



# Smart Homes 2019: State-of-the-art and expectations for the future



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# 1. Highlights

- Smart device adoption has reached a tipping point – the Smart Home is already here
- Smart Homes mean more than just gadgets – they comprise complete systems (e.g. a house or neighbourhood), technologies (e.g. speech processing, sensors, authentication), and they use context (e.g. eHealth)
- As autonomous things proliferate, we expect a shift from stand-alone intelligent things to a swarm of collaborative intelligent things, with multiple devices working together
- Responsible innovation issues include: Accessibility & Adaptability, Openness & Interoperability, Transparency & Technology Literacy, Environmental Impact, Cyber-Security, and Privacy & Data Practices

# 2. About the project

[LIVING INNOVATION \(LIV IN\)](#) is a new initiative that aims to develop responsible, smart home solutions that tackle societal challenges and respond to pressing societal trends. Uniquely, and for the first time, the initiative involves industry leaders that engage with lead users in co-creation processes to create solutions that meet user needs and leverage collective creativity to uncover new business opportunities.

Funded by the European Commission's Horizon 2020 programme, the project creates two distinct opportunities.

- LIVING INNOVATION gives lead users and citizens the chance to be involved in the design of the technology that will shape their future lives
- LIVING INNOVATION gives industry the possibility to respond directly to changes and needs of users and society.

In doing so, the initiative aims to demonstrate to industry and the public what Responsible Innovation is, and how citizens can be involved in developing innovations. Other industries will also be able to take up the outcomes of the project, and use them to tap into human-centered, and user-led responsible innovation. By directly engaging users and by working together, both industry and citizens can benefit from innovation.

LIVING INNOVATION is coordinated by the Institute for Managing Sustainability at Vienna University of Economics and Business. The project unites 14 partners from 10 European countries, including nine leading companies in the areas of smart homes and smart health.

# 3. About the author

This Knowledge Unit's author, **Ad van Berlo**, is founder and R&D Manager of Smart Homes in Eindhoven. Over two decades, van Berlo and his team have run "the smartest home of the Netherlands", pioneering the development of smart home technology in Europe. Recently, he is looking into high-profile emerging technologies (artificial intelligence, augmented reality, robotics) and their potential impacts on smart home systems.

## 4. Introduction

Smart Homes, as predicted by generations of sci-fi writers, are finally becoming real – and some of the new systems and devices fulfil the most ambitious sci-fi fantasies. Today, one third of the total number of private households in the United States may be defined as a “Smart Home”, closely followed by The Netherlands and the Scandinavian countries, where Smart Home penetration rates<sup>1</sup> range from approximately 25-30% (see Figure 1).

