

User Needs of Smart Home Services

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Technological advances have improved the functionality of smart home systems and services, enabling consumers to automate some of in-home tasks, enhance their safety and security, and save energy. Despite improved functionality, user adoption of many available products and services remains low. This phenomenon suggests that smart home technologies may not be meeting the needs of potential users. Furthermore, continued technological advancement combined with changes in people's lifestyle and attitudes towards in-home technologies require updated investigations to gain a clear view of current user needs. This study presents findings from a set of semi-structured interviews and card-sorting activities with eleven participants from different socio-demographic backgrounds, with a focus on describing ten challenges commonly experienced in the home environment. Possible technological solutions are discussed from the existing unmet needs within the scope of smart and connected homes.

INTRODUCTION

The definition of "smart home" has always been tied to the most recent technological advances. In the 1930s, a smart home was referred to as a home with electricity. Later in 1955, a home with television was often considered smart (Deschamps-Sonsino, 2018, p. 20). Currently, many smart home definitions are present, including eleven prominent ones discussed by Sovacool, & Del Rio (2020) in their review of concepts, benefits, risks, and policies of smart home technologies in Europe. These definitions that were gathered from 1992 to 2019 reflect different perspectives of different researchers (e.g., improving comfort and security, saving energy); however, information and communication technologies play a central role across them.

Past research has sought to conceptualize smart homes by creating an in-home networked system where devices can communicate with each other and tasks are integrated, as discussed in FakhrHosseini, Lee, & Coughlin (2020). The Internet of Things (IoT) technology has played an important role in achieving such a vision by enabling higher degrees of interoperability (Noura, Atiqzaman, & Gaedke, 2019) among in-home devices as well as with related services. A group of interoperable devices and services use a large amount of data from various channels, leading to a better understanding of users' routines and needs. In turn, this facilitates smart home goals such as energy saving and improves the users' lifestyle. Hui, Sherratt, & Sánchez (2017) discussed seven major requirements for building smart home with IoT technologies: heterogeneity, self-configurability, extensibility, context awareness, usability, security and privacy protection, and intelligence.

Along with investigating technological advances, researchers have focused on the perspectives of users to better understand their needs and factors impacting adoption (e.g. Lee, Rudnik, FakhrHosseini, Lee, & Coughlin, 2020). In a study on smart home appliances, Coskun, Kaner, & Bostan (2018) explored user expectations, feature preferences, and desired interaction styles through in-depth interviews. The interview results showed that autonomy is considered the most preferred feature over remote control and multi-functionality.

Participants also mentioned their willingness to receive information about the decisions made by autonomous appliances without being overwhelmed by constant feedback such as continuous smartphone notifications. However, Yang, Lee, & Lee (2018) found that automation does not significantly affect the acceptance of smart home services. Their findings instead show that participants' intention to adopt technologies is highly correlated with controllability, interconnectedness, and reliability. Similarly, Park, Cho, Han, and Kwon (2017) showed that connectedness, controllability as well as compatibility are the key determinants of user acceptance of IoT technologies in a smart home environment. These differences between past study findings might be affected by the participants' age, technology literacy, and other user-level factors. For example, De Ruyck, Conradie, De Marez, & Saldien (2019) found that older generations value multi-functionality more than younger generations. Furthermore, many of these findings focus more on abstract concepts like automation, controllability, interconnectedness, than specific and concrete needs.

As new systems and services increasingly enter lives and homes, and as lifestyles continue to evolve and change, studies on user needs should be conducted frequently to identify new challenges. This study provides an in-depth understanding of potential users' unmet needs, challenges, frustrations, and experiences in and around their homes to gain insights for future technological solutions. The goal of this study is to answer the following questions: What are the challenging in-home activities? What are the reasons behind the challenges? Are there any associations between the challenges and people's living arrangement and sociodemographic status? Can technology address these challenges within the scope of connected and smart homes?

