Future-proof platforms for aging-in-place

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Future-proof platforms for aging-in-place

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Preface

This thesis is the result of the PhD project I started February 2009. In 2008, I earned my master's degree in Building Services. My supervisor, Annelies van Bronswijk, asked me to continue working on my graduation subject. As I had enjoyed this topic, 'smart-homes for older people', I decided to embark on this 4-year adventure. And here we are, at the end of the ride, having traveled from pleasure to despair and back again, just as Annelies promised. Sometimes it felt like she personally ensured there would be moments of despair, but the same can be said of the moments of pleasure. In the end I feel I had about the right dose of both.

Of course I learned a lot over the past 4 years. As a building services engineer, I learned about the needs and ambitions of older people. I also delved into smart-home technology, and found out that this is a very complex topic. Technology for older people has a tendency to get complex very quickly: older users often lack affinity and understanding of the logic of a new technology and this translates into a difficult adaptation process. If they have trouble adapting to technology, then, quite obviously, the technology must adapt to them! This technology must therefore be developed with in-depth knowledge of their circumstances and context, or it will not be of any use. This requires a vast amount of information. Imagine, for example, the information that a little robot needs to safely and efficiently put a pan of spaghetti on the dining table: what is the fastest route? Are there any obstacles? Is the floor slippery? Where should the pan be placed? Where should the robot be positioned? Will a fast-moving robot scare the user? What height is the dining table? And so on. I leave it to your imagination to figure out all the things that can go wrong if the system misses one crucial bit of information.

On a personal level, the most valuable lesson has been to ask questions about myself: who am I, what do I want, and what skills do I have, what are my strengths and weaknesses. These are things I learned to answer and I am sure this will stand me in good stead to get to places that best fit my skills.

A doctor's title is something you must achieve by yourself, but you never do it alone. I would therefore like to thank everybody who supported me during my PhD: friends, family, colleagues, and organizations. Some I would like to mention by name:

First of all, I would like to thank BAM Techniek and Stichting Promotie Installatie Techniek (PIT) for their financial support. This allowed me to pursue my PhD on a fulltime basis; this is a luxury that most of my PhD colleagues do not have.

I would also like to thank the members of the PhD core committee: Professor Yeh-Liang Hsu PhD, I. González Alonso PhD, and dr. ir. R.H. Cuijpers. Your comments were very helpful and undoubtedly improved my thesis. Thank you all for your efforts and time. I would also like to thank Saied Tazari from Fraunhofer IGD, one of the coordinators of the universAAL project; you allowed me to closely follow that project and gave me access to all sources that I needed. I would also express my appreciation for the advice that I got from the masters of the ISG master class, mainly Professor J.L. Fozard PhD, Professor A. Tinker PhD, and Professor A.J. Sixsmith PhD.

Special thanks go also to my grandmother and her friend Mrs. Fokkelman, and to Marijke and Herman Hilberink. The interviews we had were ever so useful as a starting point for my PhD research.

Of course I also greatly appreciated the help I received from my colleagues, or co-victims: Wim, Frans, Lilliana, Remy, Gaby, Jeroen, Ruben, and Francesco: thank you for all our discussions, the input that I received, and the effort you took to review my papers. A special thanks goes to Adriana Schalkwijk Ribeiro MPH MD, for her great contribution to the research of health profiles and ICF.

I would also like to express my strong appreciation for my second promoter, Professor dr. H.S.M. Kort: your comments and guidance were extremely helpful.

Thank you in particular for your support and flexibility during the final phases of this thesis.

I want to express my gratitude to my supervisor Professor Annelies van Bronswijk: you created an impressive training program for me, put me through my paces so that I would learn as much as possible. Since I am told by a reliable source (my girlfriend) that I can be quite stubborn I have often had to learn the hard way, so I would like to thank you for bearing with me. Thank you for all the help and guidance during the past 4 years, even when the going got tough. I know that my imperfect command of English has driven you mad at times, so it's my special pleasure to thank you for your patience and perseverance in that language.

Finally, I want thank all my friends and family for the support, large and small, that they gave me. My parents, you are always there when I need you, always generous with your support, expertise, and opinions; it has been a great help to know that my frustration shared, would be a frustration halved. Also many thanks to my girlfriend's parents for their interest in my work and supporting me all the way. Gratitude also goes to my brother and sisters: Monique, you gave me plenty materials and hints that helped you earlier in your own PhD research, Bart, for giving me sound career advice, and last but not least Eveline, for help with the cover design. A big thanks goes also to my friend Tom, you were always online when I needed to unwind in the evening. But the person who suffered most and therefore deserves the most recognition is of course my girlfriend, Zanne, who managed to survive my entire 4 years of adventure. Zanne, you were there when I needed the support, picked me up when I was down, but also gave me all the space that I needed. You are my tower of strength, and the most important person in my live. It is thanks to you that I could completed this travel from pleasure to despair and back again, to finish this PhD.

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Chapter 1: General introduction

The topic of this thesis, “*future-proof platforms for aging-in-place*“, addresses two domains. The first is the domain of ‘future-proof platforms’, which is part of the field of Information and Communication Technology (ICT). The second domain related to aging-in-place, is the domain of housing for older people. This includes the built environment, but also several gerontological and technological disciplines, that are combined in Gerontechnology.

In this chapter, we will first introduce aging-in-place and its growing relevance due to demographic change. We will explain the role of smart-homes to support older people at home and introduce the concept of software platforms for smart-homes. This will be followed by a discussion on how platforms can be fitted for aging-in-place. We will conclude this section with the goals and objectives of this thesis.

1.1 Aging-in-place: living at home

Aging-in-place is a philosophy and a concept that is often defined as ‘having the ability to live in your own home as long as possible in an independent, safe, comfortable and healthy way’. The idea of aging-in-place is more than 20 years old and was first described by Pastalan in 1990[1].

Many older people choose to age in place, because they wish to maintain an independent lifestyle among their friends and aquaintantces[2,3]. It was common for grandparents to share a home with their children as they grew old. This way adult children could take care of their parents. Today, however, the number of older people that live on their own is increasing.

1.2 Demographic change

Aging-in-place is increasingly important due to the recent changes in size and compositions of populations, also called demographic change. Societies are aging, which means that the median age of the population rises[4]. This is the result of two mechanisms:

1. Life expectancy has increased due to improved public health, e.g. housing, diet, and medical care. According to the United Nations, the life expectancy at birth increased globally by over 20 years, from 46.5 years in 1950-1955 to 67.9 years in 2000-2005[4].
2. Fertility rates are falling: the average number of children that are born to a woman over her lifetime is decreasing. Globally, the fertility rate dropped from 5.0 to 2.7 over the last half century. Currently, the fertility rate is lowest in industrialized countries: in practically all of them the total fertility rate is below the replacement level of 2.1. In some countries it is as low as 1.3 children per woman[5].

Both trends are expected to continue. Life expectancy at birth is projected to increase globally with 10 years, to reach an average of 76 years by 2045-2050. Furthermore, the average global fertility rate is expected to drop to the replacement level over the next half century[4].

The recent rise in life expectancy and the decline in fertility rates will result in a higher proportion of older people in the near future (Figure 1.1). Data from the United Nations (medium-fertility variant)[4] show that in 2011 28.8% of the population in Europe was 55 years or older (Figure 1.2), while in 2050 this is projected to increase to 39.6%: an increase of over 30%! However, within that group the most dramatic increase is expected for people that are over 80 years of age: in 2011, 4.3% of the population in Europe was 80+, while this is expected to be 9.3% in 2050. This is an increase of over 100%.

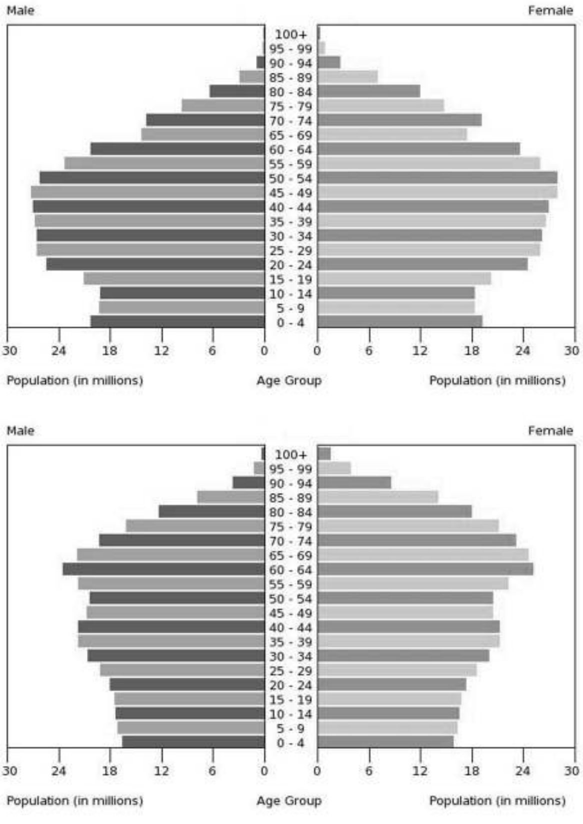


Figure 1.1: *Age pyramids of Europe showing the population profile in 2011 (top) and 2050 (bottom)[6]. The proportion of older people is expected to increase*

This doubling of the 80+ population will have a substantial impact. In business management, this impact is assessed by a PEST-analysis, where PEST stands for Politics, Economics, Sociology, and Technology[7]. Political factors include governmental intervention; economic factors are economic growth and the inflation rate; social factors are cultural and demographic aspects; and development of new technology and automation form the technological factors.

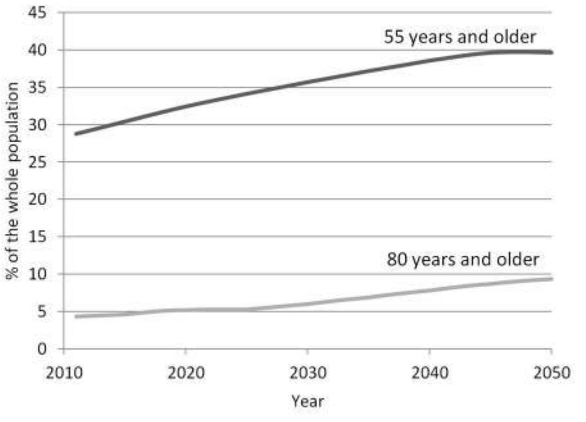


Figure 1.2: *The percentage of older people in Europe of the whole population, for 55 and 80 years and older (UN projection 2011 to 2050, medium-fertility variant)*[4]*. The percentage of persons older of 55 years and older is expected to increase with 1/3, while persons of 80 years and older is expected to double*

One such political and social impact of the increasing number of older people is the need for more care. Especially those who are older than 80 need care, since they commonly have one or more chronic diseases[8]. At the same time, the labor force is shrinking. This means that there will be fewer nurses and other personnel for nursing homes[9]. The number of family members who can take care of older family members is also decreasing. These changes have an impact on the economy, since it is expected that, unless it is organized differently, the costs for care will increase significantly.

Aging people who want to continue to live at home require support to compensate for the limitations of age-related inflictions to minimize disruptions in daily functioning. This is important for a person’s well being, since the degree to which disease disrupts daily functioning is inversely associated with loss of happiness[10]. Especially when older people are progressing into the 3rd (active retirement) and 4th phase (frailty) of life, more and more support is needed[11].

Technology that supports aging-in-place could offer a solution. If older people were assisted by technology at home, their need for care personnel could diminish. They would be able to be healthy and independent for longer in their own environment. This could results in a reduction of demand for professional care and in the burden of assisting family members[12,13].

1.3 Smart-homes

This thesis addresses the technological aspect of the PEST-model on the graying world population. Technologies may compensate for the lack of manpower by providing the required support to age in place [14]. Well-known technologies for aging-in-place include home automation, robotics, assistive technology, geriatric telecare, and telemedicine. When these or other technologies are integrated in the home environment, this is called a smart-home.

A smart-home is often defined as “any living or working environment that has been carefully constructed to assist people in carrying out required activities”[15]. To assist people, smart-homes use technology to improve the performance of dwellings in several domains such as health, comfort, safety, security, entertainment, and environmental impact (e.g. energy usage). Examples of functionalities that are offered by a smart-home include social gaming, improved communication, fall-detection, telecare, health monitoring, and burglar alarm. Today, most smart-homes focus on comfort and security aspects, and more recently energy saving as well.