### Global Comparison - Household Penetration in the Smart Home market

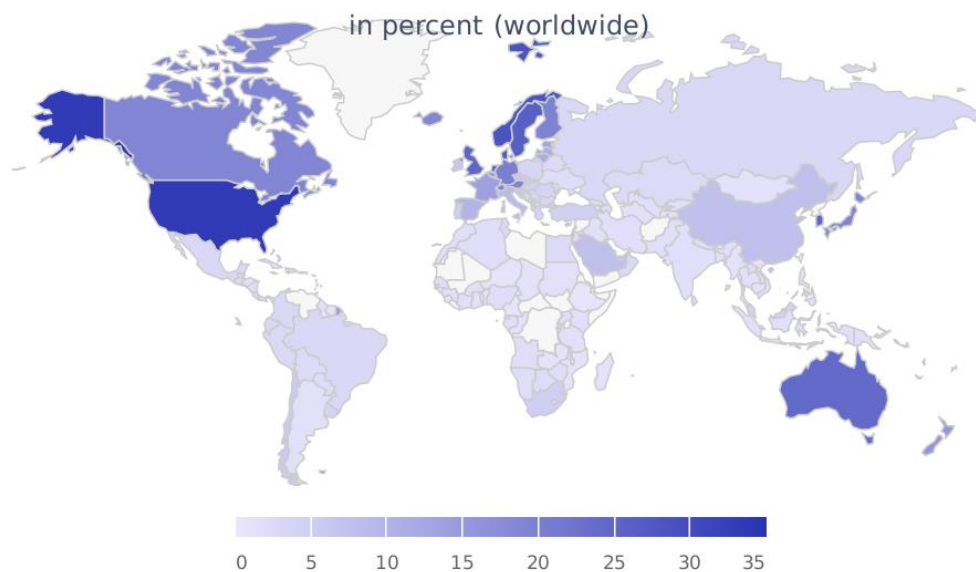


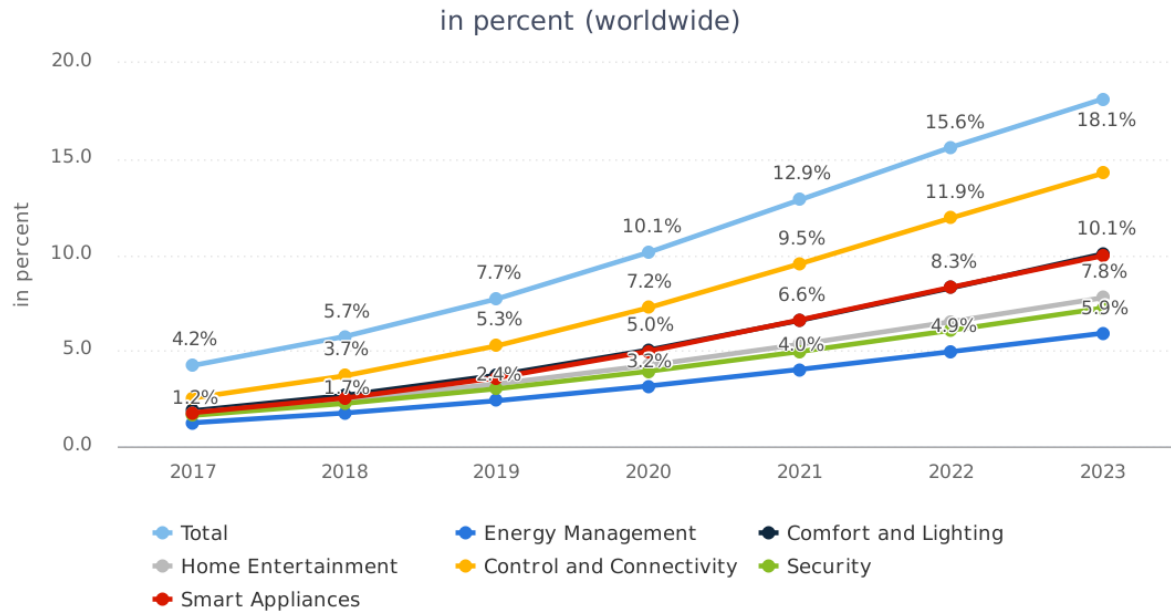
Figure 1<sup>2</sup>

Many Smart Home devices remain in the realm of luxury, e.g. assistive robots, or devices for holographic communication. However, devices such as Amazon’s Alexa or Google Home have already crossed many of our doorsteps. On a global scale, the share of Smart Homes within the total number of private households is sharply on the rise (see Figure 2).

<sup>1</sup> Penetration rate represents the share of Smart Homes among the total number of private households in the selected market (market segment, region) for each year.

<sup>2</sup> <https://www.statista.com/outlook/279/100/smart-home/worldwide#market-globalRevenue>.

## Penetration Rate in the Smart Home market



Source: Statista, March 2019; Selected region only includes countries listed in the Digital Market Outlook



Figure 2<sup>3</sup>

The term “Smart Homes” is widely used with different meanings, from the development and marketing of Smart Home technology, products and services, to statistics of sales and forecasts. This has often created confusion, in particular for the resident, home owner or new house buyer. The expert center Smart Homes, based in Eindhoven, the Netherlands, came up with a first definition in 1992: **a Smart Home is a home in which sensors, actuators and equipment are seamlessly connected and integrated for a better quality of living.** Over the years, most technical developers and academia have adopted and further expanded on this definition and way of thinking.<sup>4</sup>

However, in more recent times some resellers of Smart Home products and services also refer to Smart Homes, when promoting single “smart” products and gadgets. These gadgets may contribute to the feeling of “smartness”, and may even fulfil the most ambitious sci-fi fantasies, as stated earlier. However, Smart Homes involve more than just gadgets – they comprise complete systems (e.g. a house or neighbourhood), technologies (e.g. speech processing, sensors, authentication), and differ in the use context (e.g. eHealth). Consequently, they enable a plethora of scenarios, automate services, and thus improve both the quality of living and quality of life. The recent strong development of Artificial Intelligence will reinforce the feeling of an “intelligent” or “empathic” house<sup>5</sup>: where patterns of the lifestyles of the resident are recognized by the many sensors, accidents are recognized, and suggestions for improvement or help will be given automatically. In this paper, the state-of-the-art of Smart Home development and expectations for the near future will be outlined.

<sup>3</sup> <https://www.statista.com/outlook/279/100/smart-home/worldwide#market-users>.

<sup>4</sup> Harper 2003, Jiang 2004, Ricquebourg 2006.

<sup>5</sup> Augusto 2006.

## 5. Socio-economic developments and trends

Two socio-economic macro trends drive the development of Smart Homes: the “Ageing Society” and climate change.

An ageing population is a phenomenon affecting almost all modern, industrialized countries. In the next two to three decades, a sharp increase in the proportion of elderly people is expected in countries such as Japan, Germany or Italy. The percentage of people aged over 65 in the European Union is projected to increase from 18% to 25% by 2030.<sup>6</sup> In the EU, only two working age people per elderly person will be available in 2050, compared to the four currently needed.<sup>7</sup> This shifting demographic structure will have severe implications for economies, mobility structures and pension systems all over Europe. Under the auspices of “ambient assisted living”, attempts are being made to develop technologies that will help ageing persons to age “in place”, meaning in their choice of home.<sup>8</sup>

**{ SMART HOMES, AS PREDICTED BY GENERATIONS OF SCI-FI WRITERS, ARE FINALLY BECOMING REAL – AND SOME OF THE NEW SYSTEMS AND DEVICES FULFIL THE MOST AMBITIOUS SCI-FI FANTASIES. }**