METHOD

Participants

Recruiting was done by email to eligible people in an online volunteer database organized and maintained by the MIT AgeLab. Inclusion criteria were set to ensure representation of

different demographic characteristics. A total of 11 individuals participated in the study; more details about their demographic characteristics can be found in Table 1.

Procedure

Prior to the interview, participants were provided with a description of the study through a brief intake call. During this call, participants were asked to send two pictures from two parts of their home or things in their home – one that they associate with positive feelings and another one that relates to negative feelings. These pictures were gathered to understand participants' views on preferred and frustrating aspects of their home and to gain some context around their living arrangements and lifestyle.

Generation	Generation Z (1997-2012) (1 participant) Millennials (1981-1996) (4 participants) Generation X (1965-1980) (1 participant) Baby boomers (1946-1964) (3 participants) Silent generation (before 1945) (2 participants)
Gender	6 Females, 5 Males
Income	Less than \$25K (1 participant) \$25K to 49K (3 participants) \$50K to \$74K (1 participant) \$75K to \$99K (3 participants) \$150K to \$200K (2 participants) \$200K or more (1 participant)
Education	Post graduate degree (6 participants) Some college (4 participants) Some post-graduate work (1 participant)
Type of home	Apartment (6 participants) Single family home (4 participants) Dorm (1 participant)
Residential environment	Urban (4 participants) Suburban (7 participants)
Homeownership	Rent (4 participants) Own (6 participants) Dorm (1 participant)
Type of cohabitation	Lives with roommates (3 participants) Lives alone (4 participants) Lives with a family member (4 participants)

Table 1. Participants demographic information

Interviews were conducted in-person at the MIT AgeLab between February 26 to March 12, 2020, before the COVID-19 shutdown. Each interview lasted about 90 minutes and consisted of five steps (Table 2).

#	Steps
1	Interview consent
2	Icebreaker: General questions, living arrangement, typical daily routine, and pictures
3	Card sorting activity: Descriptions of routine and in-home tasks, focusing on frequency and frustration
4	Task mapping activity: Details about selected tasks, probing questions around tools & strategies, burden & costs, etc.
5	Outlook for the future home: What does a smart home mean to you? What do you want a smart home to be able to do? What do you think the home will look like in 2030?

Table 2. Interview procedure

After each participant reviewed and signed the consent form, a moderator started the interview with some general questions about their living arrangement such as where they live, whom they live with, and the type and layout of their

home. During this 10-minute icebreaker session, participants were also asked to explain the two pictures of their home and describe what they like or dislike about the pictured space or object.

The next step consisted of a card sorting activity. For this part, participant engagement was facilitated by providing a card sorting activity (Figure 1). This activity was employed to encourage participants to concentrate on their day-to-day challenges and needs, rather than being fixated or biased on the concept of smart home technologies or having their ideas limited to existing solutions. For the card sorting activity, a wide range of common activities and in-home tasks slightly modified from a list of activities of daily living (ADLs) and instrumental activities of daily living (IADLs) (Graf, 2008; Katz, 1983), as summarized in Table 3, were gathered and printed onto small cards. The task descriptions and categorization were validated through a small pilot study conducted with five people from the AgeLab.



Figure 1. An illustration of the card sorting activity

This part of the interview process was designed for participants to first easily enumerate a broad range of in-home challenges, and then to facilitate the selection of tasks and challenges that are most important or severe. As cards containing items listed in Table 3 were presented, a participant was asked if they experience any challenges with the corresponding in-home activity. The participant could either say yes and place the card on a two-dimensional sorting board (see Figure 1) or say no and discard it. The sorting board's X-axis represented task frequency (1 = a few times a year, 2 = monthly, 3 = weekly, 4 = daily), while its Y-axis represented the level of frustration experienced in association with a given task (1= a little bit, 2 = somewhat, 3 = a lot). Participants were asked to think aloud as they placed cards on the sorting board. After mapping all the challenging activities on the board, participants were asked to pick three most important tasks among the ones that they have placed on the board. Participants were also told that these three activities do not have to be the most frequent or frustrating ones. Participants then provided details of the three tasks and explained any challenges they are experiencing with them. As a participant spoke, a moderator took notes on a whiteboard to guide the participant's thoughts, and asked follow-up questions around

1) when the given task is usually done; 2) if other people are involved in the given task; 3) what old and new strategies they have tried, if any; and 4) what external help and resources they use, if any.

