A Taxonomy of Home Automation: Expert Perspectives on the Future of Smarter Homes

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A Taxonomy of Home Automation: Expert Perspectives on the Future of Smarter Homes

Shabnam FakhrHosseini[1] · Chaiwoo Lee[1] · Sheng-Hung Lee[1] · Joseph Coughlin[1]

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Abstract
Recent advancements in digital technologies, including artificial intelligence (AI), Internet of Things (IoT), and information and communication technologies (ICT), are transforming homes into interconnected ecosystem of services. Yet, discourse on home technologies remains fragmented due to inconsistent terminologies. This paper addresses the lack of a framework, studying distinctions between smart and non-smart homes and forecasting connectivity and automation growth. Experts (21) participated in online surveys and interviews in 2021, exploring language, structure, and technical/social aspects of basic and smarter homes. Quantitative survey data and qualitative interview analyses yield insights on defining smarter homes, barriers to adoption, and framework improvements to establish universal definitions. This study underscores the urgency of harmonizing language and concepts in the domain of smart homes, revealing user understanding gaps and usability issues as barriers. This bridges gaps for consumer engagement and tech adoption.

Keywords Smart home · Levels of automation · Connected home · Interoperability

1 Introduction

The concept of a smart home remains ambiguous and closely linked to the latest technological advancements (e.g., FakhrHosseini et al., 2020; Gram-Hanssen & Darby, 2018). This ambiguity has been exacerbated by the lack of standardization and a coherent framework, resulting in the emergence of numerous inconsistent terminologies (Alam et al 2012; Etzrodt & Engesser, 2019; Venkatesh, 2008). These terms often describe similar functionalities and technical capabilities, such as connected homes, smart living, tech-enabled living, intelligent homes, home automation, and automated living, among others. Although some of these terms are used interchangeably, it is important to carefully distinguish and recognize the extent to which they capture different technical capabilities and practical applications. For example, while automation may enable various capabilities of a smart home, not all smart home technologies directly equate to automated home technologies.

In this context, frameworks and standards play a vital role by establishing a shared set of criteria and benchmarks for evaluating the quality and performance of products and services. This was emphasized by Hopkins and Schwanen (2021) in the domain of automated vehicles. They discussed how such a framework's establishment could enhance communication and collaboration among vendors and brands. Furthermore, they highlighted those discussions would extend to encompass different stakeholders, including a broader array of communities such as legal professionals, insurers, planners, and policymakers, in addition to technology developers, innovators, and engineers.

This study aims to address the absence of a widely adopted framework related to different types of home, their intelligence and automation level that can guide industries and stakeholders to follow proprietary standards. In this paper, we critically discuss different suggested frameworks with 21 experts in industry and academia from Europe and North America. In addition, experts' opinion on different areas of smart home concept such as technology adoption, barriers to interoperability, and short- and long-term visions were asked through a survey.

Our key contribution is to introduce a framework that is built based on the previous attempts and interviews with experts in the domain of smart home. This framework is a

✉ Shabnam FakhrHosseini
shabnam1@mit.edu

[1] Massachusetts Institute of Technology, AgeLab, Cambridge, USA

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discussion platform across stakeholders to achieve a consensus in terminology and build a common language that can benefit users ultimately.

In the following sections, this paper is structured to provide a coherent flow of information. After establishing the introductory foundation, the literature review provides a comprehensive detail concerning the definition of smart and connected homes as well as introducing previous efforts and studies toward standardizing terminologies and building a unified framework within the domain of smart home and home automation. Next, the method section navigates readers through the study's overarching framework, participant demographics, study procedure, and the specific survey and interview questions employed.

The fourth section delivers the findings that are organized into the following categories: barriers to making homes smarter, definitions of smart homes, interoperability considerations, the role of different home technologies in making homes smarter, data security and breach, future use cases and tasks, expert forecasts for the smart home landscape over the next decade, and future contributors, players, and stakeholders. The second part of the results section includes the outcomes of interviews with experts, highlighting their insights and suggestions for creating an improved taxonomy of home automation, along with experts' opinions regarding enabling technologies. Concluding this section, we addressed suggested modifications and comments followed by a discussion, where the new taxonomy is presented.

2 Literature Review

The term "smart home" was first introduced by David Macfadyen and Peiter VanDerWerf in 1984 (Deschamps-Sonsino, 2018, p. 73). During the last three decades, efforts in the domain of IoT, home automation, and connected home technologies have introduced many smarter in-home technologies such as assistive technologies, health management systems, safety tools, communication devices, energy management systems, and so on. Many of these new in-home technologies have changed the layout of the houses and encouraged people to spend more time at home by providing new and remote ways of accomplishing tasks (Deschamps-Sonsino, 2018, p. 107).

Sovacool and Del Rio (2020) discussed 11 definitions of smart homes from 1992 to 2019. Although some of these definitions are different in their focus, there are many overlaps across the 11 definitions. Understanding residents' needs, remote and automatic controls, communication network to provide convenience, safety, and efficiency for the residents are the common characteristics of a smart home in these definitions. For example, Hargreaves and Wilson (2017) defined, "a smart home collects and analyses data on the domestic environment, relays information to users (and service providers), and enhances the potential for managing different domestic systems (e.g., heating, lighting, entertainment)." Geeng and Roesner (2019) simply put it into three factors: "a home that contains computing devices that assist with automation, remote usage, and/or sensing for domestic use." They also distinguished "smart home" from Internet of Things (IoT), which the latter refers to Internet-connected devices.

Recently, the phrase, "connected homes" have become popular. "Connection" in the area of smart home have been defined in many ways. The most primitive type is a hardwired connection between tightly coupled home devices, such as a binary motion sensor and a porch light, via electrical wires and circuits. This type of connections facilitates cooperation of functionally correlated home devices. However, Internet and wireless technologies, including WiFi, Bluetooth, ZigBee, and InfraRed communications, have empowered standalone home devices and sensor modules, facilitated dynamic connections between independently deployed home devices. Currently, connected home usually (e.g., Bugeja et al., 2018) refers to a residence that uses internet-connected devices to automate and control various household tasks and functions. This allows residents to monitor and control their homes remotely through a smartphone app or voice-controlled assistant, creating a more connected living experience.

Creating a connected living space is a challenge. To do that, we need to create an interoperability mechanism "to enable the exchange of data regardless of the underlying incompatible communication protocols" as well as an intelligent system where data sharing (generated by different devices) gets coordinated, said Miori et al. (2019). In other words, interoperability refers to the ability of devices, applications, and services to be connected with each other to work together. Although in theory, this is a great solution to create a seamless experience in homes by orchestrating the devices and ultimately the tasks, the goal has not achieved in practice yet.

Achieving different levels of interoperability (basic, network, and syntactic) within the home is not the final goal. This mechanism should be incorporated beyond homes to enable isolated homes to be connected with outside services. This wider integration of smart home services within the neighborhoods, cities, and regions requires a standardization that can regulate and facilitate the integration of services at the level of global Internet of Things. Miori et al. (2019) correctly pointed out to the lack of standardization in communication systems and protocols because of the "persistence of business models towards closed proprietary solutions."

Poudel (2016) discussed how the lack of standardization and coordination among stakeholders not only harm interoperability, but also leads to data security issues. Within IoT,

data security breach can occur at different levels (Poudel, 2016): within the device, during data transit to the cloud, and in the cloud. With the granularity of personal and interpersonal information through IoT, users' vulnerability for intruders to access their information is high (Ghirardello et al., 2018). Sovacool et al. (2021) discussed the role of government policy that can establish regulations to ensure sustainability and privacy of smart home devices and systems.

Some efforts have been made in facilitating the standardization of terminologies and developing a common framework/vocabulary in the domain of smart home and home automation. However, there is no cohesive framework that everyone agrees on. One of the earlier efforts in establishing a common terminology in understanding smart homes is built by Pilich, 2004. The core concepts in this taxonomy are control and agency. Based on this framework, three types of homes, controllable, programmable, and intelligent, were identified, with subcategories in each. Primarily, this taxonomy introduces three types of connected homes, from a basic one to a more progressed version. Although this was a great attempt in understanding homes through different levels of agency and the active and passive roles of users in each category, this taxonomy fails to take into account the factors which determine the roles of users and capabilities of emerging homes.