The use of technology in the built environment is not new. The domain of structural engineering is a technological one, and originated at the time that people started to create the first building constructions. Only recently domains such as Mechanical and Electrical engineering, and Plumbing (collectively known as MEP) became integrated as part of the construction industry. The domain of ICT is not yet fully incorporated in construction, although with the introduction of building automation systems (BAS) and smart-homes, this is changing.

Smart-homes are not yet widely applied to support older people at home. However, the idea of using smart-homes to improve the quality of life for older people is not new. Since the 1980s, elderly have benefited from devices that alert assistance services. Since then, smart-homes have been improved thanks to major developments in ICT; computer chips, consumer products like smart-phones and tablets, and the continuous growth of the internet[15].

Most research on smart-homes for aging-in-place use monitoring older people as the starting point. Well known examples are the GatorTech Smart House[16] (USA), Aware Home[17] (USA), Welfare Techno-Houses[18] (Japan), Smart House Osaka[19] (Japan), and CarerNet (UK)[20]. Today, the scope has widened and research has moved beyond the smart-homes for monitoring only. Smart-homes for aging-in-place fit well with the goals and objectives of the Ambient Assisted Living Joint Programme (AAL)[8,21]. A number of research projects funded by the European Committee are closely related to smart-home for aging-in-place, like SOPRANO (Service-oriented Programmable Smart Environments for Older Europeans)[22], OASIS (Open architecture for Accessible Services Integration and Standardization)[23], and PERSONA (PERceptive Spaces promoting iNdependent Aging)[24], although these are not yet commercial available.

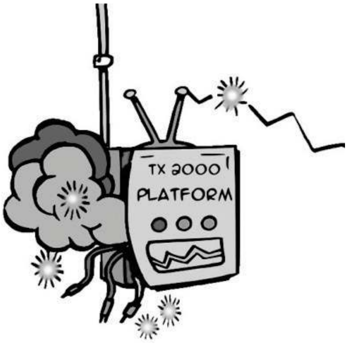
However, developing smart-homes for older adults is a challenge, since their requirements are different from those for younger people[25]. Developing technology to support older people requires understanding of both the technology and gerontology (knowledge of older people). This is addressed by Gerontechnology.

The main goal of Gerontechnology is to encourage and promote technological innovations in products and services that address older peoples' ambitions and needs[26]. These products and innovations will always address both a technological and a gerontological discipline[25]. For instance, this thesis addresses the technological discipline of information and communication technology, and gerontology disciplines such as physiology and psychology.

To arrive at successful aging-in-place, the products and services to support the older person address multiple technological and gerontological disciplines. In the next section, we will explain the concept of a platform that can be used to integrate the technology from multiple disciplines.

1.4 Platforms

The word 'platform' has different meanings. It may be a physical platform, like an oil platform or podium, or figuratively it can mean a group of people that organize themselves for some common purpose. The topic of this thesis, '*future-proof platforms for aging-in-place*', relates to a technology platform. We will focus on software platforms for smart-homes in particular.



Smart-home platforms

A technology platform is a piece of technology that is the basis for technological products or services. Because the platform is the basis or the foundation of a system, it is commonly said that other pieces of the system are placed 'on top' of the platform.

Platforms are used as a starting point for the development of products or services, so the development does not need to start from scratch. The technology of the platform is then reused, which is an important feature that allows the boost global technological development[27].

The purpose of platforms is to provide basic functionality. The products, processes, or services that are on top of the platform, will use this functionality (Figure 1.3). A familiar example of a software platform would be an operating system of a computer (OS, like Windows, Linux, or Mac OS)[28]. The OS provides the functionalities that a software program needs for its operation, for instance the functionality to read or write on the hard disk of the computer. Another example of a software platform is a software framework. Software frameworks are put on top of the OS and deliver more functionality than the OS, like compilers, code libraries, application programming interfaces (API), and tools[29].

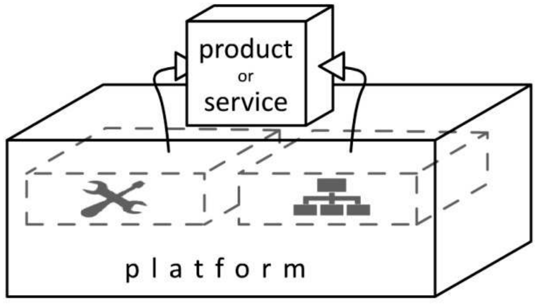


Figure 1.3: *A technological platform is a basis that can be used by a product or service which is put on top of the platform. The platform provides some basic functionalities to the product or service, like tools or network functionalities*

The use of a software platform in smart-homes should reduce the complexity of the technology of the smart-home (also called the smart-home system). A smart-home without a platform would quickly become a too complicated system since smart-homes typically consist of a network with numerous devices (like sensors) that should cooperate in order to fulfill one or more tasks. Although the purpose of applying platforms in smart-homes is clear, the actual use of platforms is a recent development.

History

The first smart-homes, or homes that were equipped with home automation (also called domotics), did not use any platform. The whole smart-home system was designed for a limited range of targeted functionalities. An advantage of this method is that it is relatively easy and cheap to create a prototype. However, this approach led to systems that offer poor quality to support the more complex functionalities, and they are hard to reuse and difficult to maintain[30]. Slowly, the idea for smart-homes to address higher level functionalities developed and the technology followed suit[31]. Nowadays, software platforms play an important role in smart-homes.

Before software platforms were used in smart-homes, they were typically used in Building Automation Systems (BAS) to integrate different existing systems in utility buildings[32]. Example of well known BAS's platforms are BACnet[33] and LonWorks[34].

The first home-automation standards were similar to the BAS platforms. Many commercial standards emerged, such as X-10, CEBus, LonTalk, BatiBUS, EIB, and HBS[35]. Unfortunately, these systems were not compatible. Vendors locked their system, also called a vendor-lock-in. The main motivation behind a vendor lock is to ensure customers cannot expand their system of vendor A with products of vendor B, forcing the customer to keep buying products of vendor A[36]. This economic aspect (see the 'E' of the PEST-analysis) has become a tremendous barrier to the rollout of smart-homes.

Although some European standards (BatiBUS, EIB, and European Home Systems) merged into KNX[37,38], this did not solve the lack of interoperability: KNX supports *devices* of different vendors, but it is not easily compatible with other *systems*. Therefore, interoperability remained an issue, and integration of technology (system integration) became a primary goal of research in the field of smart-homes. Solutions were sought in the latest development of the field of Information and Communication Technology (ICT).

State-of-the-art

Recently developed platforms are based on the use of computer networks and internet protocols. Consequently, the focus of research has moved from an electro-technical issues to ICT (or software).

Currently there are a large number of platforms for smart-homes, or they are under development. The RAALI project[39] identified 54 different platforms (October 2012). Amongst them, there are commercially developed platforms (e.g. IP-Symcon[40], mBS Smart Home SDK[41], OpenRemote[42]), open-source platforms (e.g. HYDRA[43], MundoCore[44], openHAB[45]), and those that focus on Ambient Assisted Living (e.g. universAAL[46], openAAL[47], OASIS[23]).

Typically, a state-of-the-art platform consists of the following components:
Middleware: a piece of software, that sits "in the middle'', between the OS (and networking software) and the smart-home specific applications[48]. Middleware is the most important component of a platform. Its main purpose is to provide access to resources of devices in the network. Applications that use the middleware do not need to know how to reach the device, or how to use the

network. Middleware simply hides these aspects. One could compare it to a grocery store: customers can buy all ‘resources’ they need at one place, without having to visit or knowing the farms or factories where the products come from. Middleware can also handle the management of the platform, and this can include a register of devices, or the administration of subscriptions. Examples of traditional middleware are COBRA[49], Java RMI[50] or DCOM[51]. For buildings, examples of commonly used middleware are Universal Plug and Play (UPnP)[52] or OSGi[53].
Semantics/ontology: middleware helps to share resources on the platform, but does not ‘understand’ the information. Humans might understand the information that comes from a sensor if they have the right context. For example, if a signal from a temperature sensor is “21”, than a human could understand that the air-temperature on the location of the sensor is 21 degrees Centigrade, which is a comfortable temperature for human beings. Without any further information, devices on the platform do not know this. Somehow, the value “21” should be linked with the understanding of temperature, at least by giving it a uniform label like ‘temperature’, ‘temp’, or ‘T’. The platform uses semantics or ontology to deal with this issue and helps to solve the problem of how to make the system interpret information. An example of well known semantic frameworks is The Semantic Web[54].
Tools: most platforms provide a set of tools to provide extra functionality, such as the support for context awareness, or tools to ease the development of an application for the platform.

It is to be expected that the demand for smart-home applications will increase in the future because of the graying societies. Because the support for older people does not stop with services related to comfort and security, but also includes health, care, safety (monitoring), social inclusion, and leisure activities, a platform that integrates all these aspects is all the more important.

1.5 Fitting smart-home platforms

Fitting the technological concept of a platform with the needs of older people who wish to age in place, is the main topic of this thesis. However, there is no direct relation between platforms and the older end-user who ages in place. In this section, we will explain in what way platforms are connected to aging-in-place, what knowledge is missing in this field, and how this thesis addresses those issues.

As stated in Section 1.4, a platform is needed to support a wide range of smart-home technology, like services, applications and products. In turn, these smart-home technologies are needed to support the system's older end-user who ages in place. In other words: the smart-home technology sits between the platform and the older end-user (Figure 1.4). The relation between the older end-user and the platform is therefore not a direct one.

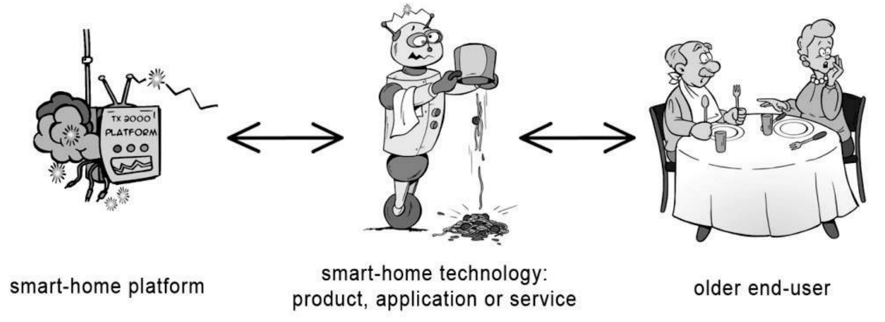


Figure 1.4: *Relation between a smart-home platform and the older end-user that ages in place: between the platform and the user is always the smart-home technology (e.g. a product, application, or service) that supports aging-in-place*

Although there is not a direct relation between the platform and the older user, the platform has a huge impact on the support the smart-home technology offers to the older user. The architecture of the platform determines what technology will be available for the user, both now and in the (near) future[55].

Because technology evolves rapidly, it is hard to determine which types of future technology should be supportable by today's platforms. One way to overcome this, is to use the needs and aspirations of the older user as the starting point for the development of a platform[56]. Although the average needs of people in a population also change in time[25], this is slow compared to the rate of technological change (Figure 1.5). Therefore it makes good sense to base the development of platforms in an aging society be on the requirements of older people, and not on the need to integrate today's technology.

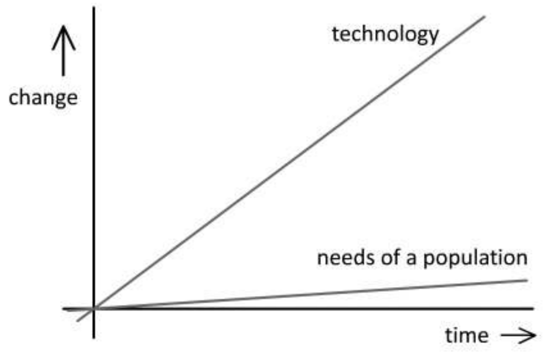


Figure 1.5: *Since technology changes fast, the change of the average needs of a population can be ignored*

However, it is not common practice to take the needs of end-users as a starting point for the development of a platform. A review on smart-homes shows that platform developers focus primarily on product design instead of end-user design. This means that they focus on technological requirements, without a clear view of what is really needed by the end-users[57]. This is reflected in the research that focuses on several types of technological solutions (e.g. peer-to-peer, universal model, integrating multiple middlewares, or web-services) across several countries (e.g. Israel, Spain, South-Korea, and Malaysia)[54,58–61].

