theme of research on smart homes and their users is concerned with the challenges of realising the smart home future. SHTs are not yet widespread despite apparent consumer demand (GfK 2016). The technical literature that dominates smart home research (Fig. 2.1b) identifies the key technological challenges and design challenges to be overcome. These two sets of challenges are in line with the social barriers to the adoption of smart homes identified in public deliberative workshops by Balta-Ozkan et al. (2013): loss of control, reliability, privacy, trust, cost. But there is also a third set of challenges that more explicitly situates users in the adoption environment of the home, and examines how and whether SHTs may be effectively domesticated.

Hardware and software: Developing smart home technologies for users

SHTs require extensive research, development, testing, and trialling before their widespread commercialisation becomes a realistic prospect. Key technical issues identified by Cook (2012) include: (1) monitors and sensors that can reliably detect and sense what is going in the home; (2) algorithms that can accurately infer activities and patterns from the resulting abundance of data; (3) interoperability and retrospective compatibility of SHTs, supported by well-designed and flexible standards; (4) functional reliability and manageability (Cook 2012). The salience of these technological challenges varies widely depending on technology developers' underlying vision for the smart home.

For Friedewald et al. (2005), reliability is the central challenge as this attribute will underpin user-friendliness and empowerment. Smart homes must neither fail nor do unpredictable things. Edwards and Grinter (2001) highlight several different aspects of the reliability challenge, including: debugging smart homes created 'accidentally' by technologies introduced piecemeal; administering and fixing smart homes through self-healing systems that remove the need for household or third party system administrators; and inferring occupancy activity from sensor data that may be both ambiguous and unreliable. Reliability is most important in smart homes for assisted living in which failures to sense or make inaccurate inferences about the nature of occupant behaviour could have life-threatening consequences. As Orpwood et al. (2005, p. 162) note in relation to dementia sufferers: "judgements made (on human behaviour) are always going to be probabilistic, and the designer has to incorporate means of dealing with errors, particularly in safety critical situations".

A recurring theme in research on reliability, debugging, and interoperability of SHTs is the importance of 'future proofing' to ensure compatibility both between successive generations of SHTs as well as between interacting components. Modularity, flexibility, and retrospective compatibility are frequently cited as necessary technological attributes (e.g., Perez et al. 2011). Future proofing also insulates SHTs from changes in regulatory frameworks, standards, and policy objectives, particularly in the energy domain (Martiskainen and Coburn 2011).

Acceptability and usability: Designing smart home technologies for users

The acceptability of smart homes to users is closely linked to issues of security, privacy and trust as well as practical and ergonomic concerns with user-friendliness. These issues present critical design challenges for how users interact with SHTs.

With respect to security, for example, Cook observes that "many individuals are reluctant to introduce sensing technologies into their home, wary of leaving digital trails that others can monitor and use to their advantage, such as to break in when the house is empty" (Cook 2012, p. 1578). In smart homes for assisted living, Demiris et al. (2008) similarly note user concerns with privacy. Technologies that detect and monitor activity within the home risk being seen as intrusive violations in the domestic environment. For energy smart homes, concerns around both data security and the potential for utilities to monitor or even control household demand have led to consumer backlashes against smart metering (AlAbdulkarim and Lukszo 2011; Darby 2010). In the UK, a study on attitudes and values towards energy-system change found general support for the development of smart homes, but with caveats around data sharing and a perceived loss of control through remote interference by utilities (Parkhill et al. 2013). Paetz et al. (2012) report similar findings from Germany.

How smart homes are designed will condition their acceptability to prospective users. Cook (2012) advocates for clearly defining and guaranteeing levels of privacy and the safety and security of technologies. Paetz et al. (2012) suggest the need for much greater levels of transparency and accountability on behalf of smart home developers—particularly energy utilities—and the need to be explicit about how all stakeholders may benefit from smart home development.

Several other studies highlight more narrowly-framed design challenges regarding the user-friendliness of smart homes. Park et al. (2003, p. 189), for example, outline the immense variety of potential smart applications but caution against 'overpowering' users with 'complex technologies'. Several studies have highlighted the difficulties of creating intuitive and easy-to-use user-interfaces given the level of complexity and number of user-control options that can potentially lie behind the interface (e.g., Demiris et al. 2004; Koskela and Väänänen-Vainio-Mattila 2005; Park et al. 2003).

User-centred design is widely cited as an appropriate response to smart home design challenges. Rohracher (2003) argues that many issues might be avoided through more participatory approaches to design. He suggests engaging with a wide range of different stakeholders even at the visioning stage for SHTs to ensure the widest possible range of interests and concerns are recognized and addressed. Orpwood et al. (2005) identify a number of simple design solutions that could help overcome specific difficulties faced by dementia sufferers, including wariness of new devices and forgetfulness. By working with carers, researchers could identify simple and often low-tech solutions such as making devices look familiar, concealing them from view so as to avoid causing alarm, and providing prompts and reminders rather than taking control away from users. Different groups of users are likely to require different design solutions, not just between households but also between cultures. Jeong et al. (2010), for example, reveal stark differences in the understanding of control functionality between US and Korean smart home users.