In another example, Ball et al. (2010) investigated the concept of multi-agent architecture using Adjustable Autonomy Intelligent Environment (AAIE) similar to the concept of adaptive automation discussed by Kidwell et al. (2012). Adjustable autonomy allows for a dynamic level of automation from full, high, and low to no autonomy based on the situation and the user preferences (Mast et al., 2012). Adjustable autonomy is desirable to build flexible interactions in order to address different types of users and their needs. This is a great step in designing automation based on users' needs and preferences. In addition, in this work the adjustability was introduced through different types of automation for various conditions. However, there is little discussion on the technical and practical aspects of the concepts. For example, how the boundaries between low and high autonomy can be defined? How are levels of autonomy different in terms of technical capabilities? To switch from a level to another level of automation, what type of environmental information are considered as the system input?

In a different study, Sovacool and Del Rio (2020) discussed a spectrum of smart home types and defined six levels: Level 0 (basic), level 1 (isolated), level 2 (bundled), level 3 (automated), level 4 (intuitive), level 5 (sentiment). To differentiate the levels and smartness of the homes, they considered smartness of home technologies, levels of connection among the home technologies, adoptability of in-home technologies, and home capability in anticipating user needs, and connection to services in the neighborhoods, cities, and states. Similarly, FakhrHosseini et al. (2020) discussed some of these factors based on information processing theory. These two studies provide a great insight on the current and future types of homes and home evolution and therefore they were used as a foundation for this study.

Overall, each of the above attempts provide an important angle to creating a framework in this domain with different purposes. Standards and frameworks can support sustainability by promoting environmentally and socially responsible practices. Moreover, having a framework can ensure that products and services from different vendors or providers can work together seamlessly and reliably to reduce the risk of errors, interoperability issues, and downtime, and increase the convenience and flexibility for users. Another angle is towards the market access facilitation by complying with recognized standards. Finally, a common set of criteria and benchmarks can help with the quality and performance of products and services and help users to make informed decisions.

In order to bridge the gaps identified in prior research, we conducted a series of expert interviews with the aim of establishing a shared terminology. Through discussions with experts, we explored established models and taxonomies, seeking terms applicable across various industries. All questions presented in both the interviews and surveys are built based on the following research questions:

1. How does the meaning of a smart home differ from that of non-smart homes?
2. What are the perspectives of experts regarding the barriers that exist, both from user perspectives and technological capabilities, in making homes smarter?
3. To what extent do experts believe a framework is necessary within the smart home domain?
4. How do experts view the proposed taxonomy, and what suggestions do they have for its improvement?
5. What do experts expect for the future of smart homes in the near future?

3 Method

A series of interviews and survey was conducted, centering around an established home taxonomy and levels of automation introduced by FakhrHosseini et al., 2020. To analyze the survey outcomes, we quantified the responses for multiple-choice and open questions. For the open-ended questions in the survey and the interviews, we ran qualitative content analysis with an inductive approach.

We divided the process into two phases—survey and interview—to streamline the study process, as fitting all

questions into one session could have overwhelmed the interviewees. Moreover, we concentrated solely on the taxonomy during the interview to ensure ample time to gather the experts' insights and suggestions. Additionally, analyzing the quantified responses from the survey allows us to understand the narrative from the perspectives of those actively involved in designing and developing systems for users.

The interviews were recorded and transcribed. The transcripts and answers to the open-ended questions were coded based on the number of unique comments and patterns for each question and topic. All other unique contents and comments were reported as well. Therefore, the focus was not only on finding general themes and topics that were mentioned by most experts but highlighting some of the rare debates and futuristic ideas that experts discussed based on their knowledge and expertise.

In the upcoming subsections of the methodology, we detail the preliminary version of a home taxonomy that formed the foundation for our discussions with experts. Additionally, we provide information about the backgrounds of our experts, outline the study procedure, and introduce the survey questions.

3.1 Study Framework: Taxonomy of Home Automation

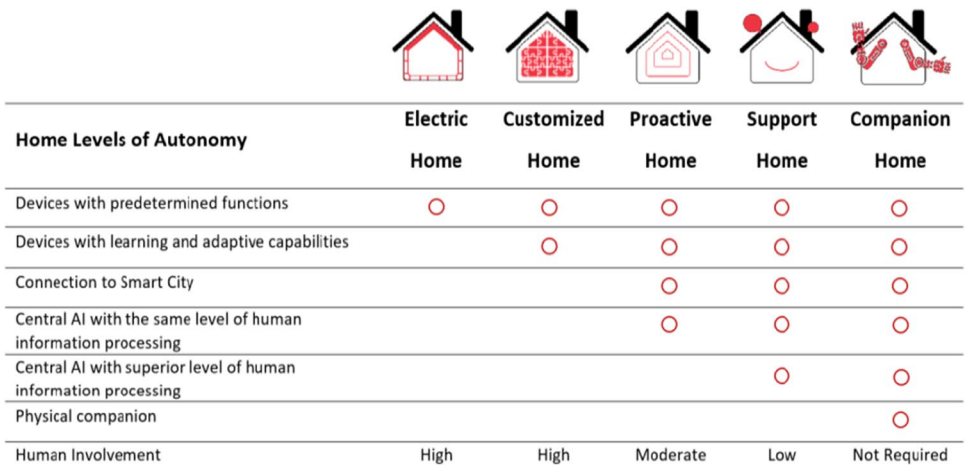
The initial version of proposed framework was used as a discussion material for the interview. The framework discusses the status of smarter and more automated homes, as well as possible future directions and goals in this domain (see Fig. 1). In this taxonomy, five types of homes have been defined: Electric Homes, Customized Homes, Proactive Homes, Support Homes, and Companion Homes. Each level is defined based on the complexity and intelligence of in-home devices, their capabilities in understanding user needs, the home's ability in receiving information, processing data, decision making, and making actions, aspects of companionship that a home can provide to its residents, and user controls. Experts were asked to analyze each level, the determinant factors that differentiate the levels, the names of the levels, and whether they would propose any new levels or eliminate any existing ones. A summary of each level is explained in the following paragraphs:

Electric Homes (Level 1) There is no connection among the devices that leads to a coordination across tasks and the needs. All the in-home technologies run with pre-determined functions (excluding universal controllers such as smartphone and computer). Electric Homes do not understand resident needs and/or act upon that. There is no awareness of users, their habits, status, and activities in Electric Homes.

Customized Homes (Llevel 2) There is at least one technology in the home that runs with programmable instructions. Users can customize the device to address their needs but still there is a high level of user involvement. Technologies may be connected with one another, but connection is not a requirement. Customized Homes have a limited understanding of user needs.

Proactive Homes (Level 3) Proactive Homes are aware of users, their habits, status, and activities through the in-home technologies that run with a central AI. The central AI receives and processes all the information, makes decisions, and acts if necessary. The central AI manages the in-home activities and requires only a moderate amount of user involvement.

Support Homes (Level 4) What discriminates level 3 and 4 is the central AI's ability to understand human needs and. Although homes in both levels have a clear image of users, their routines and behaviors, level 4 is associated with superior abilities in decision making, prediction abilities, and adaptation particularly in complex situations such as residents' emotional needs and affective states. In these homes: All the in-home technologies run with a central AI. Homes



Home Levels of Autonomy	Electric Home	Customized Home	Proactive Home	Support Home	Companion Home
Devices with predetermined functions	○	○	○	○	○
Devices with learning and adaptive capabilities		○	○	○	○
Connection to Smart City			○	○	○
Central AI with the same level of human information processing			○	○	○
Central AI with superior level of human information processing				○	○
Physical companion					○
Human Involvement	High	High	Moderate	Low	Not Required

Fig. 1 A summary of the proposed taxonomy which shows the initial idea of different types of homes and levels of automation (FakhrHosseini et al. 2020)

are aware of users, their habits, status, and activities. They understand users, their emotions, and needs better than themselves. They can make better decisions, provide better options, and act upon them. Homes belong to this category have a wide connection to outside communities for the efficiency of services.

Companion Homes (Level 5) Companion Homes have all the capabilities of proactive or support homes but also include one or more physical entities that can manage all physical tasks and chores. The physical entity could be built into the in-home technologies or a separate entity like a social robot. This physical entity provides companionship to the residents that go beyond basic functionalities and encompasses social and emotional aspects.