At the end of the interview, participants were asked to answer three questions to gauge their perceptions around the idea of the smart home: 1) What does a smart home mean to you? 2) What would you want a smart home to do for you? And 3) what do you think homes will look like in 2030? These questions were gathered to gain insights on the definition of smart home from the prospective consumers' view, in what ways they are different from the existing definitions in the literature, and whether they expect any challenges within the homes in the next ten years.

Categories	Activities
Energy management	<ul style="list-style-type: none"> ○ Use and control of energy systems ○ Physical management of energy resources ○ Electricity, gas, oil, water bills
Safety	<ul style="list-style-type: none"> ○ Potential accidents caused by human error ○ Deliberate threats to your home ○ Cybersecurity of devices in your home
Housekeeping and chores	<ul style="list-style-type: none"> ○ Cooking and serving ○ Managing waste and/or taking trash ○ Home repair ○ Cleaning and laundry ○ Organizing and storing
Entertainment and hobbies	<ul style="list-style-type: none"> ○ In-home entertainment activities ○ Spending your spare time in your home
Social life	<ul style="list-style-type: none"> ○ Communicating with others remotely from your home ○ Your time with other people who live in your home ○ Interactions with neighbors ○ Having people over in your home
Health	<ul style="list-style-type: none"> ○ Medication management ○ Sleep routine ○ Physical fitness ○ Communicating/planning with healthcare providers ○ Nutrition, hydration, and diet ○ Taking care of personal hygiene
Pet care	<ul style="list-style-type: none"> ○ Cleaning, Feeding, Storage, Entertainment
Work	<ul style="list-style-type: none"> ○ Work-related activity at home
Outside service use	<ul style="list-style-type: none"> ○ Maintenance services ○ Delivery services (e.g. food, packages, groceries, etc.)
Technology	<ul style="list-style-type: none"> ○ Using in-home devices ○ Managing in-home devices

Table 3. In-home tasks and activities

RESULTS

The interviews were recorded and transcribed. Using qualitative content analysis with an inductive approach, the transcripts were coded by the number and contents of selected cards, participants' underlying reasons for the challenges, why they use a specific strategy, and how they want the task to be accomplished. In this analysis, the focus was on finding general themes and topics that were mentioned by multiple participants.

Current experiences and challenges

Participant-provided pictures. All of the pictures from the participants' homes were compiled and categorized based on the type of space/object and the type of involved technology/task. Some patterns were observed among the

positive and negative pictures. Most of the pictures in the positive category were related to an area in the home or something that were mostly described as a social component e.g., a living room, shelves, and plants that they can display and share with others. Negative pictures mostly included spaces that were shared with others such as a freezer for a person who lives with roommates, or part of a living room that is devoted to caregiving tools. Participants explained that the source of their frustration is associated with having different preferences, habits, and lifestyle from their cohabitants.

Card sorting activity and in-depth interview. The card sorting activities allowed participants to recall and describe the details of the majority of their in-home activities and tasks. Results showed that pet care, home repair and maintenance services, sleep routine, dealing with neighbors, struggling with spare time and using in-home devices were on average rated above somewhat to very frustrating. Also, tasks that were frequently identified as frustrating included using in-home devices (7 of 11 participants), managing sleep routine (7 participants), and doing maintenance services (6 participants), with the majority of participants reporting that these were quite to a lot frustrating. The most frequent activities included using appliances, safety concerns around deliberate threats, home repair, having people over, and pet care, which were rated on average to take place daily to weekly. However, none of the tasks were reported as highly frequent (i.e. daily or weekly) by the majority of participants, which suggests that people's routines and the frequency of activities vary significantly. A high positive correlation was observed between the frequency of the tasks and the reported frustration ($r(27) = .49, p = .001$), implying that the more frequent tasks are often perceived as more frustrating. Among the given activities, using home appliances, home repair, and pet care were rated as most frequent and frustrating at the same time.