Not all ageing persons will experience severe illnesses such as Alzheimer’s disease, chronic conditions and/or mobility impairments, but roughly one third will develop one or more severe problems, and will need some level of help and care.<sup>9</sup> This means that while roughly two thirds of ageing persons will have no or very limited age-related problems, the one third that will have them, pose a lot of societal challenges, if they prefer to stay living independently. Barrier-free houses are often a requirement, but this needs major adaptations to existing houses. In the Smart Home area, several technical developments have begun. The Smart Homes Expert Centre in Eindhoven has been involved in dozens of larger experiments within the Netherlands in the first two decades of this century. Many technologies for surveillance, to access control to the house, safety and security, and integrated care in the home have come up (see below). In late 2018, the International Panel on Climate Change published its *Special Report on Global Warming*.<sup>10</sup> Scientists from 40 countries stated that it “would require rapid, far-reaching and unprecedented changes in all aspects of society” to limit global warming to the 2 degree limit negotiated within the Paris Agreement in 2015.<sup>11</sup> Efficient energy management in the housing sector could contribute a significant share to mitigate global warming.<sup>12</sup> Smart energy management systems have the potential to support households in reducing energy consumption.<sup>13</sup> Furthermore, smart grid systems may help to better match energy supply, storage and demand at the neighbourhood or even city level.<sup>14</sup>

<sup>6</sup> [https://ec.europa.eu/eurostat/statistics-explained/index.php/Population\\_structure\\_and\\_ageing](https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing).

<sup>7</sup> [https://ec.europa.eu/info/publications/economy-finance/2018-ageing-report-economic-and-budgetary-projections-eu-member-states-2016-2070\\_en](https://ec.europa.eu/info/publications/economy-finance/2018-ageing-report-economic-and-budgetary-projections-eu-member-states-2016-2070_en).

<sup>8</sup> Rashidi 2013.

<sup>9</sup> <https://www.who.int/ageing/about/facts/en/>.

<sup>10</sup> <https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/>.

<sup>11</sup> <https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/>.

<sup>12</sup> [https://cdn.friendsoftheearth.uk/sites/default/files/downloads/Future%20of%20Heating\\_August\\_2018.pdf](https://cdn.friendsoftheearth.uk/sites/default/files/downloads/Future%20of%20Heating_August_2018.pdf).

<sup>13</sup> Attia 2018, Fiorini 2018, Van Dam 2013.

<sup>14</sup> Pratt 2010, Miceli 2013, Costa 2013.

## 6. Technology Trends

In the last few years, the development of Artificial Intelligence (AI), Internet of Things, Virtual & Augmented Reality and Robotics has gained momentum. These emerging technologies will have a big influence on Smart Homes and on our lives, our lifestyles and the way we live, work, learn and entertain at home. In a comprehensive online survey from 2018, Jabil, a service provider in the global electronics and technology sphere, asked over 200 professionals in the connected home and building industry about opportunities and challenges in their sector:

What improvements or emerging technologies are most likely to accelerate the adoption of connected home and building solutions as they become generally available?

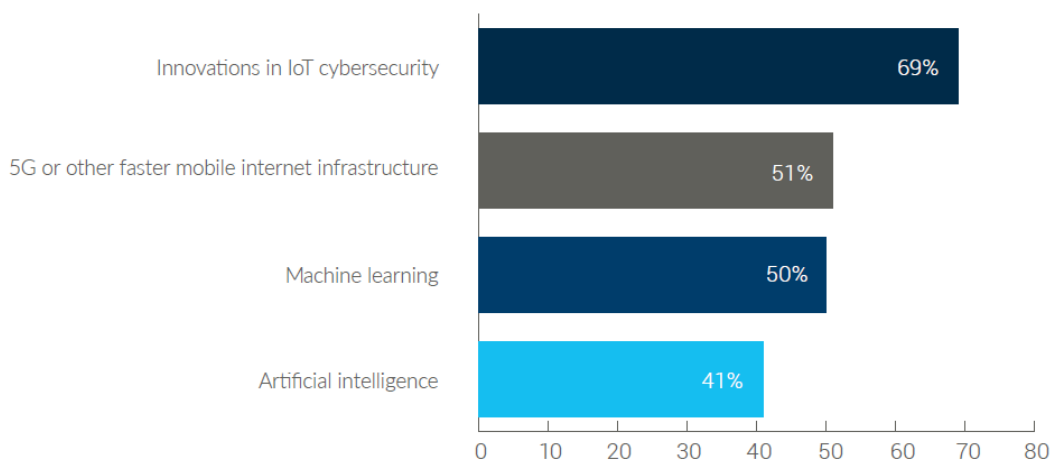


Figure 3<sup>15</sup>

The Internet of Things development has existed for some time around elements such as Smart Cities and Smart Homes. Utilising user patterns, environmental factors and other data, future services such as energy management in the home will be delivered according to the SAAS model: Smart Home As A Service. A period of accelerated delivery of robust Smart Homes is arising with technology becoming an integral part of our daily lives.

Another important requirement for a truly Smart Home is connection to broadband internet. For several of the services and technologies listed in the previous sections, the traditional ADSL connection is in many cases no longer sufficient. Remote areas often suffer additionally from poor ADSL. Access to optic fibre infrastructure is desired for most Smart Home services.

Autonomous objects, tools and devices, such as robots, drones and autonomous vehicles, use self-learning algorithms to automate functions previously performed by humans. Their automation goes beyond rigid programming models, and they will exploit AI to deliver advanced behaviours that interact more naturally with both their surroundings, and with people. As autonomous things proliferate, we expect a shift from stand-alone intelligent things to a swarm of collaborative intelligent things, with multiple devices working together, either independently of people or with human input; this will make the original goal of a Smart Home, as stated in the Introduction, realizable.