3.2 Participants

A total of 21 experts, actively engaged in the smart home services domain for at least two years, were purposefully recruited for the study. These participants, who hold diverse roles such as senior directors, professors, researchers, consultants, principals, and company owners, bring a wide range of expertise in fields like energy efficiency, human–computer interaction, smart home strategy, and technology consultancy. They are affiliated with a mix of organizations including universities, research institutes, technology companies, design firms, and advisory councils, extending to globally recognized educational and research institutions as well as industry-specific companies. Their professional activities cover several domains, such as smart home technologies, energy efficiency, user experience design, and social robotics. The recruitment strategy was purposive, utilizing professional networks and academic or industry connections, as well as sending invitations on LinkedIn after reviewing experts' backgrounds and work, to invite individuals known for their relevant expertise. The geographic diversity of the participants is notable, with 11 experts from North America and 10 from Europe, representing countries like the United States, the United Kingdom, Sweden, France, and Finland. The mix of six academics and the remaining industry practitioners enriches the study, blending theoretical insights with practical perspectives.

3.3 Procedure and Questions

After agreeing to participate in the study, each expert was asked to fill out a survey within a two-week period. Next, a 30-min individual interview was scheduled with each of them. During scheduling the interview, experts were asked to read a paper in order to answer the questions in the upcoming interview. The interview questions were sent to the experts as well. Therefore, each expert received the proposed taxonomy (FakhrHosseini et al. 2020) which is introduced in the materials section (Table 1).

3.3.1 Survey and Interview Questions

Prior to the interview, each expert was asked to fill out a 30-min survey. A few goals were defined for this survey:

a) To gather quantitative data on experts' opinion on barriers to adoption of smart home systems and future directions: All these multiple choice and ranking questions were designed based on the findings of previous studies for validation or providing new insights.

Table 1 A summary of study procedure and discussion points in the survey and interviews

Survey	Background	Levels of experience Research focus/topic
	General questions	Definition of smart home and differences between smart and non-smart homes (Hargreaves & Wilson, 2017; Sovacool et al., 2020) Barriers to making homes smarter (Feng et al., 2017; Geeng, & Roesner, 2019; Li et al., 2021) Critical concepts and barriers to establishing interoperability (Miori et al., 2019 & Poudel, 2016) Role of different home technologies in making homes smarter (Hargreaves & Wilson, 2017; Pilich, 2004; Poudel, 2016; Park et al., 2003)
	Challenges and opportunities for future	Data security and breach (Hammi et al., 2022; Geneiatakis et al., 2017; Ghirardello et al., 2018) Future use cases and tasks (Bugeja et al., 2018; Li et al., 2011) Smart home technology progress over the next 10 years (Kidwell et al., 2012; Li et al., 2021; Miori et al., 2019) Future contributors (Li et al., 2021)
Interview	Open discussions around the necessity of building a taxonomy Experts' critics of the suggested taxonomy (paper; see Sect. 3.3.2)	

b) To gather qualitative data about experts' definition of the smart home and their insights for future directions.
c) To prepare experts for the interview by adding questions about the paper and other research to learn about their views about different angles of research and existing framework.

4 Results

All the data gathered from the experts were categorized into two major themes: survey and interview results.

4.1 Survey Results

Barriers to Making Homes Smarter Through a multiple-choice question in the survey, experts were asked to choose the top three items that explain the biggest barriers to making today's homes smarter. Figure 2 shows all the options provided in the question based on the number of votes. Results show that "usability issues", selected by 11 experts, is the top factor. "lack of user understanding of smart home technology" was ranked second and "user privacy concern" was ranked third. None of the experts considered lack of legal/regulatory clarity and the channel distribution problems as the top three barriers to making homes smarter.

Definition of Smart Home Results show that "automation" and "responsiveness to user needs" were recognized as the top two qualities of smart homes, and that providing different ways of control, safety, comfort, and sensor-equipped were other important characteristics, similar to what were discussed in the eleven prominent definitions of smart homes by Sovacool and Del Rio (2020). The majority of the experts defined smart homes as places where tasks are highly automated, and which understand user needs, address residents' safety and comfort, and are equipped with sensors and various control modalities. One expert said, "users are now able to access their home regardless of their location." Another expert pointed that "smart homes use digital intelligence to collect information about an individual or group of individuals to provide services that offer greater comfort, security, assistance and sometimes cheaper and tailored outcomes". He added "smart homes can also connect multiple products and services together to provide an enhanced experience."

Interoperability In a question we specified different components of interoperability and asked experts to rank the most critical steps and the biggest barriers to establishing interoperability in a smart home. Interoperability between venders was ranked highest. Regarding the barriers to interoperability, majority of the experts (N = 17) reported that currently devices of each brand mainly work within their own platforms. Although there were not a lot of consensuses among experts for other reasons as barriers to interoperability, some of them suggested technological capability and user privacy concerns as important barriers (Fig. 3).

Role of Different Home Technologies in Making Homes Smarter To understand if there are any associations between smartness of the homes and type of home technologies, experts were asked "The following home technologies may be included in a smart home. Which of the following do you think will play an integral role in making a home smarter? Please rank them from 1 = most integral to 11 = least integral by dragging the items." Results showed no patterns in experts' responses. In other words, the type of home technology (smart lighting system, smart physical health care system, social robots, smart water and leaking system, etc.) was not core to experts' definition of smart homes.

In terms of control modality, 10 of experts believe voice activated systems play an integral role in making a home

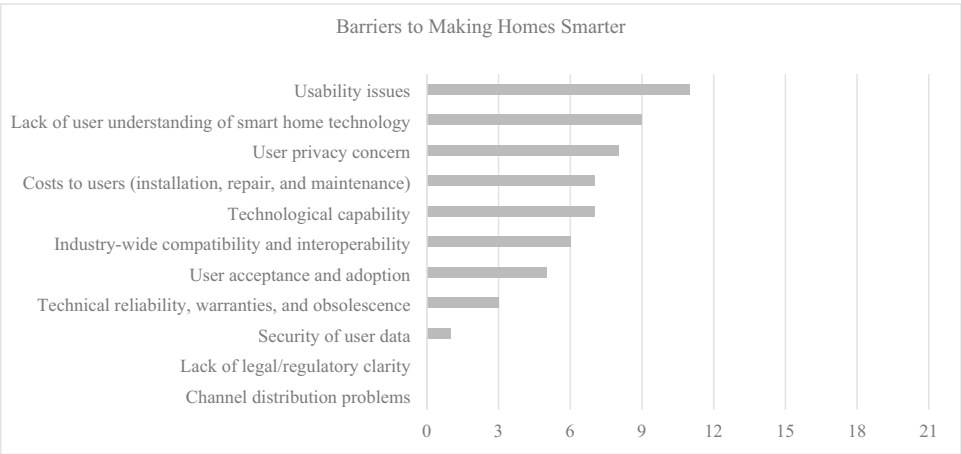


Fig. 2 Experts' opinion on barriers to make homes smarter

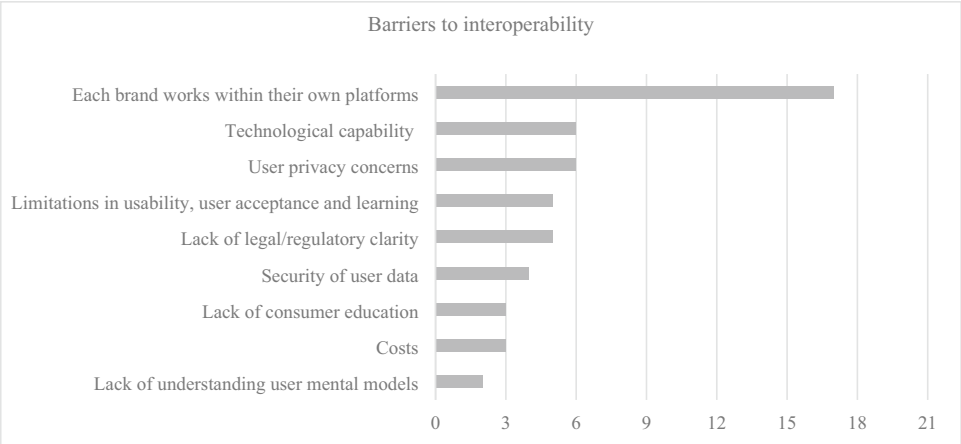


Fig. 3 Experts' opinions on barriers to interoperability

smarter. Five experts selected gesture controls and three picked virtual or augmented reality systems. Social robots and remote-control systems (from outside of the house) were picked last.