Projects that take user needs as their starting point employ several scenarios or use cases during the development of the platform. These scenarios include specific user needs and define the requirements for the platform. However, most of these scenarios describe typical situations, are not based on empirical data, and only cover a small portion of the end-user needs. Since the performance of the developed platform is highly influenced by the scenarios that are used by the designers[62], scenarios should cover a range of end-user requirements as wide as possible.

User requirements

But what are the user requirements that a platform should meet? Are these requirements known? The research on platforms is dominated by technological issues that are addressed by engineers, and for that reason never include a comprehensive study of user needs. Younger engineers are likely to be unfamiliar with the needs and abilities of the older users of the technology they develop[63], and a database for engineers that holds information on this topic is missing[64]. Large research projects, such as European projects, claim to include the user in the design of smart-home systems. However, they often focus on a limited number of smart-home applications, resulting in a lack of a comprehensive set of user requirements. One project, the universAAL project[46], collected all user requirements from previous European projects, to arrive at a comprehensive set of user requirements. This resulted in a set of requirements which state that the universAAL platform must support a wide range of applications[65]. However, they did not specify the user requirements.

Researchers that focus on older people’s needs in relation to technology, often focus on product designs of specific applications or products. Until now, they have not translated their findings into user requirements specifically for platforms[57]. And although a number of user requirements from these researchers are directly applicable to platforms, it is unlikely that this will result in a comprehensive collection. For example, Hensel and Courtney did extensive research on older people and home telehealth technologies, but focused only on the obtrusiveness of information-based assistive technologies[66,67]. Also, Demeris did several studies on older person’s needs for smart-homes[68–70], but did not address user requirements for smart-home platforms.

Bridging the gap

In summary, a platform has a great influence on the support that a smart-home system can (or cannot) provide to the end-user. Its architecture determines which smart-home device will or will not be supported. However, today’s platforms developments exclude the users, or a complete set of user needs and requirements. The platform’s architecture is designed without the knowledge of the required smart-home devices for the end-user.

This gap − between older people’s requirements on one side, and the capabilities of smart-home platforms on the other − is hard to bridge. It is hard to specify a comprehensive set of end-user requirements for platforms. Firstly, the needs of older end-users are very broad and change over time[25,71–73], which makes it hard to specify all user requirements in detail. A less concrete method could be used instead, such as the use of a comprehensive set of scenarios or use-cases. Secondly, since the smart-home technology is always between the user and the platform, a set of end-user requirements will consist of a collection of smart-home devices that should be supported. However, the number of devices in this collection will be both quite large and change fast over time. To overcome this, rather than using a set of requirements, testing methods should be available to assess platforms at an early stage of their design and development. However, neither a method to generate a comprehensive set of scenarios, nor a platform assessment method exist. Therefore the gap between end-users and platforms remains.

In this thesis, we try to bridge the gap. We will focus on the end-user, and get an understanding of his or her limitations and needs. Starting with theory, we will develop a comprehensive set of scenarios that capture the user requirements. We will also focus on the technology. The resulting method spans the gap to allow for assessment of platforms for their suitability to support the end-user's needs. In addition, we will put two platforms up to the test.

The following questions are addressed:

- From a technological point of view, why does the need for a platform to support aging-in-place arise?
- Does the older person who ages in place benefit from the usage of a platform in his/her smart-home? Is a platform, apart from solving a technological problem, also required to support older persons at home?
- And, if the user benefits, what is expected from that platform now and into the future that makes it suitable for aging-in-place? What are the functionalities that should be supported?
- How can we assess platforms for their suitability for aging-in-place, and how well do state-of-the-art platforms perform?

1.6 Goals and objectives

Our main goal is to guide platform development towards successful aging-in-place, by providing knowledge, methodologies, and tools.

The subsequent chapters are organized as follows (Figure 1.6):

- In chapter 2 we explain the need for a platform to match technologies of various disciplines to support aging-in-place
- In chapter 3, we will focus on the need for smart-home platforms from the end-user's viewpoint. Smart-home projects will be reviewed and Maslow's deficiency-needs will be used to assess the need for integration.
- In the chapter 4 we will define the needs of older people who want to age in place, by introducing a method to generate health-based scenarios.
- In chapter 5, we use health-based scenarios to evaluate smart-home platforms for aging-in-place. We introduce a method to test platforms for their support during aging-in-place scenarios and assess two platforms on their suitability for aging-in-place, now and in the future.
- Chapter 6 consists of a general discussion of the results of chapter 2 to 5. We will draw conclusions, point out issues that must be addressed in future research, and discuss the practical implementations of the results.

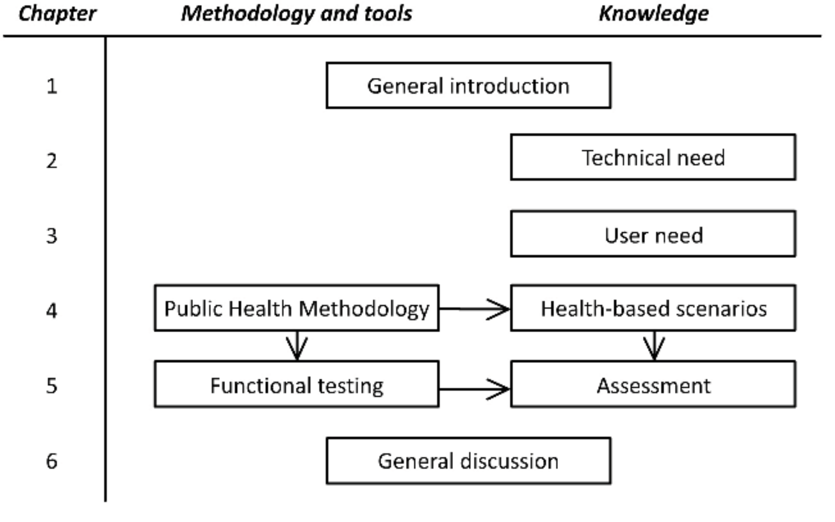


Figure 1.6: *Organization of this thesis. In the next six chapters we will provide knowledge, methodologies, and tools in order to guide platform development towards successful aging-in-place*

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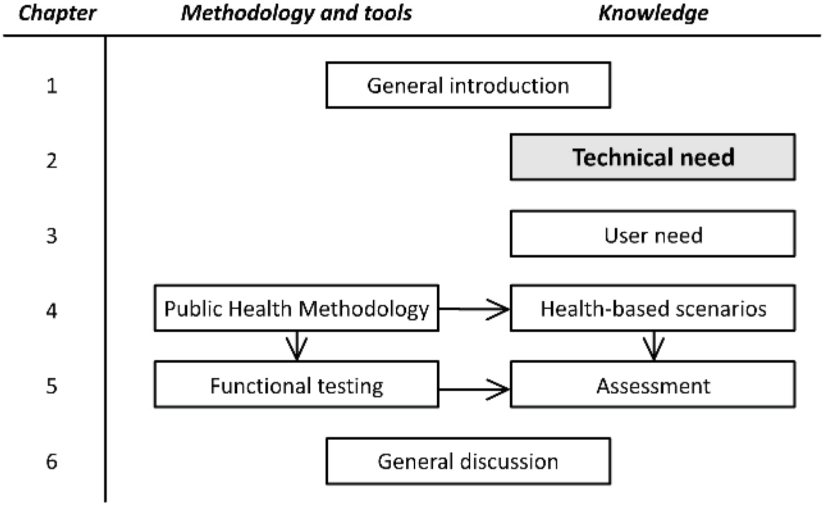
Chapter 2: Technology needs a platform



This chapter addresses technology to support older people. We will show that most of these technologies are operating stand-alone. Multiple stand-alone devices in one home might lead to conflicts, hampering efficient operation. From a technological point of view, an intelligent ICT network is needed to support a wide range of smart-home technologies to assist older people who age-in-place.

Matching technologies of home automation, robotics, assistance, geriatric telecare and telemedicine*

Francesco Franchimon PhD
Michiel Brink MSc

Abstract

The aging society could have a greater societal impact than the current financial crisis. The percentage of older adults has increased while the size of the health care workforce has remained constant. Home automation, robotics, assistive technology, geriatric telecare and telemedicine can support independence in older adults and diminish the health care burden. Currently, delivering services through these technologies is accomplished mainly through stand-alone systems. Multiple stand-alone systems in one dwelling become a multidisciplinary technological challenge of risks and benefits. Ideally, only those technology mediated services requested at a particular moment should be provided. This calls for a reduction in the barriers between healthcare and technology disciplines and an intelligent network using software agents supporting optimal integration and interoperability to increase the quality of life of older adults and decrease the healthcare burden in our aging society.

Key words: interoperability, intelligent networks, plug-and-play

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* This text has been published earlier in Gerontechnology 2009; 8(2):88-93; doi: 10.4017/gt.2009.08.02.007.00; reprinted with permission

Buckheit[1] has suggested that the impact of the ageing society could be of greater concern than the current financial crisis. The ratio of persons 65+ years of age to the labour force (15-64 years) will rise from 25% in 2005 to 31% in 2020 and further increase to 52% in 2050[2]. Since the absolute number of registered nurses is expected to remain constant[3], an enormous pressure on the health care sector will result. Most gerontechnologies are developed for functional compensation and assistance to ease the burden on the care sector[4].

In this study we address home automation[5], robotics[6], assistive technology[7], geriatric telecare and telemedicine8 (Table 2.1). These technologies have long histories of use supporting the aging society by improving the quality of life of older persons through ICT (Information and Communication Technology)[5–8]. More than ten years ago Healy[9] argued that ICT would change health care, even then telematics was found to be cost effective in terms of time, money, quality and accessibility.

Table 2.1: *Definitions of different technologies that are able to support older adults*

Technology	Definition	Source
Home automation (smart home, domotics)	A field within building automation, specializing in the specific automation requirements of private homes and in the application of automation techniques for the comfort and security of its residents	10
Robotics	Includes intelligent machines and systems used, for example, in space exploration, human services, or manufacturing	11
Assistive technology	Technology to improve quality of life in case of impairment or disability	12
(Geriatric) telecare & telemedicine	'Medicine practised at a distance'; it encompasses diagnosis, treatment, and medical education	13

Currently, most home automation, robotics, assistive technology, geriatric telecare, and telemedicine systems are stand-alone, having no operational dependencies on other systems. These technologies have individual taxonomies, methods, protocols and standards that may not integrate easily. Nevertheless, there exists a huge conceptual overlap between the intended functionality of apparently similar systems. For example, tracking people with ultra wideband (UWB) sensors inside

their home to detect wandering could secondarily serve to control entrance and exiting through doorways[14].
Technological integration is desirable to provide higher quality support at a lower cost for the changing needs of the individual elder across time. In this contribution we propose an integrated technological environment to maintain vitality of older adults, and lessen the burden on health care professionals.

Needs and functionalities

The first step to tighter integration is identifying the needs of users to define the functionalities required. Individual needs are studied in the gerontology disciplines (physiology & nutrition, (social) psychology, social demography, and medicine & rehabilitation) and are diverse in nature, ranging from health & self esteem to housing & daily living, mobility & transport, communication & governance and work & leisure[15]. The Functional Independence Measure[16,17], the Barthel and Katz indices for Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL)[18,19], the SF-12[20] and the Loneliness scale[21] are helpful for identifying many needs of older people. Maslow's hierarchy of needs is a useful guide for engineers in the design process[22,23]. These theoretical constructs and instruments applied to the study of the needs of each individual user will yield different outcomes over time as the person ages.

Translation of these needs into the complementary functionalities provided by gerontechnologies constitutes the field of engineering which aims to improve the quality of life[4], through life enrichment & satisfaction, prevention & engagement, compensation & assistance, or care support & care organization[15].

Existing classification systems are helpful in cases of compensation, assistance, substitution or care. Individual capabilities are addressed in the International Classification of Functioning, Disability and Health (ICF)[24] and technical aids are well presented in ISO 9999[25]. However, none of these classification methods capture all of the individual deficit needs defined by Maslow. They represent a first attempt to guide the collaborations of gerontologists and engineers through the use of common taxonomies and lexicons.