It was observed that tasks selected as most important by participants did not show any significant patterns with frequency or level of frustration. This suggests that people's assessment of a task's importance is independent of their evaluation around the degree of involvement or level of challenge.

Participants' descriptions of the selected in-home activities were analyzed further by probing questions to uncover the underlying causes of their frustration, if any; to translate challenges into solution needs; and to brainstorm what possible products or services may be applied to address them. For example, one participant suggested that they have challenges with using home appliances. During this interview, the participant expressed that they were unhappy with their roommates' home temperature preferences. Although this issue refers to the limitations of their heating and cooling system, it was analyzed also as an issue around communication with cohabitants. In another example, a few participants reported frustrations around remote communications with family and friends. During these interviews, some participants mentioned challenges around in-person visits and experiences, while others reported internet and WiFi connectivity issues. The in-depth interview was an opportunity to link these issues together, determine the

underlying reasons, and describe associations between different issues and challenges.

Finally, findings from the card sorting activity were aggregated with the results from the qualitative analysis of the in-depth interviews based on the frequency of the challenges, similarity among the underlying issues, and how much the existing challenges can be addressed with existing smart home technologies. Table 4 shows the 10 prominent challenges identified from the interviews. These represent needs that may be commonly experienced by potential smart home technology users of various demographic characteristics.

<p>1. Communication with other residents</p> <ul style="list-style-type: none"> ○ Miscommunication or lack of communication over habits, preferences and concerns <p>This challenge was mostly reported by people who live with roommates or do short-term rentals.</p>
<p>2. Home repair & maintenance Services</p> <ul style="list-style-type: none"> ○ Difficulties finding a dependable service provider ○ Issues with communication channels <p>This challenge was mostly reported by homeowners.</p>
<p>3. Safety & security</p> <ul style="list-style-type: none"> ○ Worries related to cybersecurity <p>This challenge was mostly reported by current smart technology users</p> <ul style="list-style-type: none"> ○ Concerns around package and service delivery <p>This challenge was mostly reported by people living in shared buildings</p>
<p>4. Caregiving needs</p> <ul style="list-style-type: none"> ○ Lack of personal and spare time ○ Worries around risky behaviors ○ Issues around channels for remote communication ○ Frustration with care recipient's use of technology ○ Challenges with involvement in health care decisions & management
<p>5. Medication management</p> <ul style="list-style-type: none"> ○ Trouble remembering and following schedule
<p>6. Remote communication</p> <ul style="list-style-type: none"> ○ Frustrations around having to use and switch between multiple channels ○ Issues with internet connection
<p>7. Sleep routine & sleep health</p> <ul style="list-style-type: none"> ○ Various sleep-related trouble for different reasons
<p>8. Food preparation and management</p> <ul style="list-style-type: none"> ○ Difficulties remembering and managing expiration dates ○ Needs around knowing what they have and figuring out what to eat
<p>9. Task Management</p> <ul style="list-style-type: none"> ○ Wanting to stay on top of multiple things e.g., drinking water, taking medications, etc. ○ Frustration with human errors
<p>10. Home energy & environment control</p> <ul style="list-style-type: none"> ○ Issues with multiple residents having different energy use behavior ○ Difficulties working around complex home layouts <p>This challenge was mostly reported by people living with others, or in places with multiple floors.</p>

Table 4. Unmet needs and challenges

Future outlook and expectations

When asked to describe what a smart home means to them, most of the participants described a smart home as a comfortable place with voice-activated systems that understand resident needs, knows the routine, and gives them peace of mind when they are away by providing remote controls. Answers to the question “what do you want a smart home to do for you?” showed that participants expect a smart home to be able to predict their needs and enable remote control functions which are in line with the definition of smart home in the literature. And finally, participants' predictions for

future homes in 2030 varied greatly. Energy neutral, more integrated, and smaller homes were the most frequently mentioned features.