Moreover, experts were asked about the home technology capabilities: receiving data from the sensors and share them with the resident(s), filtering data after receiving from the sensors and share the prioritized data with the residents, providing options to facilitate the decision-making process, providing feedback to the resident(s) to facilitate learning or optimize performance, making decisions under some circumstances, understand residents' current needs, and predicting residents' future needs. Similar question was used: "A smart home may have the following capabilities. Which of the following do you think will play an integral role in making a home smarter? Please rank them from 1 = most integral to 8 = least integral by dragging the items." Results show that "predicting residents' future needs" and "understanding residents' current needs" were ranked first and second. No patterns were observed regarding the least integral capabilities.

Data Security and Breach Data privacy and security as one barrier to making homes more connected was investigated further in this study. Experts were asked "In a situation where a home is equipped with smart safety, energy, medication management, communication, caregiving, health and wellness systems, and all the smart devices are integrated with and connected to a central AI, if the following safety–critical incidents were to happen, who do you think should be held accountable?" Similarly, most experts believe *manufacturer of the smart technology* is the first accountable followed by the *software coder* for the AI and the *manufacture of the AI* (Fig. 4). The average results show that experts consider *users* and *sellers* least accountable in these situations.

Next, experts were asked "In a situation where a home's smart devices are connected to a central AI, if there were a data breach in each of the following areas, who do you think would possibly be held accountable? If this question is not in the area of your expertise, please skip to the next question in this page." Results show that most experts believe *manufacturer of the smart technology* is the first

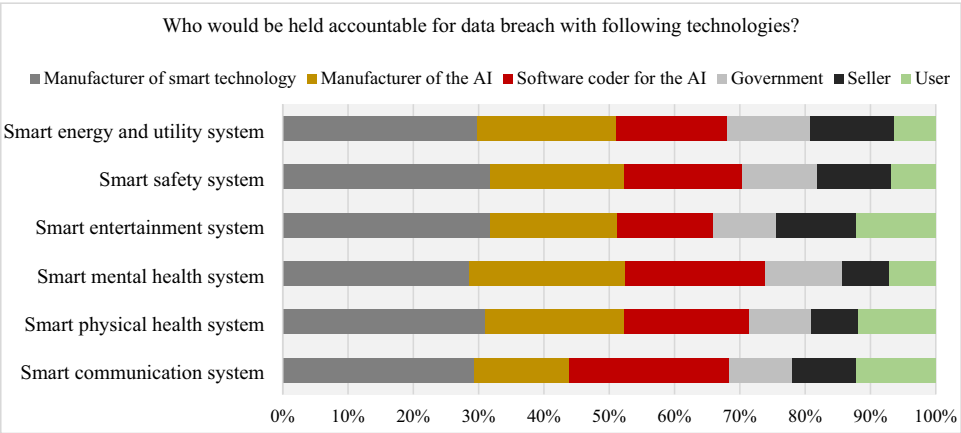


Fig. 4 Experts' opinion on data breach with different technologies

accountable followed by the *software coder* for the AI and the *manufacture of the AI* (Fig. 5). Interestingly, results show that experts held *government* least accountable.

Future Use Cases and Tasks In the survey, experts were asked about the top use cases of in-home technologies in short (years 2021 to 2024) and medium terms (years 2025 to 2035) through open-ended questions. Moreover, experts were asked to imagine in these short and medium-terms and in future homes, what new in-home tasks will be added to people's lives. For short-term experts selected security systems, entertainment, and energy systems as the top use cases of home technologies and more progressive energy systems was envisioned for medium-term: "a more energy efficient manner at a community level will be achievable."

Regarding the new in-home tasks, experts envisioned the following categories:

Digital management and maintenance: Data purge, auto updates, system debugging, and checking home status/updates, "similar to how we check our cellphones as first thing in the morning", will become a routine for many people. Experts added more examples of new skills in this regard: skills around resetting, avoidance strategies and hacking might develop along with an expectation of decent UX.

Routine setting: Tinkering with the home system to set up new rules may become a common weekly/monthly task. scheduling services and reviewing/authorizing decisions in the home such as when household chores like washing clothes should be completed by or what temperature they want to buy for a room and for a certain length of time. Other than the simple rules for basic automation, complex automation, based on learning user preferences and home sub-system integration and coordination ("TV time settings", groceries and supplies ordering, home cleaning) home system auditing (reports, anomaly detection) will be the next level.

Health check and telemedicine: Consumers will become more sensitive about wellness activities and will have the ability to take actions to make their home environment healthier.

Teleworking: Teleworking is becoming more and more common. A smart home should be able to deliver the same services as an office does. "With the pandemic, people have been forced to migrate to a digital life. With that, I think that the traditional concept of home has changed" one expert said.

Higher level interaction with smart home systems: Robot interactions and conversations with the "head" AI, like the "butler" of a noble household are the two examples that two experts discussed.

Over Next 10 Years (2021–2031) Experts' thoughts and anticipation around the future of smart home progress over the next 10 years (2021 to 2031) are as follows:

Connection to smart cities and broader communities: The majority of the experts believe in a fast development in this area. They discussed that connecting smart homes to their surrounding communities is inevitable and it is already happening e.g., neighborhood watch programs. Some believe the focus will be more on sustainability and safety systems, shared riding services, gamification (neighborhood water usage), delivery services, collaboration (next-door neighbor), localized smart grids, and virtual power plants via electric vehicles. "From an energy perspective, smart technology within homes will inevitably need to be linked to the concept of smart local energy systems to encourage whole system thinking, especially

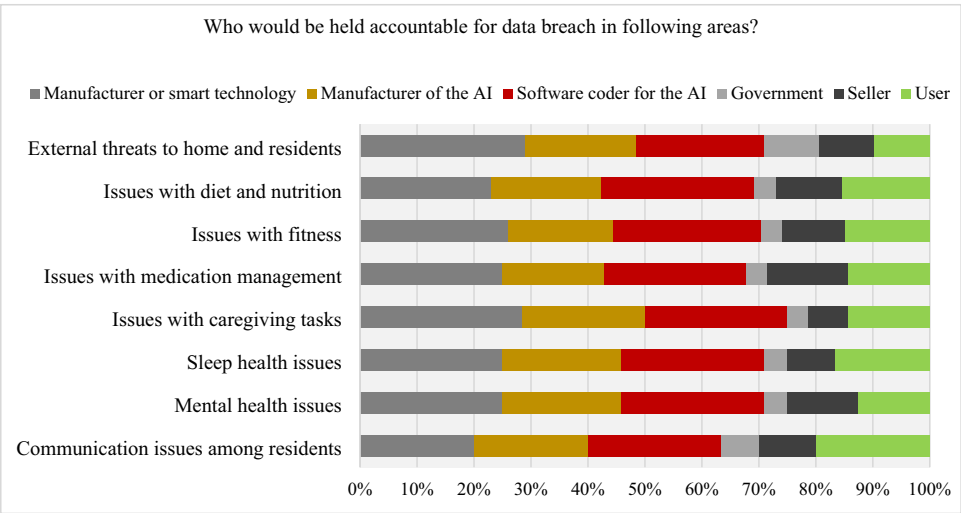


Fig. 5 Experts' opinion of data breach in a connected home environment

to reach decarbonization targets in the UK of net zero carbon emissions by 2050. Many countries are following the UK with similar targets, which will further incentivize the need for smart local energy systems, particularly if other methods to decarbonize heat (i.e., hydrogen) are not the main source" one expert said. Experts commented that the progress not only helps to create transparency and information for the community, it also can foster social connections. However, 5 of the experts envisioned slow and minimal progress with "very little of intra-building activity extends beyond the property line." These experts believe that technology is not there yet and within the ten years, except for demand response with power utilities, progress in this domain will be farther in the future.