Up till now, professional data scientists have partnered with application developers to create AI-enhanced solutions. But increasingly the professional developer can operate alone using predefined models delivered as a service. It is expected that within a decade, highly advanced AI-powered development environments automating both functional and non-functional aspects of applications, will give rise to the 'citizen application developer', where non-professionals will be able to use AI-

<sup>15</sup> <https://www.jabil.com/content/dam/insights/reports/en/connected-home-and-building-tech-survey-report.pdf>.



driven tools to automatically generate new solutions.<sup>16</sup> Of course, this will have a big influence on our Smart Home solutions.

Finally, conversational platforms are changing the way in which people interact with the digital world. Virtual reality, augmented reality and mixed reality are already changing the way in which people perceive the digital world. This combined shift in perception and interaction models will lead to the future immersive user experience, particularly in the home environment. Multimodal experiences will connect people with the digital world across hundreds of edge devices that surround them, including traditional computing devices, wearables, automobiles, environmental sensors and consumer appliances. In the home, we will use all of our human senses as well as advanced computer senses (such as heat, humidity and radar) across these multimodal devices. Smart Homes will be a physical and digital environment in which humans and technology-enabled systems interact in increasingly open, connected, coordinated and intelligent ecosystems.

**UTILISING USER PATTERNS, ENVIRONMENTAL FACTORS AND OTHER DATA, FUTURE SERVICES SUCH AS ENERGY MANAGEMENT IN THE HOME WILL BE DELIVERED ACCORDING TO THE SAAS MODEL: SMART HOME AS A SERVICE.**

## 7. Application areas for Smart Home technologies

Jabil’s comprehensive online survey also investigated the biggest market opportunities from a Smart Home industry perspective (see Figure 4).

What are the biggest market opportunities for connected home and building solutions?

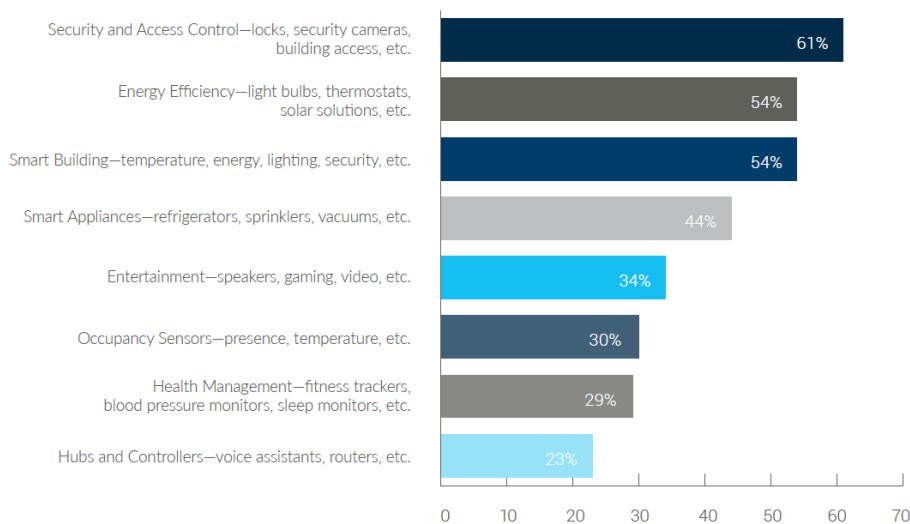


Figure 4<sup>17</sup>

It is difficult to categorize the areas of functional applications relating to what we usually do in our home environment. Here, only the most important, and those relevant to the socio-economic trends of an ageing population and climate change, will be further dealt with. The categorization is based on earlier experiences of the Smart Homes Expert Centre in Eindhoven, which appears to be useful for most applications.

<sup>16</sup> <https://www.techopedia.com/definition/30968/citizen-developer>.

<sup>17</sup> <https://www.jabil.com/content/dam/insights/reports/en/connected-home-and-building-tech-survey-report.pdf>.

## 7.1 Security

### 7.1.1 Intrusion detection

Traditional wired infrared sensors for detection of unwanted movement are being replaced by wireless sensors. The more advanced sensors can also distinguish between a human being and a pet, thus minimizing false alarms. In addition, smart cameras with AI have been introduced recently to automatically detect a person, zoom in and listen. Sharp images in different zones of the house are becoming available for identification by police. Cameras can be controlled and watched via a smartphone, which also makes it possible for residents to carry out remote surveillance by themselves.

### 7.1.2 Smoke Detection

Traditional wired smoke detectors are also being replaced by wireless devices. AI is being used for detection of early burning while cooking, early smoke detection, distinguishing cigarette smoke from other burning, and also detection of which material is burning in case of a real fire. These advanced, low-cost and (for residents) simple smoke detection sensors will reduce the number of injuries and deaths due to fires, but will also reduce the large numbers of false alarms and help conserve fire brigades' resources.

### 7.1.3 Fall prevention and detection

Fall prevention and detection for older residents has been a challenging task. Falls among older people may occur due to a range of complicated factors: medication, low blood pressure, reduced muscle strength, balance problems, obstacles, poor lighting, etc. Prevention through automatic lighting in halls, bedrooms or bathrooms has been widely implemented, but is often considered undesirable by the older persons themselves. If an older person has fallen on the floor, fast and automatic detection is wanted. Traditional personal safety alarms are often not worn by older people, but these alarms have also been improved strongly: with voice-speech technology in the pendant itself and automatic detection in belt-worn or wrist-worn devices, and even in smart watches. The concept of smart floors, with sensors in the floor is being explored, for both gait analysis and early detection of hampered walking.