Patterns across participant characteristics and living arrangements

Responses from six apartment-dwelling participants included challenges around organization and storage which can be associated with space limitations. In contrast, participants in single family homes talked more about using and managing in-home devices, and maintaining physical fitness. Moreover, the seven suburban participants mentioned remote communication as one of their biggest challenges, while those living in urban areas cited managing delivery services as a key issue.

Our analysis also showed some patterns with the consideration of type of cohabitation. People who are living with family members reported organizing and storing, remote communication, using and managing appliances, and maintenance service as the most challenging activities. On the other hand, participants who reported living with roommates and friends complained about organizing and storing, cleaning and laundry, and sleep routine. Solo-living participants described concerns around human errors, using and managing in-home devices, work-related activities and pet care.

DISCUSSIONS AND CONCLUSION

In this study, we recruited eleven participants with different demographic characteristics and living arrangements to describe common in-home needs and challenges that are widely applicable. The interviews were designed to gather information and insights about a wide range of in-home activities, without narrowing the scope to specific smart home technologies and existing solutions. This allowed for conversations around a broad set of needs, not limited to those that a participant expected a solution to be readily available, as well as an analysis around possible links between in-home activities and challenges.

Results showed that managing sleep routine, managing home repair and using in-home devices, combined with task-sharing among cohabitants, were among the top frustrating tasks expressed by participants. In contrast, participants' positive perspectives of their homes were represented with pictures of their living room or other shared spaces. In addition, participants envisioned having a voice command system in future smart homes that is able to understand needs and provide remote-control functionalities for peace of mind.

The in-depth interviews uncovered ten unmet needs (Table 4) along with underlying themes and patterns: communication, cohabitation, cybersecurity, connected home services, home extension, and decision support tools. These patterns provide insights on design of new smart home systems and improving existing products.

Communication. Some of the unmet needs, such as in-home and remote communication, home repair & maintenance services, caregiving needs, and energy management, were closely tied to the concept of communication. The underlying

reason for many of these complaints was partially related to the lack of an effective communication channel, and participants indicated that they are looking for new strategies to facilitate this task.

Cohabitation. Another theme across the challenges is related to cohabitation in multi-resident houses where people with different routines and preferences live together. This is often a source of conflict for common or shared activities. Similar challenge is envisioned in a home with smarter devices since many of the existing systems provide limited multi-user support (Geeng, & Roesner, 2019). Future studies should investigate sources of conflicts which will be an additional layer to the existing challenges.

Cybersecurity. Another concern that was found within the scope of safety and security is around user distrust toward many of the new smart home systems related to data security and privacy. Cybersecurity within the area of smart home technologies and services has dominated other concerns such as external threats to homes.

Connected home services. Interview results support for the idea of more connected and integrated homes. A caregiving portal that communicates the care recipients' tasks and needs with care providers, a task management tool that integrates all the in-home activities and informs residents about the tasks and events, and an energy control system with the awareness of user preference and home layouts are some of the examples of a more complex yet seamlessly home (Hargreaves, Wilson, & Hauxwell-Baldwin, 2018) that could provide a higher level of companionship to the residents.

Home extension. Extending homes to outside services beyond public utility is a vision for the next generations of smart homes (El Jaouhari, Jose Palacios-Garcia, Anvari-Moghaddam, & Bouabdallah, 2019). With an increasing availability of technology-enabled services, many of today's homes are already extended to external networks to some extent (e.g. caregiving technologies and online deliveries). Results of our study show prospective users' concerns over the process, security, and results of the existing services e.g. deliveries which shows an opportunity for possible improvements and at the same time bigger concerns with broader extension of homes to external services.