Consumer protection, privacy, and data security: "I imagine this will be significantly eroded" one expert said. Experts discussed that every stakeholder should address this issue to minimize their liability and reduce consumer concerns. One expert suggested that new professions specializing in data privacy may be needed in the near future. Although the majority of the experts believe in a lot of progress within the next ten years, those who were less hopeful think the efforts will be more reactive (instead of proactive) respond to highly visible security breaches.

Eco-friendly technologies: Only three experts were pessimistic towards eco-friendly technologies. One mentioned that "costs may keep market growth limited." However, most experts commented that people are becoming more sensitive to ecological concerns and will favor eco-friendly technologies and sustainable practices. Likely greater development of domestic battery storage, greater interconnection of micro renewables into localized smart grids, more peer-to-peer energy trading, possibly more demand side response measures, and other measures to improve the efficiency of existing devices without questioning the broader role of "smart" devices in increasing energy demand and individualizing responses to collective challenges are some of the views that experts discussed. They view solar panels, home batteries, and electric vehicles will become more common as regulations/standards are applied over time and as an accompaniment to convenience.

Standardization and regulations: Among all the experts only three mentioned that standardization and regulation are unlikely to happen over the next ten years. Experts mentioned that people are becoming more aware of some of the risks these technologies entail and if these are not properly regulated, people will not be encouraged to use technologies. These will demand significant government response and will be more security-focused regulation. A few experts pointed that standardization is essential for interoperability and increasing compatibility between systems and platforms. Some examples that experts suspect to be regulated within the next ten years are as follows: data privacy, transactive energy and microgrids, utility contracts, open platforms, shared tech, and rental systems.

Smart home ownership and sharing economy: Experts had a blend of opinions over this topic. Only four people had positive views. They pointed that the trend indicates less and less people are able to own a home; however, urbanization keeps sprawling. Concepts such as "fluent homes" like Home Airbnbs, shared storages space and furniture, digital keys, ID for each home, decentralized brokers and sellers are some of the current examples. Three experts commented that there will be a slow increase same as smart city concept. The home as a service may become a thing in future.

Subscription models for smart home services: The majority of experts (N = 13) predicted subscription models will increase quite a lot for some services and this we be a default purchase option. Insurance industry, maintenance and repairs, groceries, and supplies deliveries will start using data from smart devices and subscription services more actively. In care home contexts where the needs exist for a short period of time or may change over time, subscription models can provide flexibilities. Experts discussed that many homeowners would prefer a more holistic approach that is considered for them with a regular payment plan. High market penetration will be achieved with no upfront costs' models. Many may not be able to afford such services so they will need to be sponsored in part by insurance and other organizations. Three experts showed some doubts around the model: "Jury is still out on whether this is a promising path to broad market adoption." Only one expert showed negative view: "consumers are reluctant to add more monthly fees to their budgets. Who would have thought households would pay hundreds of dollars a month for entertainment and communication services 30 years ago?".

Future Contributors, Players, and Stakeholders Majority of experts believed that the current big companies that already deliver today's technologies, e.g., Apple, Google, Samsung, and so on will play the major roles. Moreover, some experts commented that government and public agencies need to be held accountable for the highest privacy and security standards. Therefore, partnerships of the companies with government and public agencies that support all the essential services such as hospitals/public health, security/police, fire department, utilities companies are necessary.

4.2 Results of the Interviews With Experts

At the beginning of each interview, we asked experts if there is a need for a framework similar to the proposed taxonomy.

All the experts agreed that building a framework will be beneficial. One expert said, "If you have a vocabulary to express the levels of automation, then a person who purchases products knows what to expect and researchers know what is expected of them when they design the technology." He continued "if we have a common understanding of what was expected, then, we can make quicker progress in the field instead of replicating each other's work using slightly different vocabularies."

After asking experts about their general opinion on the framework, we continued the interview with questions about the details of the proposed taxonomy. We classified the discussion into the following subsections, each provides valuable insights in revising the proposed taxonomy.

4.2.1 Insights and Suggestions for Building an Improved Taxonomy of Home Automation

A New Level Between Levels 1 (Electric Homes) and 2 (Customized Homes) or Levels 2 and 3 (Proactive Homes) Several experts suggested that there is a gap between Electric and Customized Homes that should be filled by defining a new level. Two of the experts – a US-based academic with research background and one who was working at a research center in Finland, commented that learning and adaptive capabilities do not belong to Level 2: "I was reading the description of Customized Homes and I would imagine that the one level up. For level two would be devices that can be customized or adapted, but not devices with self-learning or self-adaptive capabilities. I would say that Nest thermostat is almost like an intelligent sensor and so I would say that belongs in Proactive Homes but not a Customized Home". Another expert said, "it should be another state where a lot of data is gathered and analyzed, and the results are shown to the inhabitant yet doing anything. The automation is not really doing anything but it's giving integrated and analyzed data that helps the inhabitant to understand the functions of the home and what is happening."

Three experts discussed the need to introduce a new level between levels 2 and 3. One of them, a director of a consultancy specializing in smart home systems, remarked, "I feel you're missing a level in between. Right now, if I take a look at smart homes, very few would fit into the category of devices with learning capabilities. I mean, other than the Nest learning thermostat and there may be a couple of another like ecobee and so forth, there are very few devices that really learn. We have cameras and window blade coverings and bulbs in our house, but they don't learn. We can set them to a pre-condition, e.g., the light turns on at sunrise, that sort of thing." He added that there is a missing category that should be described as devices connected to a platform in current high-end homes, but that are not learning. These homes are sophisticated with their platform and can orchestrate many devices to operate. Echoing this idea, another expert, a researcher in Finland, suggested that level 3 should be divided into two: "Basically, I see Proactive Homes into two levels. First, is a kind of everything connected, but they are just giving information to users. And then the second level, we get to a point into that whole is making a lot of the decisions, but also informing."

The senior director of product management at his consultancy, mentioned that there is a significant jump between levels 2 and 3: "to get to level three you need to get then move to a deeper finer grain integration in compatibility and that is traditionally quite hard for the industry! From a functionality standpoint, it's still quite difficult to pull off between major vendors, a consistently uniform outcome for the paying customer that can benefit the best of breed between brands. From a time dimension that the definition of level 3 will evolve over time and maybe in a very visible discrete chunks." He added that level 3 requires a more of the unity of communication and sharing of data and "people can't even agree on the privacy principles when you talk about Google vs Apple. Fundamentally, they're coming from two different angles in the data privacy."

Dimensions and Criteria A few experts suggested adding new dimensions to the taxonomy. One expert, a professor at a University in the US, emphasized the concept of home contextual awareness. They stated, "Home awareness of user needs within the taxonomy could probably be distinguished into different levels and types of awareness." This expert elaborated, "you do not only need awareness of residence, but you need awareness of physical surroundings. What is going on inside and outside the physical surroundings. You need to be able to predict your future behavior. Interaction with others, inside and outside the home and then their needs on so many different planes". Another professor from a university in Europe mentioned, "what you could have is another column that maybe talks about risks with each of those levels. What is the big risk for a level one home or what types of risks emerge? For example, interoperability would be a risk in a Customized Home, and things like privacy and surveillance would be risks for many of the types of homes."

Language and Terminology Other than the distinctive criteria to each level and the definitions, experts commented on the names of the levels as well. For level 1, several experts discussed the name, Electric Homes, and mentioned it is confusing to people who study home energy management, sustainable energy, and interactive efficient buildings, because it can get conflated with the concept of beneficial electrification. Electrifying buildings refers to using mixed fuel and eliminating the use of natural gas, propane, and oil.

In these buildings, residents can power everything by using electricity only. One expert with home energy management background in industry added: "we talk about electric homes as sort of fully electrified homes." Another expert with a similar background suggested "Analog homes" can replace electric homes: "To me, you're talking about automation not energy."

Regarding level 3, called Proactive Homes, one expert who is a director of a consultancy specializing in smart home systems suggested "Helpful Homes" which is being used by Google: "I like the name Helpful Home for that people understand that this technology helps them and it is not going to change the world and their life e.g. a robot going around, but it is helpful."

For level 4 (Support Homes), one expert suggested "Smart city homes" to refer what ties in at this level. Other discussions about the names of the levels were around having neutral and unbiased names such as "partially automated homes", "fully automated homes", or the "sentient home" as one mentioned "You could even keep it very neutral and say, simple, moderate, sophisticated, advanced, and very advanced."