### 7.1.4 Home access control

Home access control has many facets: electronic door locks for personal or remote access, remote camera observation, intrusion prevention, security issues, etc. From the very beginning of Smart Home developments, access control has been one of the major focus points. The most recent innovations are in the area of adding a small external motor above the door, with an app on the smartphone. With the app one can see who opened the door at what time. Automatic opening of the door is also possible when approaching the house. These door locks have a single point lock which makes them less resistant to intrusion than three-point electronic locks. However, the latter are much more expensive. These remote locks are being used to give one-time access to deliver packages, groceries, meals, etc. into the house. Remote camera views are often part of this service. For home care providers electronic locks are important if a resident has asked for emergency help after a fall. After checking remotely, a call-center specialist may give access. But the resident him/herself can also give remote access when he/she is unable to come to the front door because of immobility or chronic illness. Of special interest are the upcoming biometric solutions: finger scan access is many years old, but face recognition for accessing one's own house is the most recent innovation.

## 7.2 Energy management

### 7.2.1 Automatic control of heating and cooling

Smart thermostats are becoming one of the key Smart Home hubs. Other Smart Home control functions can be connected to these hubs. But the smart thermostat is also evolving: it takes into account not only the personal settings of the residents, but also the external weather conditions, and the lifestyle patterns and profiles of the residents. AI is used to predict their behaviour, and to operationalize the desired indoor climate conditions through both heating and cooling. More sophisticated solutions will emerge with the connection of an electrical car to the house, or sharing electricity with neighbours.

### 7.2.2 Air quality and humidity

Indoor air quality has gained more attention due to the upcoming insulation of houses for reduced energy consumption. Indoor air, which is too humid, will cause the growth of micro-organisms and reduce the quality of life. But an increase in CO<sub>2</sub> levels might cause headaches and other ailments. So, in a Smart Home, sensors measure CO<sub>2</sub> and humidity levels and automatically open windows or turn on the heat-regenerating air exchange systems. Central vacuum cleaning systems are also considered part of a Smart Home, as they remove very small particles, which might otherwise be harmful, e.g. for people with COPD or asthma.

## 7.3 Comfort and Lighting

### 7.3.1 Comfort and control

Voice activated virtual assistants, e.g. Google Home, Amazon's Echo, Samsung's Galaxy Home, Apple HomePod, have become the most widespread Smart Home devices. These assistants are not only speakers and/or tools in their own sense, but offer the possibility to control peripheral smart devices, enabling interaction with the entire Smart Home system. However, tools and devices from different Smart Home resellers use different operating systems and do not integrate seamlessly at the moment. Therefore, interoperability between different systems remains an open issue.

### 7.3.2 Lighting

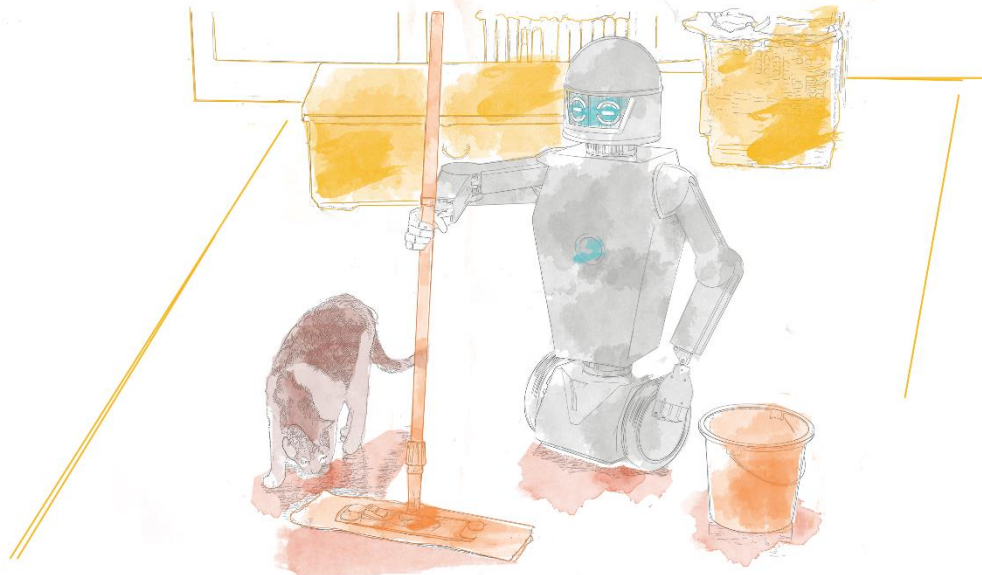
One of the first applications in Smart Home development has been the possibility for light scenarios: different lighting combinations for different situations, such as reading, cleaning, watching TV, etc. With new options to include different colour lighting, the remote control and pre-programming of lighting scenarios have become even more popular. Also of interest are new light sources, which mimic daylight and smooth transitions from daylight to night and vice versa; this might compensate the 'post-lunch dip', or stimulate melatonin production before sleep.

### 7.3.3 Automatic/remote control of blinds and curtains

The classic application is the remote control of blinds and curtains via a handheld remote control, or automatically via a weather station. Control of heavy curtains has been seen as useful for older persons, but this has never become widespread due to costs. Recently, smart glasses have been introduced, which control the amount of light to be blocked. However, they are still too expensive for widespread market adoption.