Stand-alone

Most technologies are developed to operate as stand-alone systems. This design choice is commonly made in anticipation of adverse impacts of dependencies with other systems. Today multiple stand-alone systems for home automation, robotics, assistive technology, geriatric telecare and telemedicine may be found in a single home environment (Table 2.2). This is cumbersome to the user and is an inefficient use of resources.

Table 2.2: *Examples of typical stand-alone technologies for home automation, robotics, assistive products, geriatric telecare, and telemedicine in relation to their goal and application domain*

		Application domain				
		Health Self-esteem	Housing Daily living	Mobility Transport	Communica-tion Governance	Work Leisure
Main goal	Enrichment Satisfaction	- Nike+©	- Intelligent thermostat	- Movable steering-wheel[26]	- Assistive social robot[27]	- Wii-fit©
	Prevention Engagement	- Ventilation[28]	- Ventilation[28]	- Low boarding-step busses	- Cellular phone	- Home trainer - Wii-fit©
	Compensation Substitution	- Home robot	- Toilet for disabled person	- Segway© - Wheelchair	- Wireless phone	- Hearing aid
	Care support Care organization	- Telesession with physician	- Entry control	- Public transport for disabled	- Personal alarm - Video phone	- Sporting heart rhythm monitor

Multiple stand alone systems force the user to learn to manage a number of different devices and services requiring mastery of multiple user interfaces: different ways of signaling the user (sound signal, text message, graphic user interface), and different control interfaces (buttons and menu structure, touch screen or just one on/off switch). Older people often have problems mastering a multitude of interfaces[29] which may increase feelings of anxiety and even hostility towards new technologies[30].

Since user needs are usually multiple, differ from person to person and change over time, a static system cannot by definition fulfill them. For example, an ICT network capable of hosting most stand-alone applications (Table 2.2) also needs to be extensible to new, not yet invented applications.

Sharing resources

Another disadvantage of multiple standalone systems is the limited use of resources offered by other systems. Information and hardware are not shared, yet sharing information leads to better informed decisions[31,32]. For instance, after observing that a dwelling occupant has an irregular heart rhythm, the telemedicine system might issue an order to the home automation system to unlock the door so emergency service personnel may enter the dwelling. This is hard to realize with stand-alone systems which lack integration.

Besides information, systems may also share hardware components (sensors, processing power, etc.) of other systems. This avoids superfluous hardware components and capitalizes on economies of scale. For instance, only one movement detector needs to be installed in an area for both the automatic lighting and the burglar alarm system.

To guarantee reliability, however, redundant components can be included. As an example: systems that need internet connectivity, can also be equipped with a Universal Mobile Telecommunications System connection (UMTS), currently used in mobile phones, to use when the internet connection is down. When the redundant UMTS system is shared by all systems requiring internet services, only a single UMTS device is needed.

The disadvantages of stand-alone systems could be solved by connecting all applications to a centralized host containing all required intelligence, leaving the stand-alone systems devoid of smartness. Although information and hardware are shared, failure of the centralized host means the loss of all functionalities. Thus centralized systems may lack the robustness needed for real life applications.

A system having distributed intelligence, akin to stand-alone systems, but with the ability to share information and hardware components, as in centralized systems, is therefore desirable.

Multidisciplinarity

Integration of technologies implies careful attention to their multidisciplinarity. All technological disciplines have evolved their own vocabularies, methods, protocols and standards. Experience has shown that without a set of well defined standards and protocols, problems of technology integration are to be expected. For example, interoperability of home automation and telemedicine systems has not been successful because of the lack of a standard communication language[33]. The rapid evolution of the ICT disciplines opens a way to diminish the barriers between applications, by designing an intelligent heterogeneous ICT network able to cope with technology differences and hosting distributed intelligent systems supporting the technologies required.

Integration

Kearns & Fozard[34] reported two rapid technological changes in the last decade that make advantageous integration possible: (i) an increase in network speed and bandwidth (ii) the evolution of computational devices as embedded systems in the built environment.

In addition, the 7th Framework R&D Programme of the European Community, includes a thematic activity on ICT & Aging (FP7 ICT-2009.7.1) with a target 'Open Systems Reference Architectures, Standards and ICT Platforms for Ageing Well'[35]. One of the participating projects, OASIS[36], seeks to achieve better integration by providing a platform which is open, modular, holistic, easy to use and standards compliant. In the previous Framework Programme (FP6), this topic was addressed in the Information Society Technology area, and one of the supported research activities in this area was the 'Amigo' project[37], that aimed at integrating technologies by following the Service Orientation Architecture paradigm, in which software developed as services are delivered and consumed on demand. Several research projects in different technologies have used software agents (task-performing software components that are autonomous, not requiring other software components)[38], in home automation[39–41] and in telemedicine[42,43].

Applying this new knowledge to a home environment for 'Aging-in-Place', leads to the notion of an intelligent ICT network. All devices of older stand-alone systems (e.g. sensors and user interfaces) are equipped with intelligent software agents (ISA) that perform tasks autonomously to satisfy user needs by monitoring the status of and controlling the device and attempting to make the appropriate decisions based on artificial intelligence algorithms. As an example, a television equipped with such an agent would optimize the screen settings, check all channels and decides to switch to the DVD-channel when a DVD is inserted in the DVD player. Because the ISAs are connected through a network, they are able to communicate and mediate with each other. By sharing information and issuing each other orders, the multiple agents cooperate as a system and integrate each other's functionalities. In the example of the television, the home automation sensor agents will be aware that all occupants have left the dwelling, so the television can switch itself off.

Distributed intelligence

Multiple software agents in the network result in one form of distributed intelligence. This increases robustness by avoiding the need for an intelligent central host. Functional interdependencies are handled by a Service Orientated Architecture (SOA) as validated in the Amigo project: all functions are defined as services[33]. In this scheme, agents offer one or more services to users or to other agents. The communication protocol used by the software agents should be, as far as possible, independent of the technological discipline governing the development of the agents' devices, or types of devices supervised by the agents. Furthermore, the networks chosen are heterogeneous and support multiple communication protocols, since a uniform standard or protocol for home automation, robotics, assistive technologies, geriatric telecare and telemedicine does not exist. Software agents so designed constitute the universal interface between different devices, systems, entities and technologies.

To account for temporally changing needs, the agent network supports intelligent plug and play. After connecting a new device to the network, the agent of the device will automatically detect other agents, configure itself and commence its operation, as has been demonstrated by Universal Plug and Play (UPnP)[37,44–46].

Conclusion

Matching technologies of home automation, robotics, assistance, geriatric telecare and telemedicine is required for assuring an optimal quality of life in our aging society. The complexity of combining technologies from different disciplines while taking into account the variety of individual user needs that evolve over time, demands integration with an intelligent ICT network. The ideal network should be based on existing technology: intelligent software agents, fully distributed intelligence, SOA, UPnP, and should support multiple standards and protocols. Development of such a system is currently in the simulation phase to be followed by testing in a housing project[41]. This approach combines functionalities and applications from different technologies to perform more effectively in providing the best environment for aging individuals, while reducing the burden of care.

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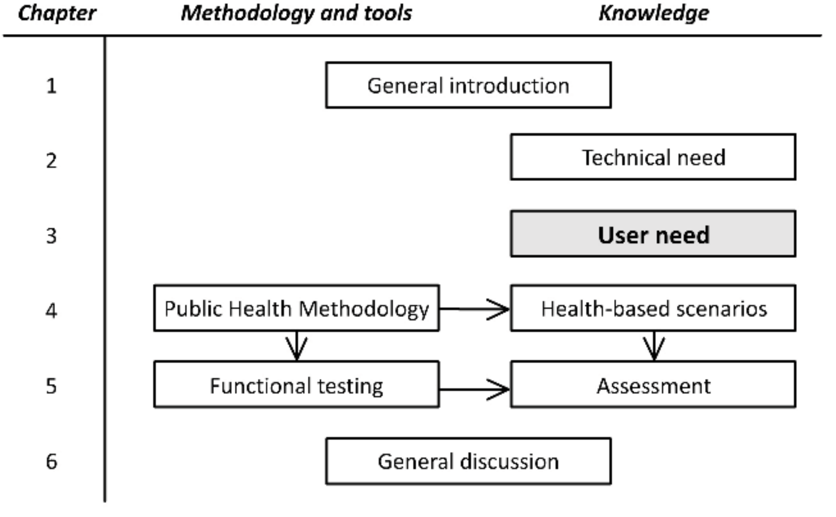
Chapter 3: The user needs a platform



In Chapter 2 we explained that from a technological point of view an intelligent ICT network or technological platform is needed to support a wide range of smart-home technology, like services, applications, and products. But does the older person who ages-in-place benefit from the use of a platform in his/her smart-home? Or is a platform only required for solving a technological problem? And if the user benefits, what can be expected from that platform now and into the future for it to be suitable for aging-in-place?

In this chapter we evaluate current ICT systems for aging-in-place and gerontology theories. The results show that systems that are integrated (through a platform) support higher levels of deficiency needs (Maslow), are more dynamic, and are better suitable for large-scale introduction of aging-in-place.

Addressing Maslow's deficiency-needs in smart homes*

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Abstract
Modern smart homes contain elements from different technical disciplines, such as home automation, robotics, and tele-heath. We investigated to which extent smart-home systems address the different levels of deficiency needs of Maslow, and the corresponding level of integration of smarthome systems. Reports published between 1993 and 2010 concerned 28 prototypes or concepts, which have been analyzed. Functionalities that are supported by these smarthome systems are not equally distributed over the deficiency-needs levels of Maslow. The focus is on the two lower levels (physiology and safety), while preventing end-users to install and adapt the system (an esteem-related deficiency). Among the minority of fully integrated smart-home systems the highest level of deficiency needs (self-actualization) was addressed in 4 projects, with half of them also allowing the end-user to be master of installation and adaptation to changing needs in time. Fully integrated smart-home systems have so far not made it onto the market. The Maslow hierarchy of deficiency needs may act as a guide to developers and marketers to make sure that relevant needs are addressed effectively, and no new deficiencies are introduced.

Keywords: smart home, user needs, Maslow, aging-in-place

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Introduction

In their review of the different elements of smart homes, Franchimon & Brink[1] state that matching of existing technologies of home automation, robotics, assistance, tele-health (including geriatric telecare and telemedicine) is required to assure an optimal quality of life in our aging society. However, the roll-out of smart homes leaves much to be desired. Besides technology issues to be solved, business models are lacking to remove vendor locks, and to combine with other types of business (health care, entertainment, security, etc.)[2–4].

Even more important is the discrepancy between user needs and offered functionalities[5]. Earlier, Maslow's[6] hierarchy of deficiency needs was proposed as a framework for catching user values in design and development of technologies for a longer vital life[7].

Maslow[6] identified consecutive layers of deficiencies in needs of human subjects: (i) physiological, (ii) safety related, (iii) concerning a sense of love and belonging, (iv) esteem related, and (v) room for self-fulfillment or self-actualization. The more basic physiological needs (such as breathing, eating, walking) have to be fulfilled before the higher deficiencies (such as social and safety needs) start to matter.

Smart home elements may not only address the needs of daily life directly, they may also become sources of new need deficiencies, such as loss of mastery over one's own situation (esteem related). Since older adults generally do not wish to have technologies in their homes before they need them, the smart-home systems must have a large degree of adaptability with different functionalities activated at different times[8].

Although all levels of needs are neither age- nor culture dependent, their diversity increases with age and varies among cultures[8,9]. In addition, the variation in individual demands broadens as one goes from the basic to the higher deficiencies to be supported[7]. Both progressed age and support of higher-level deficiencies call for a broadening of the range of ICT (Information and Communication Technology) supports to guarantee wellbeing.

Smart-home initiatives, such as related to Ambient Assisted Living (AAL), specifically aim at improving the well-being of older people by using relevant ICT-innovations. Aim of this study is to elucidate the coverage of end-user needs by published complete smart-home systems in development.