4.2.2 Expert Opinions Around Enabling Technologies (AI, Social Robots, and Smart City)

AI Although everyone agreed on the role of AI in creating a more connected and automated home, as well as supporting the advancing processing power described across the levels, three experts with diverse backgrounds in both academia and industry raised several concerns. First, there are some concerns around agency of the system and centralization: "agency of the system and centralization of the system as being assumed good. One expert said "The way in which you're presenting even this diagram, it's got that natural curve of more with time. It implies the lack of human autonomy, more technological centralization, and more cyber security risk is good." Another expert discussed the unity of communication among the vendors: "digital living room network alliance where the most degenerate things like pressing play or fast forward or stop for your movie was finally shared among different vendors like Samsung and Google but it took quite a movement to make that just happen. And now you're talking about very sophisticated AI with models and insights that understands how people think, that's the secret sauce. Why should they share it with my competitor? Right. That will be a whole different game of battles." And third, a few experts suggested the concept of central vs. distributed AI: "The one aspect of your home that maybe I disagreed with a little bit was you kept talking about a central AI and didn't allow room for considering distributed intelligence and at a community level that is obviously going to become more of a need."

Social Robots Experts expressed a mix of opinions on the concept of social robots for fully automated homes. Out of 21 experts, seven expressed strong positive views. Three, all of whom work in industry at the director level in the US, disagreed with the concept, while the rest of the experts remained neutral. One expert said, "I definitely see it as the ultimate level we're trying to reach! This is you know when technology and human really come hand in hand, and it will feel like a companion to your life not someone trying to overrule or take away your agency."

Experts discussed different situations in which a social robot can benefit people. For example, if someone goes on vacation, the home is fully functional, or it can care for someone who has special needs. They also envisioned some new tasks such as maintenance and data analysis that humans would have to do after adopting robots.

Other experts mentioned that level 5 is biased towards the idea of assisted living: "if you tell me read this paper as a lens for understanding elderly care design, then I like to call it assisted living, which I consider some kind of companionship. These homes would be able to interact not only in making more efficient routines or behaviors, but also to affect sentimentally users."

Some experts believe that people might not want to lose control over some aspects of their life: "the classic example I can think of is my own grandmother, who's 96 years old. At the moment, she can still walk with help. She is getting to a point where she's needing more and more help. I think of an interesting question, and actually weirdly, the most social the most pro social thing a robot could sometimes do is get out of there and let leave people to it." Similarly, an expert commented that social robots in older people's homes have been actually rejected massively by the Japanese.

Another concern around the concept of social robots involved the intrusiveness of social robots: "The best user interface is no user interface… you walk into the home and stuff happens because the home knows what your preferences are… I would agree with you that. Let's think about some kind of a role, but it might not look like a human. It might be more like a vacuum cleaner kind of a thing where you don't even think of it as a robot. It just runs around the house."

Smart City All of the experts agreed on the concept of home extension with some considerations. Out of all, seven experts emphasized that the connection of home to a broader community can be associated with different organizations such as safety, energy, and delivery systems. One expert commented that the concept of home extension should not

only be tied to the idea of smart city as has been defined in the proposed taxonomy: "Why not connection to energy trading and connection to digital platforms, or connection to other smart systems, just because I think that smart cities don't even exist in many places." Another expert mentioned "You may want to qualify that this concept is inclusive of connecting to a doctor, connecting to the rehab or it is connecting to the only like the power utility company." Similarly, another expert emphasized that "actually connection to other homes is probably just as important as connectivity between homes, perhaps connectivity between family members." In addition, four experts suggested that level three is too early for the concept of smart city, and this should be moved further down in the taxonomy: "I would put smart city into the 10 years plus category because now you have to get governments involved and it just takes time." Some of the experts discussed that the concept of home extension can be recognized as new dimension. Various connections of home to outside services can be associated with differences in lifestyle applications of inter-home connectivity – referred to as a smart community. Such connections have also been presented for energy saving, resource sharing, and collaborative security purposes (Kim et al., 2017).

4.3 Response to the Suggested Changes and Comments

In this section, a summary of all the experts' suggestions will be discussed in the order of the levels. We aggregated the similarities among the comments and explained the reasonings behind accepting or rejecting any of the comments to revise the proposed taxonomy. This discussion will cover not only the common themes observed among the experts, but also all of the unique ideas that have been reported in the result section.

Level 1 Experts with backgrounds in energy management, sustainable energy, and interactive efficient buildings commented that the name of level one (Electric Homes) is misleading. Since a key goal to this taxonomy is building a framework that is usable by all the stakeholders, we agreed on changing the name to "Traditional Homes."

Level 2 (Customizable Homes) Discussions around Customizable Homes suggested that there are very few examples of systems with adoptive and learning capabilities which can limit this level to only homes with those options. Moreover, learning and adoptive capabilities are more advanced than other capabilities e.g., basic pre-condition network and connection of some devices. According to these reasonings, the concept of Customizable Homes was expanded to homes that have one or more technologies with adoptive, customized, personalized, or programmed capabilities. Learning capabilities is not a requirement anymore. As the evolution of smart home technologies in the market shows, these homes have some technologies that can function based on schedules and triggers of sensors that connect some those technologies together.

Level 3 (Networked Homes) Experts also suggested to push proactive homes further or divide it into two levels. According to this idea, there are some emerging connected homes that do not belong to the Proactive Homes but have some capabilities beyond Customizable Homes. Moreover, some of them predicted a longer delay achieving Proactive Homes due to regulations and barriers to interoperability. Based on these comments, we pushed down the Proactive Homes and defined a new level before that: "Networked Homes." Limited interoperability and interconnection among the devices are the core concepts to this level. In this level, homes are evolving into an ecosystem of devices where the concepts of interoperability, home awareness, and home as a platform emerges into our descriptions of the levels.

Level 4 As a result of the addition of Networked Homes into the taxonomy, the Proactive Home concept has been moved to level 4 with minor additions. Home awareness to individual users and the concept of distributed AI require these homes to integrate more advanced levels of interoperability, which differentiates this Proactive Home level from the new level before it, the Networked Homes. More complex and stronger data processing power, as well as a more robust and secure system, are some capabilities of distributed AI that are envisioned to be highlighted in an advanced Networked Home in which most of the devices are orchestrated and information related to individual users and tasks being collected and processed.

Level 5 Experts had different opinions on defining a social robot as a distinctive criterion for level 5. Results of our discussion led us to keep all the capabilities of level 4 in the original draft and define it as level 5.

A New Dimension Some experts suggested that home awareness to user needs, home connection to outside services, and social robots are fluid concepts that can be defined as separate dimensions. Among all these suggestions, the new updated framework used this discussion and added a new dimension where home extension is a more fluid concept and can vary across the levels to some extent. Regarding social robots, more investigation is required to clarify their role in current and future homes. In addition, home awareness is a concept that has been addressed by separate levels in the taxonomy and extracting it as a separate concept does not improve the language.

5 The Updated Framework

The concept of a smart home has evolved over time, initially focusing on the automation of basic tasks and remote controls. However, as technology advanced, the definition expanded to encompass interconnected devices, energy efficiency, security, and convenience. This evolution has been shaped by technological advancements, consumer preferences, and the integration of various devices and systems. Additionally, the adoption of smart home technology has been influenced by factors like affordability, sustainability, and accessibility.

Moreover, the perception of smart home technology can indeed vary from one country to another due to cultural, societal, economic, and technological differences. For example, in some cultures, there is a strong emphasis on family and community, so people may be more interested in using smart home technologies to connect with their loved ones. In other cultures, there is a greater focus on privacy and security, so people may be more hesitant to adopt smart home technology that collects data about their activities.

Standards and frameworks can foster innovation by providing a base for collaboration, research, and development. By agreeing on common rules, procedures, and specifications, different stakeholders can work together more effectively and efficiently, share knowledge and resources, and accelerate the pace of innovation. Moreover, building a common language can facilitate market access by increasing user technology literacy and providing a level playing field for competition and reducing barriers to trade. By complying with recognized standards, companies can demonstrate their commitment to quality and safety, and gain access to new markets and customers. This study aims at creating a base of discussion to build a framework in the domain of smart home technology and services. Previous efforts in this domain were discussed with experts. Results provide insights in understanding different types of smart home, barriers in this domain, and improving a framework that explains home levels of automation and intelligence in regards with its technological capabilities and user role.