### 7.3.4 Automatic Cleaning

Cleaning a house is still difficult to achieve with an automatic or robotic system. Nevertheless, vacuum cleaning robots are maturing. The early devices moved at random and bumped against walls and chairs. The more recent robots use better sensors and machine learning techniques to scan the room and clean very efficiently.



## 7.4 Health and Care

### 7.4.1 Self-management of vital signs

Self-management of health, in particular via e-health, has not yet reached a major breakthrough, despite high expectations over the last 10 years. Nevertheless, thanks to the popularity of wearables and the increasing awareness of citizens and governments that the burden of chronic diseases can be reduced through prevention, blood pressure monitoring, ECG measurement and other devices will soon have a place in the home.

For such self-management, a Smart Home environment is not required, but it is expected that these tools will be connected, and that readings will become visible on e.g. smart mirrors and other screens, which will remind us to measure vital signs and demonstrate the effects of different lifestyle.

### 7.4.2 Activity monitoring

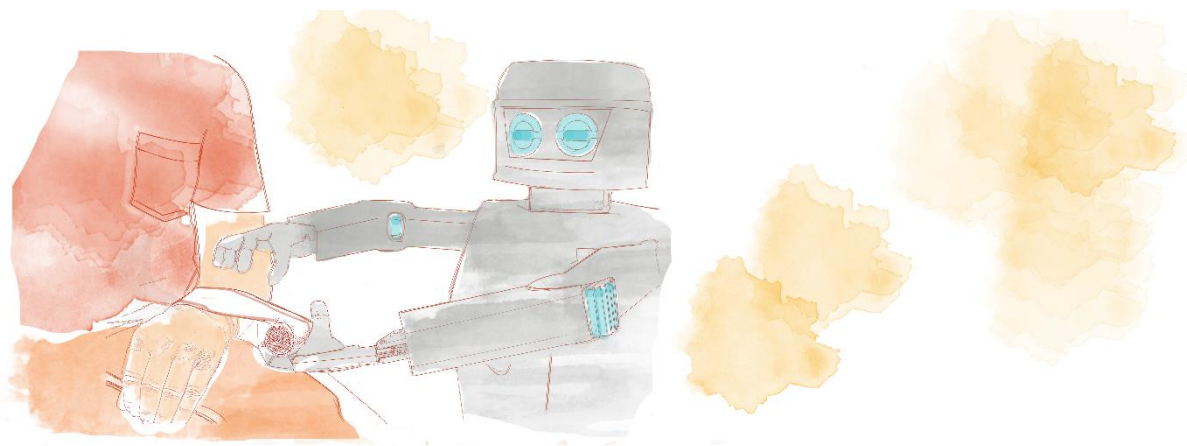
For older persons living alone and with mild impairments, such as early dementia, it might be useful to have their daily activities continuously monitored. For this, so-called activity monitoring has been developed: with infrared sensors and door magnets (including on the fridge), AI is able to follow the activity patterns of the older person. If there is a strong deviation from the expected pattern, family members or care centers can be warned. The activity monitoring can be enhanced with other sensors such as for water flow measurements in toilet and tap water, bed and floor sensors.

### 7.4.3 Medication reminders

Forgetting to take medication at the right time causes public health care costs, and has for many years been the focus of innovation in health care technology. For this problem, there is the same option as for self-management of vital signs, and one can use smart medication reminder devices in a normal house. So far, only a few devices have shown partial success. Devices connected to a smart mirror or other displays, or reminders on the smart mirror might provide better solutions.

### 7.4.4 Home rehabilitation

There are several rehabilitation programmes that can be carried out at home with the help of medical equipment, sensors, apps and connection to a hospital or care center. For example, exercising on a home bike after a heart attack; exercising after a hip or knee operation; or engaging in recovery programmes after a stroke or surgery. Such rehabilitation equipment can be personalized and very attractive to use, e.g. via serious gaming or cycling programmes with roads displayed on a screen when doing home training. "Hospital at home" concepts are being developed, and for this a Smart Home would be very helpful to access such facilities.



### 7.4.5 Emergency alarms

For several decades, a pendant with an emergency button has been used when older persons live alone in traditional homes. However, many older persons find this stigmatizing and don't wear it. In a Smart Home, several other possibilities have been investigated, such as automatic alarming after detection of a fall, or after a certain time of non-movement, and it is expected that with AI and several sensors in the house, the automatic alarm after a fall can be improved significantly. Automatic alarming after smoke or intrusion detection is very limited so far, because of the high number of false alarms.

## 7.5 Home entertainment

### 7.5.1 Virtual Reality and Augmented Reality

As virtual reality (VR) is maturing, and content is being developed, it will become integrated into the home. VR will be useful for education, health consultations, business, and multi-player gaming. Audioscapes and projection mapping already allow for mixed reality spaces. These mixed reality rooms will begin to compete with dedicated home cinemas, as residents of a Smart Home will seek entirely immersive, 360° experiences where you cannot only see and hear your favourite movie, but engage all your senses at the same time. And augmented reality (AR) will arrive in the smart home as digital information overlays aspects of our real-life experiences.

### 7.5.2 Audio and video

Digital and interactive TV has become widespread, which makes new services possible: the resident can watch any programme, including films, on demand using simple online payment. With ever-expanding and higher resolution flat screens, TV watching will gradually become part of a total immersion in different (virtual) worlds. Smart speakers, wirelessly connected to the broadband Internet are of very high quality, and can be installed in the house with several interactive audio services, and also operated via voice control.