Domesticating technologies: Situating smart home technologies amid everyday life at home

"More than control of their devices, families desire more *control over their lives*" (Davidoff et al. 2006, p. 20 emphasis in original). A core user-related challenge for the realisation of smart homes is to align and adapt technologies with the messy and differentiated nature of users' everyday lives at home (Herczeg 2010).

New technologies are rarely used in homes in the ways their designers intend because they must always enter pre-existing environments that are contested, emotionally-charged and dynamic (e.g., Heath and Bell 2006). These environments already possess their own 'smartness' or 'intelligence' in the way, for example, that households manage communications (Crabtree and Rodden 2004), make use of surfaces such as tables or fridges (Taylor et al. 2007) or organise the flow of clutter and mess through the home (Swan et al. 2008). SHT development to date has assumed everyday life is made up of specific, repetitive and relatively predictable routines and schedules. But on closer examination, life at home is "organic, opportunistic and improvisational" (Davidoff et al. 2006, p. 19).

This generates new sets of design principles for SHTs that support users in managing everyday life. Technologies should be robust to "ambiguity, instability, concealment, and disinterest, and to be treated casually" (Swan et al. 2008, p. 21). Davidoff et al. (2006) offer a set of seven principles that suggest new technologies should account for "the organic evolution of routines and plans", "periodic changes, exceptions and improvisation", "breakdowns", "multiple, overlapping and occasionally conflicting goals" and that they should "participate in the construction of family identity" (Davidoff et al. 2006, p. 28).

Unless the smart home concept is re-thought in these ways it is unlikely to succeed. Yet as Howard and colleagues caution, such principles would be "fiendishly difficult to apply to technology research" (Howard et al. 2007, p. 329). Perhaps the central user-related challenge for the realisation of smart homes is therefore not to improve the reliability or functionality of technologies, nor to design out concerns around trust, privacy or user-friendliness, but to re-define the notion of 'smart' itself, recognising that it emerges within users' everyday lives and in the ways technologies are used in the home. As Taylor and colleagues explain: "it is people who imbue their homes with intelligence by continually weaving together things in their physical worlds with their everyday routines and distinct social arrangements" (Taylor et al. 2007, p. 383).

2.6 Analytical Framework for Research on Smart Homes and Their Users

We have identified three meta-themes in the literature on smart homes and their users: (1) views or 'grand narratives' for the smart home; (2) users and their uses of smart homes; and (3) user-related challenges to realising smart homes. Within each of these meta-themes, we distinguished three distinct lines of enquiry in peer-reviewed research. These are organised in Table 2.1 into a comprehensive analytical framework for research on smart homes and their users. The 3 × 3 framework shows how different lines of enquiry provide contrasting answers to key research questions.

Although Table 2.1 distinguishes nine research themes grouped into three meta-themes, there is clearly much overlap. Figure 2.2 shows the main interrelationships between the nine themes identified. The strong links in Fig. 2.2 between 'functional', 'user-technology interactions' and 'hardware and software' typify the engineering and technical scientific approach. Similarly, the strong links between 'socio-technical', 'home as complex places', and 'domesticating technologies' characterise a critical social scientific approach. The solid vertical lines in Fig. 2.2 therefore represent the concerns of different research traditions and disciplines shown in the final row of Table 2.1, and of the competing perspectives and understandings within the research community.

Table 2.1 Analytical framework for research on smart homes and their users

Views of the smart home	**Functional view**	**Instrumental view**	**Socio-technical view**
What is the smart home?	A monitored, sensed environment that informs occupants allowing active control or automation	An optimally-managed building energy system allowing information and price-responsive adjustments to behaviour	A digital, technological, networked vision confronted by the mundane realities of domestic life
What is the purpose of the smart home?	Improve quality of home life through new services and enhanced functionality	Enable energy demand reduction in the home and improved system management by utilities	No inherent purpose, functions emerge as SHTs are incorporated into domestic life as part of digitalisation of homes
Users and use of the smart home	**User needs and wants**	**User-technology interactions**	**Homes as complex places**
Who uses smart homes?	Users with specific health needs or users who are price or information responsive in both existing and new-build homes	Users seeking control over the domestic environment and energy usage through flexible or schedulable behaviours	Differentiated households with negotiated roles within the distinct spaces of the home
How is smart home technology used?	Varies according to application with assisted living smart homes emphasising passive usage and energy smart homes active usage	From continuous and active user-mediated control to passive one-off 'set and forget'	A gradual and adaptive process of domestication into the existing dynamics of routines and practices
Challenges for realising the smart home	**Hardware and software**	**Acceptability and usability**	**Domesticating technologies**
How can smart homes be realised?	Develop and improve technologies to ensure robustness and reliability as basis for social acceptability	Participatory co-design for user needs, address privacy concerns through clear and transparent rights and roles, and participatory co-design	Ensure technologies are adaptable to everyday domestic contexts, and allow flexibility for domestication and appropriation
What research approaches are useful?	Computer science, electrical engineering, design	User-centred design, human-computer interaction, behavioural and social psychology	Sociology, ethnography, science and technology studies, innovation studies