Methodology

Project selection

Our sample of running smart-home projects to be analyzed, originates from reports published between 1990 and 2010. We used 'home automation' and 'smart home' as keywords in Web-of-Knowledge[10], Science Direct[11], Google Scholar[12], and the database of European Research Projects[13]. Initially this resulted in 900 publications. The following inclusion criteria were applied in a second step of selection: (i) the system had been implemented; (ii) it contained system-integration software (for instance, middleware), and (iii) it was described in detail. A total of 28 smart-home prototypes or concepts, described between 1993 and 2010, remained, and were described in 39 publications originating from Asia, Europe, North America, and Oceania.

User-needs analysis

For each selected project, we extracted included functionalities and classified them by Maslow's hierarchy of deficiency needs. Functionalities that serve a physiological aim like tele-care, physical health (monitoring), or food preparation, are categorized in the lowest, physiological layer of deficiency needs.

The second layer (safety) includes functionalities to improve safety or security, such as fall detection and activity monitoring. Although 'weather forecast' does also have an entertainment component we chose to consider it as a form of safety, since weather conditions may be unsafe for older persons[14].

The third layer (social) covers functionalities that support social activities or interactions.

Cognitive training and energy saving are both included in the fourth layer (esteem). Although these functionalities, especially energy saving[15], also relate to other layers, the main intended result of both is a higher level of self-esteem. In addition,

Table 3.1: *End-user needs addressed by published multifunctional ICT-systems for aging-in-place, as sorted by need-deficiency level according to Maslow*[6]

Need deficiency level	**Specific needs addressed**
Physiology	Activity coach[17,18]
	Activity level monitoring[17,19–34]
	Blinds, curtain and window control[19,21,30,32,35–37]
	Blood glucose, oxygenation, and pressure monitoring[18,21,26,38,39]
	Body movement, temperature and weight monitoring[17,24–26,34,38–40]
	Food supply monitoring[41]
	HVAC control[17,35,36,42–44]
	Heart rate monitoring[17,26,34,39,45–47]
	Kitchen use, meal reminding[19–21,29,32,33,45,48]
	Medication use & reminding[19,21–23,27–32,40,48]
	Nutrition advisor[17,27,28]
	Personal hygiene assistant[40]
	Remote access to monitored data[19,24,25,32]
	Remote (snail)mailbox checker[40]
	Remote rehabilitation[22,23,27,28]
	Respiration rate monitoring[39,45]
	Shopping assistant[27,28]
	Sleeping pattern[19,22,23,32,40]
	Sweating monitoring[39]
	Tele-care[18,49]
	Toilet use monitoring[48]
Safety	Activity detection[17,20–23,26–31,33,34,37,39,43–47,50,51]
	Alarms (burglary, fire, smoke, community)[19–21,26,29–31,33,39–41,46,47,49,52,53]
	Automatic lighting, lighting control[17,19,21,32,35–37,42,43,52–54]
	Bath and cooker monitoring[21,54]
	Control of oven, microwave, washing machine[40,41]
	Door camera[42]
	Fall detection[17,21,27,28,30,31,39,49]
	Flooding detection[24,25,29,40,41]
	Home-access control[21–23,27,28,40,49]
	Memory support, including item localization[26,54]
	Panic button[22,23,27,28,30,31,43,49]
	Person identification[39]
	Pressure sensors (bed, chairs, floor)[30,31,34,39,45–48]
	Room occupancy monitoring[19,21,24,25,32,39,44,48]
	Room-temperature monitoring[20,24,25,30,31,33,38,39,46,47,50,51]
	Security cameras[19,32]
	Weather forecast[21]

Table 3.1 (continued): *End-user needs addressed by published multifunctional ICT-systems for aging-in-place, as sorted by need-deficiency level according to Maslow*[6]

Need deficiency level	Specific needs addressed
Social relations	Activity reminder[19,26,32,35,36] Distant dining[40] Group cooking[21] Internet access[21–23,30,31,49–51] Message service[24,25] Photo viewer[42] Reminding services[21–25,27,28,35,36,40–43] Social media[17,21,26] Tele-consulting[27,28] Videophone[21,27,28] VoIP calls[38]
Esteem related	Cognitive training[17,24,25,40] Energy saving[35,36,52,53]
Self-actualization	Entertainment, including multimedia[21–23,35,36,38,40,52,53]

being master over the system is esteem-related. Two aspects of this mastery could be found in the descriptions of the systems: end-user installation and end-user adaptation.

Entertainment and multimedia are both leisure activities and for that reason mapped to the highest level of needs[7].

System-integration analysis

Based on the Intelligent-Building Pyramid introduced by Wang[16], we defined four levels of system integration:

I. Stand-alone: a system with a functionality that does not communicate with the outside world or other applications in the home (for instance, a motion sensor wired to a local alarm);
II. Tele-devices: systems that communicate with the outside world but do not require additional devices (for instance, a panic button);
III. Interconnected: the system has multiple functionalities; applications that provide these functionalities require additional applications for optimal

performance of the system as a whole (for instance, a home automation system that controls both heating and lighting); and

IV. Fully integrated: a system that includes all functionalities in the home (prototypes using a universal platform).

Results

All levels of deficiency needs are addressed in smart-home prototypes and concepts, but emphasis lies on the lower levels of deficiency needs, with 21 applications pertaining to physiological needs, 17 concerning safety and security, 11 addressing social relations, 2 related to esteem, and only 1 covering self-actualization (Table 3.1).

Looking at individual smart-home projects reveals that about half (15 of 28) are restricted to the lower deficiency needs dictated by physiology and safety. Among them are projects on all levels of system integration. Only in one case (Smart House Osaka) is the end-user master over the adaptation of the system (Table 3.2).

Interconnected smart home systems are most common in our sample of prototypes and concepts (15 of 28). They are dominant in the support of the lower levels of deficiency needs (9 of 15), but also support social relations (5 of 15), esteem related issues (2, but with no or doubtful support of end-user installation or adaptation), and self-actualization needs (2, but without support of end-user installation or adaptation) (Table 3.2).

One of the interconnected systems, MPOWER that allows for support of the four lower Maslow levels, claims easy installation and adaptability by the end-user. However, this could not be supported by the specifications of the system architecture[24,25].

None of the 28 prototypes or concepts allows for supportive functionalities on all levels of deficiency needs, but all of them include some physiological and safety needs. When the highest and most complicated level (self-actualization) is included (6 cases), the majority (4 cases) are fully integrated systems. Only in case of fully integrated systems is the end-user master over the system and may install or adapt it at will (Table 3.2).

Table 3.2: *Addressed levels of Maslow's need deficiencies[6], and system integration of smart-home prototypes and concepts published between 1990 and 2010, and sorted by year of publication; x=at least one item addressed in the stated category; ±=presumably; ?=data missing*

Need deficiency level					End-user maintenance option		System integration	Reference
Physiology	Safety	Social relations	Esteem related	Self-actualization	Install	Adapt		
x					No	No	Inter-connected	1994:Monitoring House[50,51]
x	x				No	No	Stand alone	1995:PROSAVE[44]
x	x				No	No	Inter-connected	1995:SmartBo[37]
x	x				±No	No	Inter-connected	1998:CareNet[39]
x	x				?	Yes	Fully integrated	1999:Smart House Osaka[34]
x	x				No	No	Inter-connected	2000:ADL/IADL House[48]
x	x				No	No	Tele-device	2000:Intelligent Monitoring[20,33]
	x				No	No	Inter-connected	2001:Gloucester's Smart House[54]
x	x	x			±No	No	Inter-connected	2001:Elite CARE (2001)[43]
x	x	x			±No	No	Inter-connected	2001:Millennium Home[30,31]
x	x				No	No	Inter-connected	2003:Tiger Place[45]
x	x				No	No	Fully integrated	2003:ExperTel[49]
x	x				No	No	Fully integrated	2003:ILSA[19,32]
	x		x	x	Yes	Yes	Fully integrated	2004:eHOME[52,53]
x	x	x		x	No	Yes	Fully integrated	2005:Gator Tech Smart House[40]
x	x	x			No	No	Inter-connected	2006:I-Living[26]
x	x		x	x	No	No	Inter-connected	2006:MavHome[35,36]
x	x	x		x	Yes	Yes	Fully integrated	2006:MONAMI[21]
x					±No	No	Tele-device	2007:SENSACTION-AAL[18]
x	x				?	No	Inter-connected	2007:EASY-LINE+[41]
x	x	x			Yes	Yes	Fully integrated	2007:PERSONA[27,28]
x	x				No	No	Inter-connected	2008:AlarmNet[46,47]
x	x	x			±No	±No	Inter-connected	2008:I2HOME[42]
x	x	x	x		±Yes	±Yes	Inter-connected	2008:MPOWER[24,25]
x	x	x	x		±Yes	Yes	Fully integrated	2008:OASIS[17]
x		x		x	No	No	Inter-connected	2008:OLDES[38]
x	x				No	No	Inter-connected	2009:AT EASE[29]
x	x	x		x	No	No	Fully integrated	2009:SOPRANO[22,23]

Discussion

Our results show that all deficiency-need classes of Maslow may be addressed by modern smart home elements, but none of the smart-home systems analyzed extend over all classes of personal and environmental deficiencies. Most systems in our sample introduce additional esteem-related problems by not allowing the end-user to easily install or adapt the system.

The ‘e-Home’ system and ‘Gloucester’s Smart-House’ support higher levels of needs, but leaves out the most basic ones (Table 3.2). We expect that these omissions will hamper a massive roll-out of smart homes that aim to support aging-in-place. But still, most smart-home applications focus on the lower levels of deficiency needs. This has to be expected since these lower levels have to be fulfilled before the higher levels start to matter.

For a full support of aging-in-place the higher levels have to be included. This, however, is more complex. For example, a virtual dress-couch that helps you to choose your clothes might improve your confidence (self-esteem), but needs an extensive database and sensor system of life style, mood, weather conditions, and requirements for the occasion. In addition, the variation in personal needs among adults tends to increase with age[7].

In our sample of 28 smart-home prototypes and concepts it was not possible to assess operational reliability (safety level), easy maintenance (esteem level), and affordability[2]. Future research on smart-home systems should include tests and reports on these technology-related barriers. Another weak point of our analysis is the general nature of Maslow’s classification. The actual acceptance of a specific technology depends on the support of specific needs by specific characteristics of the technology, rather than the support of needs in general[55]. Maslow’s hierarchy remains, however, useful as a first global assessment. It can be considered as a guide to make sure that no group of needs is forgotten and no new deficiencies in needs are introduced.

Systems adapted to the highest deficiency-need classes generally show the highest level of system integration. They commonly allow the end-user to install and adapt his or her smart home without the intervention of a technician. This way the user may freely choose and change the functionality of the system by implementing or removing certain applications, as soon as new needs arise or old ones loose value. Apparently a high level of system integration is not only needed from a technological point of view[1], but also to strengthen the user value of smart-home systems.

Although fully integrated systems could have the best performance in theory, there are a number of challenges to overcome. Most research projects result in proof-of-concept, but these concepts are rarely developed further or entered the market[2].

The domain of smart homes develops fast. The universAAL project and AALOA (Ambient Assisted Living Open Association), two initiatives supported by the European commission and started after 2010, have taken promising steps by aiming to design, develop, evaluate, standardize, and maintain a common service platform for Ambient Assisted Living[56,57], but the implementation of support at all levels of human deficiency needs has not been included in these initiatives. In addition, a recent review stresses the understanding of end-user needs to develop effective and efficient smart-homes, but does not propose a tool or theory to implement this in design and development[3].

Besides Maslow's theory of motivation, there are numerous alternative theories that can be useful for the design and development of aging-in-place technology, like Max-Neef's theory of Fundamental human needs[58]. Although Maslow's theory is criticized (especially little evidence is found on the ranking system[59]), we used this theory in this study since it is best known, easy to use, and therefore still popular. Other theories are often more complex, which form a barrier for engineers to use the theory during the development of a product.

The Maslow hierarchy may act as a guide to developers and marketeers to address all levels of human deficiency needs. The resulting total user value may ease integration and market introduction of smart homes for aging in place.