### 7.5.3 Information Management

With the strong presence of smartphones (more than 90 % penetration rate), information gathering is not limited to fixed screens in the home anymore. It is expected, however, that in the Smart Home of the future several thin and holographic screens will appear, which will provide us with the desired information on e.g. weather, news, personal health, technical status of the house, etc.

## 8. Consumer perspectives on Smart Home technologies

### 8.1 Adoption and penetration of smart devices

Smart Home adoption has been slow to gain traction among consumers, but we are beginning to see increased consumer interest; more so with a select handful of individual smart devices rather than a truly connected Smart Home consisting of multiple smart devices working together.<sup>18</sup>

The US market is currently the largest by far. Within Europe, Germany and the UK have the largest number of adopters of Smart Home technologies, followed by France, Italy and Spain. The average Smart Home technology user across all applications tends to be male, disposes of a middle-to high-income and is between 25-44 years of age.

Adoption of smart devices by people over the age of 55 is below 10% in both Europe and the US. This is significant as ambient assisted technologies, which particularly target elderly consumers, are the only application area which has seen significant discussions on responsible innovation practices and particular concern among developers to meet specific consumer needs.

In 2018, 10.7 million households in the top five European Smart Home adopter countries already owned at least one smart control and connectivity device. More than 6 million households own comfort & lighting devices, smart energy management devices, smart appliances or security devices. Smart home entertainment systems are also present in 5.7 million European households. These numbers illustrate that smart device adoption has reached a tipping point – the Smart Home is already here.

**By 2023, the number of households with Smart Home devices is projected to rise steeply in Europe, with 33.7 million households owning at least one control and connectivity device, more than 44 million households disposing of smart energy management or comfort and lighting technologies, 21 million households owning smart appliances, and around 17 million households being fitted with smart security and home entertainment devices.**<sup>19</sup>

<sup>18</sup> <https://www.pwc.com/us/en/services/consulting/library/consumer-intelligence-series/smarthome.html>

<sup>19</sup> <https://www.statista.com/study/42112/smart-home-report/>



## 8.2 Meeting consumer needs & expectations

There still seems to be a clear gap between what smart devices provide and what household inhabitants actually demand.<sup>20</sup> Currently we do not have sufficient knowledge about who the current or prospective users of Smart Home technologies will be, as there is a notable absence of user-oriented studies in actual Smart Home environments. Available data tends to be limited to specific technologies (e.g. smart meters or smart assistants) and contexts (e.g. a community, a case study or a country), which makes it difficult to identify consumer attitudes on Smart Home technologies.

However, a number of challenges can be identified for large scale roll-out and consumer adoption, which are relatively well documented across Europe.<sup>21</sup>

- 1) **The acceptability of Smart Homes to users is closely linked to issues of security, privacy and trust, as well as practical and ergonomic concerns about user-friendliness.** These issues present critical design challenges that relate to the interactions between users and Smart Home technologies.
- 2) **The central user-related challenge is to align and adapt technologies with the subjective and differentiated nature of users' everyday lives at home.** New technologies are developed under the assumption of specific, repetitive and relatively predictable routines and schedules, but they always enter pre-existing dynamic home environments. On closer examination, life at home is "organic, opportunistic and improvisational".<sup>22</sup>
- 3) **The rather high price of devices has proven to be an influential factor in whether or not a given technology is attractive to consumers.**<sup>23</sup> Concurrently, overpromising on expected cost savings jeopardizes consumer trust. For instance, many users of Smart Home technologies find benefits in the remote management and monitoring of energy consumption. However, the often-advertised promise of energy and related cost-savings is rarely delivered. Consequently, users may lose trust in both the technology as well as the providers.

## 8.3 Perceived benefits and user concerns

The perceived benefits of Smart Home technologies currently converge under the themes of enhanced **convenience, control and safety**.<sup>24</sup> A majority of UK consumers, for instance, believe that Smart Home technologies have the potential to make their lives easier.<sup>25</sup> Surveys from the US show similar consumer attitudes.<sup>26</sup> Other contexts have been less well studied. A recent global survey however, concludes that, while the appeal of Smart Home technologies is generally relatively high, there remains a significant proportion of consumers who are lukewarm to the concept of the Smart Home, which suggests that they remain to be fully convinced of the merits of adopting this technology and the ways in which it could improve their lives.<sup>27</sup>

**AMONG VULNERABLE GROUPS, INCLUDING PEOPLE LIVING WITH DISABILITIES AND ELDERLY PEOPLE, THE POTENTIAL TO GAIN GREATER INDEPENDENCE IN DAILY LIFE IS THE NUMBER ONE PERCEIVED BENEFIT OF SMART HOME TECHNOLOGY.<sup>28</sup>**

<sup>20</sup> Georgiev 2018.

<sup>21</sup> Wilson 2014.

<sup>22</sup> Ibid., p. 19.

<sup>23</sup> Georgiev 2018.

<sup>24</sup> [https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Smart%20homes%20final%20report%20\(new%20Traverse%20logo\).pdf](https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Smart%20homes%20final%20report%20(new%20Traverse%20logo).pdf)

<sup>25</sup> <https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/consumer-business/deloitte-uk-consumer-review-16.pdf>.

<sup>26</sup> <https://www.pwc.com/us/en/services/consulting/library/consumer-intelligence-series/smarthome.html>.