Overall, experts' definition of smart home showed a lot of overlaps with the existing definitions (Sovacool et al., 2020) with slight differences in their focus. Automation and responsiveness to user needs were recognized as two major factors by most experts regardless of the type of system or technology. Experts also suggested that voice operation systems play an integral role in making a home smarter.

Moreover, experts pointed to usability issues, user technology literacy, and user privacy concerns as the top three barriers to making homes smarter, above the following factors suggested to them: costs, interoperability issues, technical reliability, security of data, lack of regulations, and channel distribution problems. Although interoperability is essential to make devices, systems, and applications work together to provide the best user experience and to achieve common goals (Pramsohler et al., 2015; Son & Lee, 2019) experts did not pick interoperability as the top major barriers to make homes smarter.

Regarding data breach and accountability in a connected home where devices and services are connected to each other, experts would accuse manufacturer of the smart technology first followed by the software coder and not the government for most cases. This may be related to the lack of regulatory conduct in the smart home industry. The absence of established regulations, standards, or guidelines to ensure the privacy, security, and safety of smart home devices and their users are essential to address the potential risks associated with the use of these devices, such as data breaches, cyber-attacks, and physical harm (Geneiatakis et al., 2017; Hammi et al., 2022). Without proper regulations and standards, manufacturers may prioritize profit over user safety, resulting in devices with vulnerabilities and security flaws.

Experts also were asked to give insights about future use cases and scenarios. Experts believe that digital management and maintenance, routine setting, health check and telemedicine, and interaction with social robots are some of the new in-home tasks with the emergence of newer, smarter technologies. Experts added that there will be huge progress in consumer protection, privacy, and data security as well as adoption of eco-friendly technologies and subscription models.

The updated framework (Fig. 6) is built based on the results of interviews and surveys with experts of this study. Similar to the older version, the new framework has five levels but with some changes in the characteristics of the levels, names, and the number of dimensions.

Level 1 (Traditional Homes) The majority of homes around the world today are Traditional Homes. Traditional Homes include technologies with pre-determined functions. Below is a list of criteria for Traditional Homes:

- Technologies in Traditional Homes have predetermined functions which do not actively adjust to user needs.
- Devices in these homes can only receive and act upon inputs (stimulus-action response). They do not have decision-making abilities.
- Traditional Homes do not possess technologies that can understand resident needs. There is no monitor of the environment, users, user habits, user status, or in-home activities.

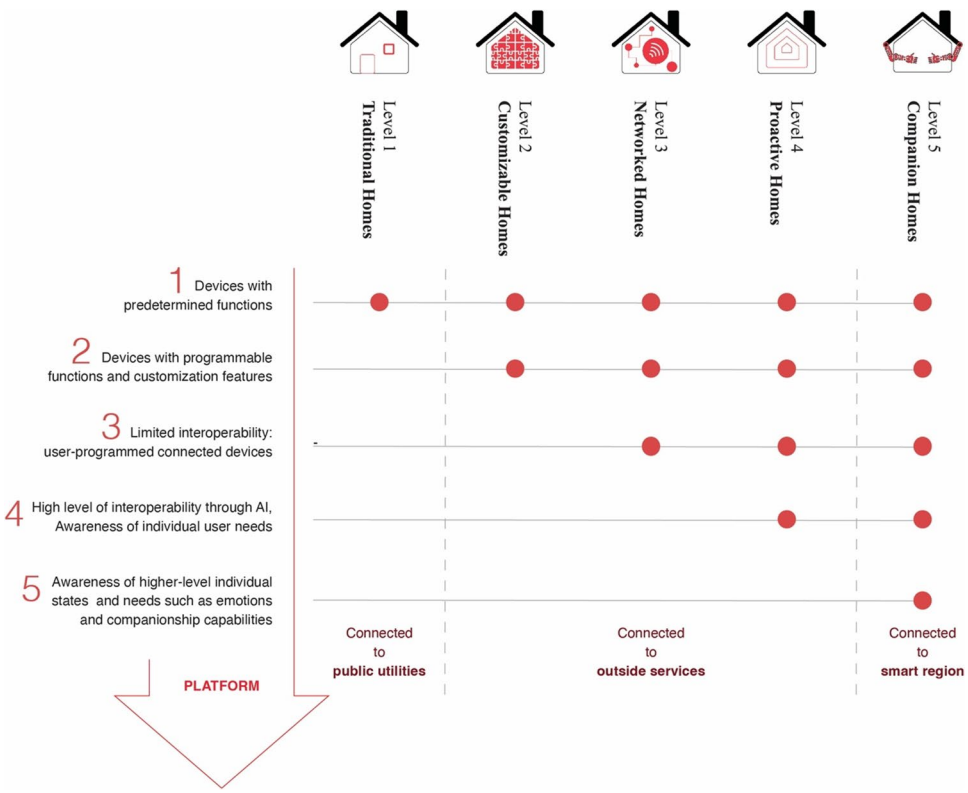


Fig. 6 The updated home taxonomy and levels of automation

- In Traditional Homes, the in-home technologies are connected to each other only through electrical wiring; no wireless radio communications are involved. Such technologies mostly operate independently, while some tightly-coupled devices (e.g., a motion sensor and ceiling light) may be deployed and operate together.
- Considering the information processing theory (Simon, 1979) for the levels of automation of devices (sense, interpret, decide, and act) in Traditional Homes, devices can only receive input and act upon that (stimulus-action response). Stages like interpreting data, making predictions and decisions, and multi-device coordination are missing in Traditional Homes' technologies.
- In terms of connection to outside services, Traditional Homes are mostly connected to public utility services. However, smartphones have opened ways to connect residents with services such as online deliveries.

Level 2: Customizable Homes Customizable Homes have been widely adopted during the last decade. Advanced technologies with internet connection, remote controls through web or mobile applications, and user-friendly interfaces (e.g., a large display, primitive voice recognition, etc.) have helped residents save energy, time, and costs by tailoring home functions and features to address their needs. Customizable Homes include technologies with programmable functions and customization features. Below is a list of criteria for Customizable Homes:

- In Customizable Homes, there is at least one technology that residents can customize, personalize, or program based on their needs. If-else features, programmable routines, and recommendation engines are some examples of customization tools.
- In-home devices that are "customizable" provide interfaces through which they can receive contextual information or action requests from other devices.
- Customizable Homes have incomplete monitoring systems and partial understanding of user needs; i.e., an understanding that is only relevant to some tasks through one or a few in-home technologies.
- Advanced technologies with internet connection, remote controls through the web or mobile applications, and user-friendly interfaces have helped residents save energy, time, and costs by tailoring home functions and features to address their needs.
- Customizable Homes are widely connected to public utility and delivery services. During the last decade, basic connections of in-home safety, energy, health, and assistive systems to safety departments, local communities, and healthcare providers have emerged in some homes of this level as well.

Level 3: Networked Homes Networked Homes are becoming increasingly popular. Networked Homes are platforms of user-programmed connected devices that enrich connections between home devices and enhance the customizations. Below is a list of criteria for Networked Homes:

- In networked homes, a richer connectivity among different devices is accomplished based on interoperability solutions (Autili et al., 2019; Bencomo et al., 2013) supporting seamless primitive data communications.
- In-home devices are connected through either wired (e.g., Ethernet) or wireless communication (e.g., WiFi, Bluetooth, Zigbee, InfraRed, etc.) technologies. Devices can discover each other and establish a network when requested by the user.
- Users can set rules for their devices through a central home gateway (e.g., turn on lights upon arrival, turn on coffee machine when waking up) according to their needs. As more devices are coordinated, users can define more sophisticated home automation logic.
- Devices do not have the capability to learn about the environment and/or user. Therefore, Networked homes may have a limited understanding of individual user needs. Basic responsiveness to the in-home environment and/or the residents can be achieved by customization rules.
- Networked homes are vastly connected to utility and delivery services. Due to higher interconnectivity among in-home devices, connection of in-home safety, energy, health, and assistive systems to outside services can be more highly automated due to enabled connectivity features e.g., the car battery charger is connected to the resident's calendar.