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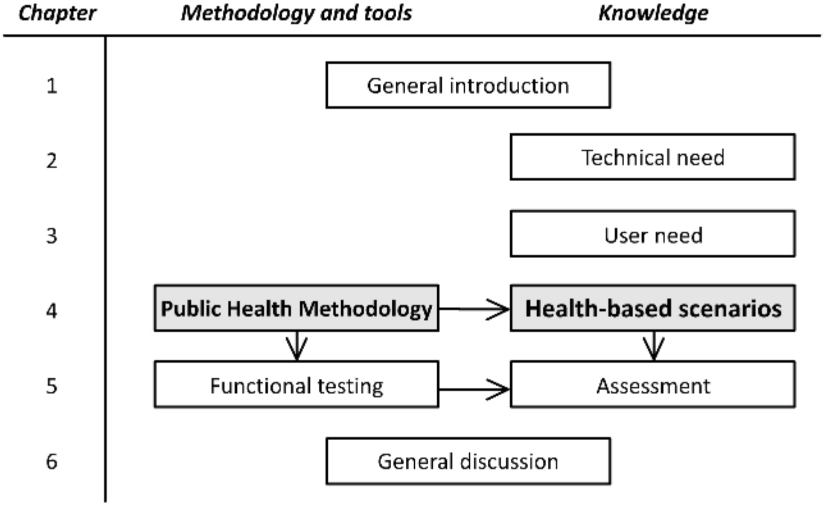
Chapter 4: Generating health-based scenarios



In this chapter we present a theoretically basis to define the wide range of user requirements. We used health-profiles to define the target population's health condition, and we used the ICF-framework (International Classification of Functioning, Disability and Health) to derive the limitations that are related to these health conditions. Together with the activities that older people perform in their homes, we give a complete overview of the support older people might need at home. In order to make these usable for design, we propose to create scenarios that capture most requirements.

Public health resources for smart-home scenario development: A methodological approach*

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Abstract

Scenarios are in use as tools during the development of smart home platforms and middleware for aging-in-place. In order to be effective, a set of scenarios that address all required functionalities are needed. Medical tools, such as WHO's International Classification of Functioning, Disability and Health (ICF) and local health profiles, characterize the majority of the aging population and with it the requirements for smart-homes, but have not yet been used in scenario development for smart-homes. In this study we develop a Public Health Methodology (PHM) in which we use public health resources for the generation of scenarios. Specific user characteristics are taken from the medical tools, while common daily user activities were supplied by research into common activities as practiced by Dutch end-users. A functional scenario is generated by combining the user characteristics and user activities with the product goal, physical and non-physical environment, and product to be developed. Using this method a complete set of 10 scenarios was created and used in virtual tests for the validation of smart-home platforms. PHM is a promising tool in the development of smart environments that should be quickly adopted by the aging population.

Keywords: scenarios, health profiles, ICF, daily activities, public health engineering, aging-in-place, Ambient Assisted Living (AAL)

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Introduction

To fully utilize the potential of smart-homes for Ambient Assisted Living (AAL), numerous human restrictions that develop as one ages will need compensation[1]. Since younger designers of smart-homes may be unfamiliar with restrictions and abilities of older end-users[2], scenarios can be a tool to help them understand these restrictions. Scenarios are hypothetical but concrete descriptions of the practical use of a product and are used for the design and validation of products[3]. They guide the design task and serve as a communication tool for the design team.

The following six so-called scenario elements, defined by Angreeni and Van der Voort, are commonly present in a useful scenario[4,5]:

- User (and his/her characteristics);
- User activities and likely events;
- Target product use;
- Physical setting (where the scenario takes place);
- Non-physical or non-tangible setting (e.g. time-pressure); and
- Product to be developed

The development of platforms and middleware for smart-home and Ambient Intelligence (AmI) has gained more interest lately, since the lack of interoperability amongst heterogeneous smart-home components is a major challenge[6–9]. Franchimon and Brink state that for successful aging-in-place, integration of heterogeneous technologies is required[10]. Furthermore, an analysis of older people's needs using Maslow's hierarchy of needs[11] reveals the necessity for integration of technologies to support the broad range of older people's needs[12]
However, developers have currently not enough money and time available to generate a complete set of scenarios that address all functionalities of a smart-home system[13]. Using an incomplete set of scenarios might result in a product that falls short of the expected functionality or reliability[4].

Different public health resources that are freely available provide a complete set of information on user characteristics, but have not been used yet in scenario development for smart homes. The World Health Organization developed the ICF (International Classification of Functioning, Disability and Health) as a medical tool to specify the implications of diseases and disorders[14,15]. In addition, a number of local bodies published so called Health Profiles that specify common disease patterns in a population that cover the majority of the aging population[16,17]. These resources form a complete characterization of the 'user' in smart homes for aging-in place.

Public-health engineering placed health central in the design of built environments[18], and this should include smart homes. Of the health functions of buildings, namely preserving health, supporting health care and supporting people in everyday activity[19], we chose the last one for our study. The better daily life activities are supported, the longer chronic care can be postponed.

Smart-homes and AmI have the potential to fulfill these needs for aging-in-place. Large scale research programs such as AAL aim to develop services and products to support aging-in-place[20].

The aim of this study is to develop a method, named PHM (Public Health Methodology), for creating a complete set of scenarios for aging-in-place using freely available public health resources. The focus will be on Dutch older adults, but since health profiles of the population are also available from other regions, PHM can easily be geographically adapted.

PHM will be based on a matrix of the scenario elements 'user' and 'user activities'. The element 'user activities' has been limited to daily activities. The scenario element 'goal concerning the product use' will be geared towards compensation and assistance only. This excludes scenarios that focus on enrichment, prevention, or care[21]. Interventions to support the older end-user are restricted to those that are performed by the product only, without any human support. The scenario element 'physical setting' is limited to the home environment. By adding the remaining scenario-elements (such as the product functionalities) and specifying all elements in detail, developers should be able to generate a complete set of scenarios.

In the next section an overview of the proposed PHM is presented and related work is addressed. Subsequently a section is devoted to the data that has been collected for PHM. This is followed by an explanation of PHM and its usage. Then PHM is used to generate 10 scenarios, followed by conclusions and recommendations for future work in this area (last section). PHM steps are presented in Figure 4.1.

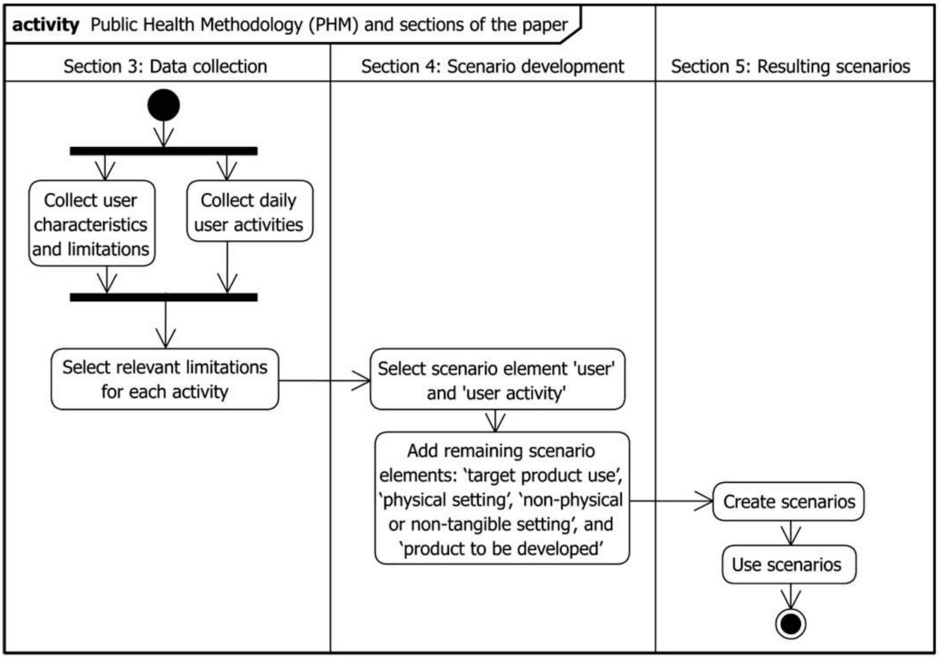

Figure 4.1: *Activity diagram for generating scenarios for assistance with daily activities, including an example (transport a cooking pot with spaghetti from the kitchen to the dining table)*

Related work

Scenario usage

The usage of scenarios is popular in the field of AmI and AAL systems. Scenarios are useful in several aspects of the design process: during the exploration and orientation phase, for the assessment of requirements, for conceptual and detailed design, and for the validation of the design[3].

Scenario development varies and depends on the scope of the scenario usage and available resources. For example, Ikonen et al. describes the generation and usage of scenarios during the MIMOSA project[22]. Scenarios were created by a number of steps that involved discussions, workshops and focus groups with all stakeholders. Müller et al. describes the development of scenarios for the SOPRANO project[23] that was based on focus groups sessions with end-users. Röcker et al.[24] explains that in the AMIGO project, scenarios were initially based on the capabilities of the AMIGO systems and were improved based on evaluations by end-users. Strömberg et al. created scenarios with role-play and discussions with end-users[25], while Lyons et al. proposes to apply use cases to test smart-homes for their interaction with humans[13]. However, none of these approaches were complete as to the support needed for aging in place.

AmI and AAL employ both scenarios as well as use cases. Where scenarios focus on end-users and their behavior, use cases focus on an interaction between the actor (might be non-human) and a system[26]. Since we view the problem from the end-user side, we chose to work with scenarios.

Generating scenarios

Carroll et al.[27] described seven general methods to generate scenarios. According to this last author, scenarios can be generated by:

a. Ethnographic field studies in which scenarios are based on observations of real users;
b. Participatory design, in which interviews, discussions, and focus groups with real users are used;
c. The reuse of prior analyses, scenarios, or knowledge regarding the use of a product;
d. Typical usage of the product that is developed;
e. A theory-based approach, with theories on human activity used as a basis for the scenarios;
f. A technology-based approach, in which a scenario follows from the use of a new technology; and
g. By transformation of an existing scenario, e.g. changing scenario's components.

From these methods, AmI developers often use the first two (ethnographic field studies and participatory design), as shown by Bonino and Corno[28]. Involving end-users to create scenarios approach results in realistic and representative scenarios. However this requires extensive research and is complex, costly, and time-consuming[29,30]. Especially during the development of a platform, a large and diverse group of users needs to be addressed to arrive at a complete set of scenarios[31]. Therefore, we choose a theory-based method (e in the list above) for

PHM. This approach should quickly be able to generate a set of scenarios that addresses the whole range of user needs of older adults.

Data collection

The core of PHM consists of the use of freely available public health information concerning the whole domain of daily activities and related restrictions. These provide the first two scenario elements: 'user' and 'user activity'. These elements are derived from user characteristics and daily user activities.

User characteristics

User characteristics are taken from the expected user's age-related disabilities and its resulting limitations. The ICF was used for the definition of these limitations. The ICF framework classifies diseases in health-related functional domains. These include individual, societal and environmental perspectives. The ICF uses codes to identify functioning, disability and health, with letters that specify broad classes of functioning. For example, the code b130 has a 'b' for body function, the 'b1'range is for mental functions, and b130 specifies 'energy and drive functions'. The codes can be found in the ICF-browser[15]. For numerous diseases, researchers have defined so-called ICF core sets, which are a collection of all ICF codes that are applicable to a disease.