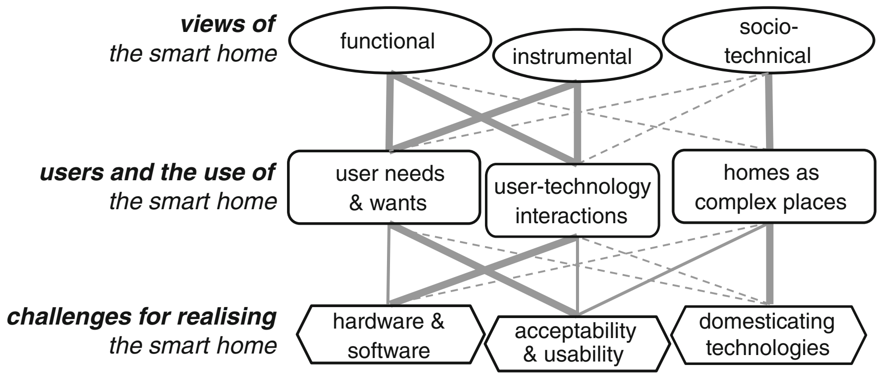

Fig. 2.2 Interrelationships between research themes on smart homes and their users (Notes: Thick solid lines = strong interrelationships; Thin solid lines = weak but explicit interrelationships; Thin dashed lines = implicit or inferred interrelationships)

The functional view of SHTs is limited to a series of technological and design challenges around how enhanced functionality can be efficiently and reliably delivered. This includes a detailed consideration of interactions between users and technology around issues such as control and automation. The instrumental view of SHTs is similarly concerned with providing for users' needs and wants but these are more tightly drawn around energy-management goals, and assume users respond to information and price signals. The socio-technical view of SHTs is strikingly different, setting up a wider and more foundational set of challenges relating to the balance between users and technologies in smart homes. This recognises the complex and contested nature of homes as places for technology adoption and use.

This coherence and consistency between the lines of enquiry identified in the vertical relationships of Fig. 2.2 has come largely at the expense of strong cross-cutting horizontal linkages between research themes. Yet as and when SHTs diffuse more widely into the fabric of everyday life at home, the functional, instrumental and socio-technical views will increasingly interact and combine, presenting more (and potentially more intractable) challenges.

The technological optimism and clarity of the functional view will confront the just-the-next-thing normality of the sociotechnical view with all its ambiguities and uncertainties. Functional service enhancements in areas such as comfort and convenience will confound the energy-management goals of the instrumental view. Smart homes may even generate more resource-intensive trajectories of socio-technical change (Koomey et al. 2013; Strengers et al. 2016). Introducing new technologies changes service expectations and use patterns. This in turn conditions users' wants and needs for new technologies and the resources they consume (Heath and Bell 2006; Nyborg and Røpke 2013).

These disconnects between research positioned within the functional and instrumental views, and research contributing to the socio-technical view are clearly shown in Fig. 2.2. Efforts to develop stronger horizontal linkages provide a clear avenue for future research. In the empirical chapters of this book which follow, we illustrate the strengths of such an approach. In Chap. 3 we ask both prospective and actual SHT users how they perceive different elements of the functional, instrumental and socio-technical views of a smart home future, focusing particularly on perceived benefits and risks. In Chap. 4 we use energy data consistent with a narrowly instrumental view of smart homes to make inferences about the complex rhythms and routines constituting domestic life. In Chap. 5 we go deeper into this socio-technical view of smart homes by examining what actual domestication trajectories of SHTs tell us about technological and design challenges for realising a smart home future. In Chap. 6 we focus on a critical issue with SHTs—control and controllability—and show how control is a multi-faceted construct which will shape the prospects of a smart home future.

2.7 Suggested Further Reading

A longer version of this chapter was published as a peer-reviewed article:

- Wilson C, Hargreaves T, Hauxwell-Baldwin R (2015) Smart homes and their users: a systematic analysis and key challenges. Personal and Ubiquitous Computing 19 (2):463-476. doi: 10.1007/s00779-014-0813-0

For other conceptual reviews of research on smart homes and users, we suggest:

- Mennicken S, Vermeulen J, Huang EM (2014) From today's augmented houses to tomorrow's smart homes: new directions for home automation research. Paper presented at the Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, Seattle, Washington, USA. doi: 10.1145/2632048.2636076
- Strengers Y (2013) Smart energy technologies in everyday life: Smart utopia? Palgrave Macmillan, New York, USA. doi: 10.1057/9781137267054

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