Automation. A different angle to the uncovered needs and concerns is looking at what part of a task or activity requires more attention and help. Interestingly, participants talked more about having tools to support decisions rather than to automate tasks. This is in line with past research (e.g. Coskun, Kaner, & Bostan, 2018) reporting that users want to be informed about the actions made by automated home appliances.

This study provides a holistic insight on challenges and unmet needs experienced by potential smart home users. The results and discussions expand on related research and provide actionable insights that can be translated into developing and improving technological solutions to transform the home into a more connected, convenient and caring environment.

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REFERENCES

- Coskun, A., Kaner, G., & Bostan, İ. (2018). Is smart home a necessity or a fantasy for the mainstream user? A study on users' expectations of smart household appliances. *International Journal of Design*, 12(1).
- De Ruyck, O., Conradie, P., De Marez, L., & Saldien, J. (2019, September). User Needs in Smart Homes: Changing Needs According to Life Cycles and the Impact on Designing Smart Home Solutions. *In IFIP Conference on Human-Computer Interaction* (pp. 536-551). Springer, Cham.
- Deschamps-Sonsino, A. (2018). *Smarter homes: how technology will change your home life*. Apress. <https://doi.org/10.1007/978-1-4842-3363-4>
- El Jaouhari, S., Jose Palacios-Garcia, E., Anvari-Moghaddam, A., & Bouabdallah, A. (2019). Integrated management of energy, wellbeing and health in the next generation of smart homes. *Sensors*, 19(3), 481.
- FakhrHosseini, S., Lee, C., & Coughlin, J. F. (2020, July). Home as a Platform: Levels of Automation for Connected Home Services. *In International Conference on Human-Computer Interaction* (pp. 451-462). Springer, Cham.
- Geeng, C., & Roesner, F. (2019, May). Who's in Control? Interactions in Multi-User Smart Homes. *In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-13).
- Graf, C. (2008). The Lawton instrumental activities of daily living scale. *AJN The American Journal of Nursing*, 108(4), 52-62.
- Hargreaves, T., Wilson, C., & Hauxwell-Baldwin, R. (2018). Learning to live in a smart home. *Building Research & Information*, 46(1), 127-139.
- Hui, T. K., Sherratt, R. S., & Sánchez, D. D. (2017). Major requirements for building Smart Homes in Smart Cities based on Internet of Things technologies. *Future Generation Computer Systems*, 76, 358-369.
- Katz, S. (1983). Assessing self-maintenance: activities of daily living, mobility, and instrumental activities of daily living. *Journal of the American Geriatrics Society*, 31(12), 721-727.
- Lee, C., Rudnik, J., FakhrHosseini, S., Lee, S., & Coughlin, J., (2020). *Development of data-based personas for user-centered design of the connected home*. 22nd DMI: Academic Design Management Conference.
- Noura, M., Atiquzzaman, M., & Gaedke, M. (2019). Interoperability in internet of things: Taxonomies and open challenges. *Mobile Networks and Applications*, 24(3), 796-809.
- Park, E., Cho, Y., Han, J., & Kwon, S. J. (2017). Comprehensive approaches to user acceptance of Internet of Things in a smart home environment. *IEEE Internet of Things Journal*, 4(6), 2342-2350.
- Sovacool, B. K., & Del Rio, D. D. F. (2020). Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies. *Renewable and Sustainable Energy Reviews*, 120, 109663.
- Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2017). Benefits and risks of smart home technologies. *Energy Policy*, 103, 72-83.
- Yang, H., Lee, W., & Lee, H. (2018). IoT smart home adoption: the importance of proper level automation. *Journal of Sensors*, 2018.