The diseases included in this study originate from the so-called 'health profiles' for older adults (65-85 years) as formulated by Deeg et al., another information source from the public health domain[16]. The first 5 (out of six) health profiles for older Dutch people encompass 73% of the female and 62% of the male population aged 65-85 years. For each health profile, user characteristics were defined based on disorders and diseases that have the highest frequency within that specific profile (Table 4.1):

I. For health profile "cancer and mild arthritis": breast cancer[32];
II. For "severe other chronic diseases, few functional limitations": depression[33] and visual impairment;
III. For "cognitive impairment and mild arthritis": rheumatoid arthritis[34] and cognitive impaired;

Table 4.1: *Dutch health profiles[16] and applicable ICF codes[15] (http://apps.who.int/classifications/icfbrowser) of the most common diseases and disorders in each profile*

Health profile	**ICF codes**
I: Cancer and mild arthritis (breast cancer)	b130, b134, b180, b265, b455, b530, b710, b720, b730, b740, d177, d230, d430, d445, d510, d520, d540, d550, d560, d570, d620, d630, d640, d650, d660, d720, d920, e115
II: Severe other chronic diseases, few functional limitations (depression, visual impairment)	b117, b1262, b130, b1300, b1301, b1302, b134, b1340, b1341, b1342, b1343, b1344, b140, b144, b160, b1601, b1602, b1603, b164, b1641, b1642, b1645, b180, b1800, b210, b530, d110, d115, d163, d166, d175, d177, d210, d220, d230, d2301, d2302, d2303, d240, d310, d315, d320, d325, d330, d335, d345, d350, d355, d360, d510, d520, d540, d550, d560, d570, d620, d630, d640, d649, d650, d660, d710, d720, d730, d920, e115, e120, e125, e155, e240, e245, e250
III: Cognitive impairment and mild arthritis (rheumatoid arthritis, cognitive impaired)	b130, b134, b140, b144, b160, b164, b167, b180, b455, b710, b7102, b715, b730, b740, d170, d230, d360, d410, d415, d430, d440, d445, d449, d450, d455, d460, d465, d510, d520, d530, d540, d550, d560, d570, d620, d629, d630, d640, d649, d650, d660, d669, d859, d920, e115, e120, e125, e155
IV: Frailty (COPD, diabetes mellitus, hearing impairment)	b130, b1300, b1302, b134, b140, b210, b230, b265, b270, b310, b455, b4550, b4551, b4552, b530, b710, b730, b740, d115, d230, d310, d330, d350, d355, d360, d410, d430, d440, d450, d455, d460, d465, d510, d520, d540, d570, d620, d630, d640, d650, d660, d920, d9201, d9204, d9205, e115, e120, e155, e260, e560
V: Cardiovascular disease (chronic ischemic heart disease, stroke)	b114, b117, b130, b134, b140, b144, b152, b164, b167, b172, b176, b180, b210, b265, b270, b310, b320, b330, b455, b530, b710, b715, b730, b740, d115, d160, d166, d170, d172, d175, d210, d220, d230, d240, d310, d315, d325, d330, d335, d345, d350, d360, d410, d415, d420, d430, d440, d445, d450, d455, d460, d465, d510, d520, d530, d540, d550, d570, d620, d630, d640, d710, d860, d920, e115, e120, e125, e155, e260, e535

IV. For "frailty": chronic obstructive pulmonary disease (COPD)[35], diabetes mellitus[36], and hearing impairment;
V. For "cardiovascular disease": chronic ischemic heart disease[37] and stroke[38]

The last health profile (VI: Healthy) was excluded, since it does not contain disorders and diseases that require assistance. Furthermore, if no ICF core set was available, the expected limitations for a disease group was selected from the ICF.

Not all limitations were taken into account, only those that may possibly require assistance with AmI or smart-environment applications at home. For example, 'blood vessel functions' (ICF code b415) can hardly be compensated by a smart-home environment, while different solutions exist for the closely related 'exercise tolerance functions' (ICF code b455) or the 'seeing' (b210) or 'lifting and carrying objects' (d510). Furthermore, body structures were not included (i.e. class 's' of the ICF-code) since we focus on the altered functions that result from altered structures. The activities and participations defined by the ICF were selected if related to common daily activities. Environmental factors were taken into account when directly related to the home environment.

Common daily user activities

Common activities practiced by Dutch end-users have been defined by the "Sociaal Cultureel Planbureau" (SCP)[39,40]. This set was filtered for those activities that are performed at home by older adults. Common activities of Dutch end-users as listed by the SCP, were condensed to 11 general activities that are subdivided in 31 sub-activities:

a. Preparing meals: cooking, serving, and cleaning up
b. Housekeeping: cleaning, laundry, gardening, and routine maintenance
c. Care: personal hygiene, medical care, eating and helping others to eat, being in company, and dressing
d. Nutrition: eating and drinking
e. Sleep and rest: sleeping, resting, going to bed / getting up
f. Social activities: having a conversation, getting connected, and receiving visitors
g. Mental activities: desk work and entertainment
h. Physical activities: sports, hobbies, entertainment, and practicing a profession
i. Listening: to media and to people
j. Watching: reading, media, in general
k. Organization of daily life

Scenario-elements 'user' and 'user-activity'

To generate a complete set of the scenario-elements 'user' and 'user activity', two inputs are combined in a matrix (see Appendix 4-A):

1. The set of limitations of one or more health profiles defines the user. The limitations are listed horizontally in the matrix.
2. The (sub)activities in daily life define the user activity, and form the columns of the matrix

The set of limitations requiring assistance to age-in-place consists of 28 items for health profile I; 72 for profile II; 56 for III; 63 for IV; and 88 for V. Since one limitation may be present in multiple profiles, the total number of unique restrictions covered in this approach computed 118.

The first author (a building services engineer) and the third author (a physician) evaluated the 3658 cells of the matrix of common activities of Dutch end-users and their possible restrictions. For instance, the limitation 'lifting and carrying objects' (d430), will be a relevant for a cooking activity, but not for sleeping activities. A physiotherapist judged the evaluation of the first and third author and made corrections where necessary. A number of 1619 cells of the matrix (44.3%) were judged as relevant restrictions for an activity, and are marked in the matrix (Appendix 4-A).

The completeness of the daily-activities/restrictions matrix was validated through the evaluation of needs for support that have been addressed by *Ambient Assisted Living Joint Programme* (AAL JP) projects[41]. Their calls for proposals address specific need themes to 'improve the quality of life of older people' and each of their projects addresses one or more specific needs. For all 74 projects in the first three AAL JP calls, we have analyzed which cells of the matrix it addresses. Two projects where excluded since they develop products for a general purpose (HERO and AALUIS). Furthermore, 45 projects had to be excluded since they developed a product that does not assist or compensate for a limitation of the end-user (which is the scope of this paper), but rather for enrichment, prevention, or care. The remaining 27 projects addressed 532 cells of the matrix (14.5%). This indicates the completeness of the matrix, but at the same time signifies that there is still much work to do for a complete smart home to age in place.

Scenario development

Based on the complete set of the scenario-elements for 'user' and 'user activity' as derived from public health resources, scenarios are generated by adding the remaining four scenario-elements: 'target product use', 'physical setting', 'non-physical or non-tangible setting', and 'product to be developed'. All elements should be specified as precisely as possible. The process is depicted in an activity diagram (Figure 4.2).

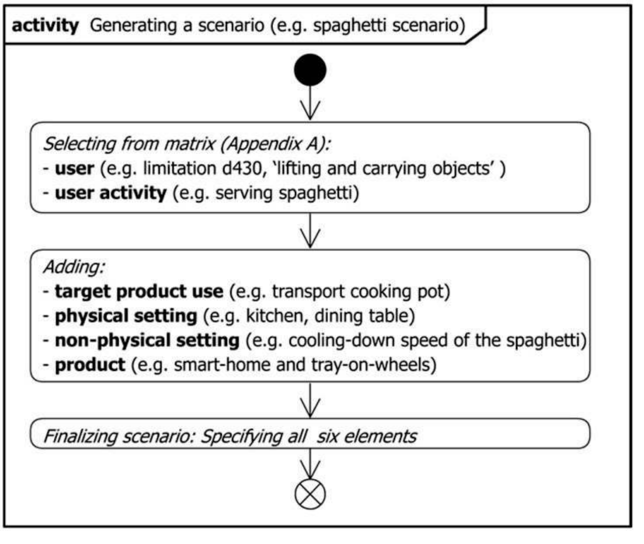

Figure 4.2: *Activity diagram for generating scenarios for assistance with daily activities, including an example (transport a cooking pot with spaghetti from the kitchen to the dining table).*

Elements 'user' and 'user activity'

The scenario-elements 'user' and 'user activity' are selected from the matrix of restrictions and daily activities (Appendix 4-A). Each marked cell in the matrix gives a potential situation that requires assistance. Those situations take the form of:

assistance with <ICF limitation> during <daily activity>

For instance, the combination of the subactivity ‘serve a meal’ (‘user activity’) and the limitation ‘lifting and carrying objects’ (ICF code d430, ‘user’ characteristic) results in a situation that requires assistance with lifting and carrying objects when serving a meal.

How the elements are selected from the matrix, depend on the main purpose of the scenario that is generated. As explained before, scenarios may be generated for exploration and orientation, requirements capture, conceptual and detailed design, and validation and testing of the design. Each of these types of scenarios requires a different set of elements from the matrix. As an example, we describe below in “Resulting Scenarios” the generation of scenarios to test smart-home platforms for their suitability to support a broad variety of smart-home devices that are needed by older adults. For this purpose, elements from the matrix are selected in such a manner as to address a broad variety of smart-home devices.

Remaining scenario elements

Next, four remaining elements are added to the scenario. The elements ‘goal concerning the product use’ is restricted to ‘assistance’ due to the scope of this paper. A specific goal is defined on the basis of the scenario elements ‘user’ and ‘user activity’. For example, when assisting a user with lifting and carrying objects when serving a meal, the ‘goal of product use’ might be to assist the user with transporting heavy objects.

The scenario element ‘physical setting’ is bound to the home environment, but will be specified based on the context of the scenario elements ‘user’, ‘user activity’, and ‘goal of product use’. In the above example, the physical setting is a cooking pot with spaghetti that needs to be taken from the kitchen to the dining table.

The element ‘non-physical setting’ is not restricted, and may be defined in any way. Going back to the earlier example, a non-physical setting could relate how quickly the spaghetti casserole should cool down.

The ‘product to develop’ may be added if the scenario goal is to validate the performance of a product. In the example case, the product could consist of a set of sensors that detect the location of humans and objects, a digital floor plan of the house, a speech recognition functionality detecting a call for help, and a robotic tray-on-wheels. If the goal of the scenario is to capture the user needs for a product (requirement capture), the product is not added to the scenario[3].

Finalize scenario

Last step is to detail the whole scenario as much as possible, to arrive at useful scenarios that embody specific and typical examples of users in a target population. If this is the case, results obtained with the scenario can be generalized to the target population. It is important not to use stereotypical characters or caricatures, or creating scenario that are too simplistic[4].

UML or SysML diagrams (Figure 4.2 and Figure 4.3) are helpful tools for describing and communicating scenarios[42,43]. A use-case diagram is used to visualize the behavior of the users and system. In the case above, the user asks for help and walks to the table, while the system recognizes the call and brings the cooking pot to the table. Activity diagrams help to visualize the actions step by step. Figure 4.3 is an example of the spaghetti scenario.

Resulting scenarios

Usage of PHM

The PHM has been applied to generate 10 scenarios. The purpose of these scenarios was to assess smart-home platforms for their suitability for aging-in-place. It is important that smart-home platforms support all applications and services that are needed to assist the older adults at home, now and in the near future. Therefore, the scenarios must address a broad variety of smart-home devices that are needed by older people. Due to time related restrictions only 10 scenarios were created. However, future assessments may require hundreds of scenarios.

For the broad variety of smart-home applications needed it is important to determine what technology is required to support all combinations of restrictions and activities in the matrix (Appendix 4-A). From the matrix, we selected 108 combinations of one or more restrictions and a relevant activity. Although these

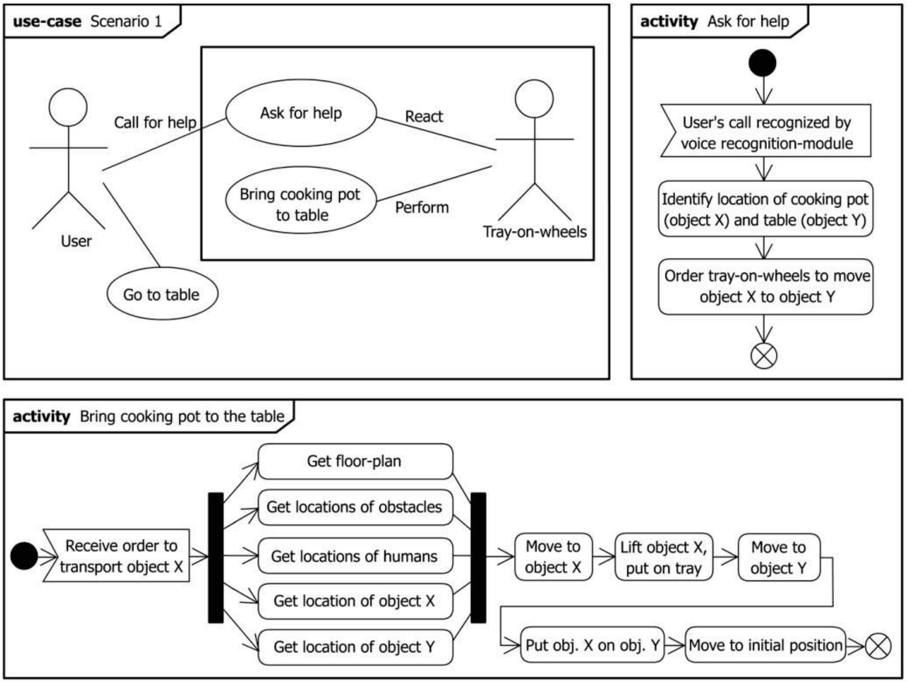

Figure 4.3: *Example of SysML diagrams of a scenario where a cooking pot (object X) is transported from the kitchen to the dining table (object Y). A use-case diagram illustrates the whole scenario (top-left). Activities diagrams illustrate the behavior of the system when receiving a call for help from the user (top-right) and when transporting the pan (bottom)*

108 cases are not even close to the 1851 possibilities of the matrix, they do address all 31 activities and all 118 restrictions.