<sup>27</sup> <https://insights.gfk.com/study-the-2018-gfk-smart-home-study>

<sup>28</sup> [https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Smart%20homes%20final%20report%20\(new%20Traverse%20logo\).pdf](https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Smart%20homes%20final%20report%20(new%20Traverse%20logo).pdf)

Consumer concerns linked to Smart Home technologies can be summarized under the headings of **cost & functionality, data security & privacy, concerns about negative impacts on behaviour & human interaction, as well as lack of knowledge and trust** related to what happens when things go wrong.

Accessibility issues, concerns over possible cyberattacks, and an inability to understand, maintain and operate smart devices are key user concerns among vulnerable groups, including people living with disabilities and elderly people.

## 9. Responsible Innovation and Smart Homes

We have identified six key Responsible Innovation issues in the area of Smart Homes:

### 9.1 Accessibility and adaptability

A well-equipped smart home would not be entirely 'smart' if it were not fully accessible by persons with certain disabilities. Barrier-free living for wheelchair bound people, for example, is not standard, but newly built houses could be designed for little extra cost in ways that mean persons with mobility impairments can always get easy access. Adaptability means that accessibility of the house should be easy, if a sudden disability should occur. These accessibility and adaptability issues might also arise when a resident becomes e.g. hard of hearing/deaf or poor sighted/blind. Apart from the absence of physical barriers, ICT enabled supporting tools and products should be easily installed and integrated with other technologies in the house.

### 9.2 Openness and interoperability

Interoperability is a difficult matter in the world of Smart Homes, and there are different levels and areas of interoperability. In general, interoperability of systems is the ability of the technology to communicate seamlessly without the programming inherent in conventional systems integration. The problem is that numerous devices from multiple vendors use different technology to communicate, and they communicate usually only within their own ecosystem. A world where devices from different ecosystems would communicate seamlessly and reliably with each other seems far away and difficult to achieve. The question here is if universal standards will emerge.

### 9.3 Transparency and technology literacy

Smart Homes are areas of high complexity. Challenges related to installation, maintenance and updating of a growing number of smart tools and devices may go beyond the capacities of individual residents and house-owners. Consequently, Smart Home equipment needs to ensure low technological requirements and to use self-learning to detect and care for possible vulnerabilities. The demographic challenges posed by ageing populations further exacerbate this need. To simplify procedures in the Smart Home, voice control seems to be a promising solution. In the past decade voice recognition and speech synthesis have dramatically improved. It is becoming the "must have" user interface, ultimately changing the way we interact with our home environment. Amazon's Alexa, Google Home and Apple's Siri are already entering our homes. Thanks to recent AI introduction, an increasing number of partnerships and integrations have become possible for new services, such as ordering a meal by simply talking to a small device.



## 9.4 Cyber Security

There are many security issues with the almost unlimited installation of smart products in the home, which makes it easy for cybercrime specialists to enter the Smart Home remotely. There is increasing concern about remote invasion of the Smart Home.

## 9.5 Privacy and data practices

Special attention should be given to the data storage of all data collected in the Smart Home. After installation of an app on the smartphone, one is asked to approve the data storage at the servers of the app maker. In the Smart Home, several owners of equipment, such as white goods, also ask for approval of data storage. But many sensors are connected to an additional gateway, or are “hidden” and connected to unknown servers. Being in control, even in a Smart Home, is one of the major concerns of Smart Home owners or residents. The more data that is collected via in house sensors and equipment about the lifestyle and life patterns of the residents, the easier it will become to monitor and “control” the life of the resident. Here, ethics becomes a concern, regarding what we consider as acceptable from smart living.

Finally, strong regulations need to be in place to avoid data being re-used beyond its original purposes – e.g. if very sensitive data collected at home is transferred to life insurance companies or used for commercial market research.

## 9.6 Environmental impact

At a global scale, e-waste is expected to increase from 44 megatons in 2016 to over 50 megatons in 2020. The EU accounted for roughly one quarter of electronic waste in 2016<sup>29</sup>. In the context of the Smart Home, re-use and recycling of smart gadgets, tools and devices seems imperative in order to foster a circular, closed-loop economy, which attributes two, three or possibly more lifespans to critical and scarce resources.

In addition, gains in energy efficiency via smart energy management systems may be levelled out by the increasing amount of electronic devices in use. Looking at their entire life cycle, energy used (and CO<sub>2</sub> emitted) during production, maintenance and disposal may even exceed the projected energy savings. Further research would be required to test conflicting arguments against empirical evidence.

# 10. What do you think?

Now it's your turn! We invite you to discuss on some of the following issues in the discussion section below:

- How can we ensure that installing, maintaining and updating a growing number of smart tools and devices does not overwhelm users, especially elderly people?
- How can we safeguard smart home systems and their individual components against cyber-crime?
- Sensors in smart homes produce a tremendous amount of sensitive, personal data. How can we ensure that big tech companies respect user privacy?
- Monitoring of body-related information is a vital component of Ambient Assisted Living. What about privacy here?
- Smart homes promise to optimize energy use. But will the prevalence of more tools, gadgets and sensors lead to more energy consumption?

Come join us at [www.living-innovation.net](http://www.living-innovation.net)

<sup>29</sup> [https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste\\_statistics\\_-\\_electrical\\_and\\_electronic\\_equipment](https://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics_-_electrical_and_electronic_equipment)

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