Level 4: Proactive Homes Proactive Homes are near-term futuristic homes. Proactive Homes are platforms of devices with awareness to current status of individual users. Interconnectivity of devices and orchestration of in-home tasks are core to this level. Below is a list of criteria for Proactive Homes:

- In Proactive Homes, the majority of technologies are connected to each other to work together beyond the primitive data transmission. An advanced level of interoperability is intended to advance the technological system's awareness of the environment and/or its users.
- Enhanced awareness of environments/users and facilitate autonomous collaboration of in-home technologies and orchestration of in-home tasks that are core to this level.
- In Proactive Homes, a central intelligence (e.g., home gateway, cloud service, etc.) or in-home devices may have enhanced awareness of the environment, users, their habits, status, and activities. Such enhanced awareness might be achieved based on a holistic and/or longitudinal view of in-home situations and probabilistic methods including machine learning.
- According to the home (network) configuration, the centralized intelligence can also be realized by orchestrated distributed smart devices (e.g., multi-agent user preference learning).
- Proactive Homes are vastly connected to utility and delivery services. Due to higher level of interoperability among the in-home devices, connection of in-home safety, energy, health, and assistive systems to outside services are more efficient, enhanced, and tailored to multi-resident homes and sensitive to users' lifestyle.

Level 5: Companion Homes Companion Homes are future homes. Companion Homes are platforms of devices with awareness of the current and future status and needs of individual users. Below is a list of criteria for companion homes:

- Companion Homes are capable of understanding users' emotions, perceiving hidden needs, predicting unseen situations, taking actions, and making suggestions.
- Companion Homes can contain one or more physical entity that can manage all physical tasks and chores. The physical entity could be comprised of an array of existing in-home technologies or a separate entity like a social robot. The support that this entity provides encompasses both practical tasks and social and emotional companionship.
- Companion Homes at this level are vastly connected to outside services and emerging smart cities and regions in many countries. High-level interoperability among the in-home devices orchestrated through distributed AI and awareness of environments and individual residents provide meaningful information to external parties such as local public safety, the city-wide housing grid and local authorities, transportation services, healthcare providers, and insurance companies for the efficiency of services.

6 Discussion

This paper explores expert opinions on the current and future states of (smart) homes. We recruited experts from diverse backgrounds within the smart home technology sector to provide insights into this area. They shared their definitions of a smart home, either from their experience or literature, and highlighted how smart homes differ from non-smart homes. According to them, "automation" and "responsiveness to user needs" emerged as the top two characteristics defining smart homes. This helps establish a baseline for the technical capabilities of home systems that meet these criteria.

The experts also identified key barriers to the wider adoption of smart home technologies, citing "usability issues," "lack of user understanding of smart home technology," and "user privacy concerns" as the top three obstacles. These challenges underscore the areas where designers and developers need to focus to accelerate both the progress and adoption of smart homes.

Further discussions during the interviews underscored the need for a framework within the smart home domain. The experts generally responded positively to the proposed taxonomy, offering numerous suggestions for its enhancement.

Experts envision new in-home tasks emerging across several categories as technology advances. Digital management and maintenance tasks such as data purging, system updates, and status checks will become routine, akin to checking our cellphones each morning. Skills related to system resetting, avoidance strategies, and hacking are also expected to develop, alongside expectations for a decent user experience. Routine setting will involve tinkering with home systems to establish rules for household activities like laundry schedules and temperature settings, evolving into complex automation that learns user preferences and integrates various subsystems. Additionally, health checks and telemedicine will become more prevalent as consumers focus on wellness, while teleworking will transform home environments to deliver office-like functionalities. Finally, higher-level interactions with smart home systems, including robot conversations and interactions with a central AI "butler," were highlighted by experts as future developments.

Additionally, new taxonomy is built to provide a framework for researchers to discuss the current status of smart homes and their levels of automation as well as possible future directions. This taxonomy is intended to help standardize terminology, instead of using a variety of languages. While stakeholders today are using different vocabularies for similar features and functions in their products, our proposed taxonomy aims to facilitate communication among researchers, designers, and developers which consequently can improve consumers' understanding of the products and facilitate adoption of connected home services.

However, we recognize that our current efforts may only be relevant for a limited time due to the ongoing evolution of the field, rather than being completely future-proof. Although the proposed framework provides a foundational platform for stakeholders to improve communication, explore new avenues, and tackle user pain points, the necessity of regularly updating our work to keep pace with technological advances, industry shifts, and evolving standards is critical. Future studies should refine the taxonomy based on the challenges and opportunities discussed by experts. For example, changes should be implemented to enhance digital management and maintenance at every level, improve data privacy, automate routines according to users' evolving needs, enable complex automation, expand telemedicine and health management capabilities, and refine interactions with smart home systems.

With a more consistent vocabulary describing the levels of automation, users and consumers will have a better knowledge of what to expect. Consistency in characterization will also inform and guide researchers and designers with a better understanding of what is expected of technology products and where meaningful changes may be made, as one expert said "This provides more opportunity to make quicker progress in the field instead of replicating each other's work using slightly different vocabularies." Finally, as seen in other domains e.g., transportation, the taxonomy would facilitate standardizations and regulations by providing a framework for policymakers and other stakeholders.

The next steps for advancing this study include several critical components aimed at enhancing the robustness and applicability of the taxonomy:

Broader Expert Recruitment To gain a more comprehensive understanding and ensure the taxonomy's global applicability, it is essential to recruit experts from diverse geographical locations and sectors. This includes construction companies and experts from various continents, which will bring different perspectives and experiences that could lead to a more universally relevant taxonomy.

Rigorous Testing and Refinement Developing an effective taxonomy is an iterative process. It requires additional testing through more rounds of interviews with experts. These interactions should focus on refining and standardizing the taxonomy based on feedback and practical application insights. This process might also include pilot implementations of the taxonomy in real-world settings to see how it performs and where it may need adjustments.

Mutual Exclusivity of Levels In future versions, it's important to focus on the extent to which the levels in each home type are mutually exclusive and the degree to which technical capabilities and automation can be implemented across a spectrum.

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Data Availability The data that support the findings of this study are available, but restrictions apply to the availability of these data, which were used under license for the current study and so are not publicly

available. The data are, however, available from the authors upon reasonable request.

Declarations

Conflicts of Interest There is no competing interest/conflict of interest to report regarding this manuscript.

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Dr. Shabnam FakhrHosseini is a Research Scientist at the MIT AgeLab. She received her Ph.D. in Applied Cognitive Science and Human Factors from Michigan Technological University. Her research now primarily aims at developing models for technology adoption, enhancing logistics in connected homes, and integrating social robots to facilitate aging in place. Dr. FakhrHosseini's commitment is to the creation of technologies that are not only accessible and intuitive but also beneficial to society.

Chaiwoo Lee is a Research Scientist at the MIT AgeLab. Chaiwoo's research focuses on understanding acceptance and use of technologies across generations, and looks into people's perceptions, attitudes and experiences with new devices and services. Her recent studies explored a variety of technology domains such as the smart home, vehicle automation, sharing economy services, virtual reality, artificial intelligence, robotics and more. Across different application domains, her research seeks to deeply understand user behaviors and decisions, to discuss issues around societal impacts, and to find implications for human-centered design of future products and services. Through research projects and other professional services, Chaiwoo has worked with companies and organizations in a variety of industries including consumer electronics, financial services, healthcare, transportation services and automotive manufacturing, insurance and more. Chaiwoo received her Ph.D. in Engineering Systems from MIT, and her M.S. and B.S. in Industrial Engineering from Seoul National University. She also teaches human-centered design at Tufts University's Human Factors Engineering program.

Sheng-Hung Lee is a designer and PhD researcher at Massachu-setts Institute of Technology (MIT) AgeLab and Ideation Lab and Board Director at Industrial Designers Society of America (IDSA). He is inspired by multiple domains of knowledge and perspectives while working at IDEO. Lee serves as Adjunct Associate Professor at Shih Chien University, Taiwan.

Dr. Joe Coughlin leads the Massachusetts Institute of Technology AgeLab. Researcher, teacher & advisor - his work explores how global demographics, technology and changing behaviors are transforming business & society. He teaches in MIT's Department of Urban Studies & Planning. Coughlin advises major companies worldwide and has served on advisory committees for the White House, the Organization for Economic Cooperation & Development and economic development authorities worldwide.