From the 108 combinations of activities and restrictions, 14 categories of support are selected that might be provided by a smart-home:

1. Enhancement of hearing (4 combinations of restriction(s) and activity)
2. Enhancement of vision of non-movable items (cannot be brought to a camera, 10 combinations)
3. Enhancement of vision of (small) movable items (6 combinations)
4. Sensing (e.g. temperature, 5 combinations)
5. Moving body, or changing body position (4 combinations)
6. Moving objects (10 combinations)
7. Environmental control (e.g. light, sound, air temperature, 13 combinations)
8. Providing a stimulating environment (when the user does not have the drive to perform daily activities, 8 combinations)

9. Advising the user (single piece of advice) based on events, circumstances and general knowledge (10 combinations)
10. Advising the user (single piece of advice) based on general knowledge (6 combinations)
11. Guiding the user (guide a whole process, multiple pieces of advice) based on events, circumstances and general knowledge (17 combinations)
12. Guiding the user (guide a whole process, multiple pieces of advice) based on general knowledge (5 combinations)
13. Health monitoring (when the user is unable to look after his/her own health, 2 combinations)
14. Providing alternative user interfaces (8 combinations)

For the creation of the 10 scenarios, the scenario elements ‘user’ and ‘user activity’ were selected in such a way that all 14 categories are addressed. Each scenario addresses at least one category, but often more than one. Furthermore, each scenario is devoted to only one health-profile and one daily sub-activity is picked as the ‘user activity’ in each scenario.

In the next step of PHM, the ‘goal of the product use’ is defined for each combination of restriction and activity. In this context, the product is the smart-home system that supports the person in performing his/her activity. The goal of the product use is followed from the restrictions and the user activity in each scenario. The physical and non-physical settings are added, and a smart-home system is designed to support the user with his/her activity while having one or more restrictions. Each scenario is then detailed by the first author as much as possible. The details are the result of the author’s interpretation of the chosen scenario elements.

PHM results

A brief description of each scenario follows.

Scenario 1: serving dinner. Health profile I, restrictions b130, b455, b710, b720, b730, b740, d230, d430, d445, and d630. *Due to low muscle power in her limbs and limited amount of energy, the user (female) cannot lift a heavy pan from the cooker and carry it to the dining table. She needs assistance to transport the pan, and calls for help. A ‘tray on wheels’ transports the pan from the cooker to the dining table. To do so, the transporter requests the location of the pan, the floor-*

plan, obstacles, and the (variable) location of human(s) from the sensors and databases of the smart-home system.

Scenario 2: cleaning. Health profile II, restrictions b130, b140, b160, d175, d177, d230, and d640. *The user (female) is depressed and cannot find the drive to clean her house. She doesn't know where to start and perceives her cleaning activities as unnecessary. The smart-home helps her with scheduling her cleaning activities. Based on the usage of the house and previous cleaning activities, the user is advised what to clean and when to do this. She is only advised on an appropriate moment of the day. Furthermore, since she has trouble with seeing, the smart-home switches on all lights in the room while she is cleaning. The smart-home uses the information of sensors that measure the usage of the water tap, the location of the vacuum cleaner, the position of the user, and a database of user preferences, usage of rooms and cleaning behavior.*

Scenario 3: providing medicines. Health profile II, restrictions b140, b144, b210, d230, d660, and d669. *Because of her depression, the user (female) has trouble with keeping her focus. She gives her husband medicines two times a day, but this can be dangerous when she is not focusing on what medicines she gives and what the dose should be. Also, because of her vision difficulties, she risks to pick the wrong jar of pills. A smart medicine cabinet detects the position of each medicine jar and monitors what jars are taken from the cabinet. A small scale measures the dose that is taken for each medicine. With voice feedback, the user is warned when the wrong medicine or dose is dispensed.*

Scenario 4: answering the front door. Health profile III, restrictions b140, b144, b160, b164, b710, b730, d410, and d450. *The user (male) has trouble with moving, like getting out of his chair and walking around. When there is someone at the door, it is a problem for him to get out of his chair and go to the front door. Furthermore, due to cognitive problems, he often does not notice the doorbell, recognize the person at the door, and reason/remember why this person is at his door. The smart-home system uses the television to draw the user's attention when someone is at the door. The system advises the user to open the door when the visitor has been invited before in the same context (time and day of the week). If the user agrees, the smart-home will open the door, let the visitor in, and closes the door.*

Scenario 5: using a dictionary. Health profile III, restrictions b140, b144, b160, and b164. *The user (male) has cognitive and memory problems. He often needs to lookup words that he is not familiar with anymore, but has also trouble with finding the dictionary. When the user vocally expresses this, a smart book case highlights the position of the dictionary. The user has also trouble with using it, since he often forgets the alphabet. By saying the word that he is looking for out loud, the smart-home advices him to search on a (location of) a page. To do so, the smart-home uses an online database that contains the content of the dictionary.*

Scenario 6: getting tea. Health profile IV, restrictions b130, b710, b730, b210,b270, d410, d450, and d570. *The user (male) has trouble with getting out of the chair, walking, and seeing where he is going. Because he is suffering of COPD, it is important he gets meals in a structured time schedule. The small service robot will therefore bring him a cup of tea on request. Also, he risks drinking the tea too hot, since he is not able to feel hot and cold with his hands. The smart-home system will therefore vocally warn him when he attempts to drink a too hot fluid. The smart-home gets its information from an infrared camera, person localization sensors, amongst others.*

Scenario 7: getting to bed. Health profile IV, restrictions b130, b134, b210, d230, and e2450. *The user (male) has problems with keeping a good sleeping rhythm and does not have the energy and drive to get upstairs, change clothes, brush teeth, and get in bed. The smart-home system will therefore, based on his sleep pattern, advise him to go to bed when needed. An appropriate moment is picked based on the user's activity, the television program guide, and the user's vocal feedback on the advice. When the user agrees to go to bed, the smart-home will light the route to the bathroom (since the user has visual problems), advise him to brush his teeth, change clothes and get to bed.*

Scenario 8: playing Wii fit. Health profile IV, restrictions b210, b230, d310, e115, and e250. *The user (male) is using Wii Fit a lot to prevent a decline of his COPD. He enjoys it, but has trouble to put the right DVD in the Wii due to his problem with seeing. By pointing at the game covers in the drawer with Wii games, the user can enlarge the image of each game cover on the television. A camera detects the game cover that is pointed by the user, and gets an image of the cover from the internet. Also, since the user has also hearing problems, he cannot hear the instructions of the Wii Fit very well. The smart-home system will therefore* *recognize spoken text in the sound stream of the Wii and displays the text in subtitle.*

Scenario 9: working out. Health profile V, restrictions b140, b455, b130, b140, d570, d920, and e260. *The user (female) has trouble with her heart and must do some exercises each day to keep fit. However, she may not overdo this, since this can be dangerous. Also, she must take care to not be in a too warm room. But since she often forgets to pay attention to this, the smart-home system will guide her so she maintains a healthy heart rate during workout. Also, the system will maintain a healthy indoor climate.*

Scenario 10: watching television. Health profile V, restrictions b130, b140, b730, and d430. *The user (female) loves to watch television, but she is easily distracted and therefore often not able to follow television shows. She will pay better attention if the television would cover a larger area of her visual field, and if other audio sources would be eliminated. However, she doesn't have the energy or muscle power to change the position of her television or closing windows to reduce sound from outside. The smart-home system will therefore move the television closer to the user when she is watching an interesting show. Also, when there is too much noise from outside, the windows will be closed.*

Scenario usage

The scenarios were used to assess the suitability of platforms for aging-in-place. The smart-home systems that are described in the above scenarios were therefore implemented with the platform (see Chapter 5 for details). The great variety of combinations of environmental conditions and devices in the scenarios called for a simulation with virtual devices. Therefore, the user, home environment, and smart-home devices were implemented in a simple simulation environment. The smart-home devices have an interaction with both the user and the home environment on one side, and are connected with each other through a real implementation of the platform on the other side. It was then tested if the platform was able to exchange all information between the smart-home devices so the older end-user can be assisted in performing his/her activity.

This way we tested two platforms: the EU supported universAAL[44], and a platform that is a combination of 'Universal Plug and Play' (UPnP[45]) and 'Digital Home

Compliant' (DHC[46]). Test results, described elsewhere[47] (see Chapter 5), show that both platforms are prepared to support about 20% of all actions that the smart-home must perform to support the user in the scenarios. The other actions that are described in the scenarios could only be supported after extending the platform. For the universAAL platform, this comes down to the extension of its ontology. The UPnP/DHC platform does not have ontology, but is based on fixed protocols. These protocols had to be custom made in order to support all devices of the scenarios. The implementation of the scenarios in the simulation environment may be downloaded from www.michielbrink.nl/simulations.

Discussion and conclusions

In this paper PHM is introduced as a new methodology for the creation of a complete set of scenarios for smart-home platforms on the basis of freely available public health resources. The core of the method is the provision of two scenario elements, the 'user' and 'user activity', in a matrix (Appendix 4-A), based on the medical tools Health Profile and the ICF. The matrix has been validated for completeness and applied in the creation of 10 scenarios for testing of smart-home platforms.

If one compares the PHM to other methods such as the one described by Carroll for example, one can conclude that other methods might result in scenarios with a higher level of detail or correctness (Table 4.2). However, this level of detail and correctness of scenarios is less important during the development of a smart-home platform, than for the development of user interfaces and smart-home services. The general disadvantage of other methods is the lack of (theoretical) groundings to ensure completeness of the set scenarios. Such a set of scenarios is useful for validating smart-home platforms that aim to address a broad range of functionalities for aging-in-place, such as the universAAL project[44]. Developers of these all-in-one systems (or integrated systems) could check each combination of limitations and user activities to find out if their system is adapted to the situation at hand.

The use of the public health resources (Health profiles, ICF) in combination with reported common daily activities resulted in a complete set of scenario-elements 'user' and 'user activity'. This provided the basis for generating scenarios that

Table 4.2: *Comparing the Public Health Methodology (PHM) with other methods to create scenarios for smart-homes to support aging-in-place*[27]

Methods for generating	Application examples	Advantage compared to ICF-based creation	Disadvantage compared to ICF-based creation
Ethnographic field study or participatory design	MIMOSA project[22], Strömberg et al.[25], SOPRANO project[23]	scenarios have a higher level of detail and are more correct	far more time consuming and set of scenarios is less complete (limited by the group of participants and addressed topics)
Reuse of prior analyses	universAAL project[48]	little time consuming	reusable scenarios must be available and level of detail, completeness, and correctness depend on reused scenarios
Scenario typologies	SOPRANO project[23]	-	no groundings to ensure completeness of scenarios and possibility of errors in scenarios
Technology-based scenarios	AMIGO project[24], Bajo et al.[49]	might have a higher level of detail	lack of completeness since scenarios have a specific aim that is picked by the developers, and possibility of errors in scenarios
Transformation	MIMOSA project[22], SOPRANO project[23]	might have a higher level of detail	no groundings to ensure completeness of scenarios and possibility of errors after transformation when not validated by end-user

cover the whole range of assistance by technology for aging-in-place. We were able to generate 10 scenarios that address all daily activities and limitations at least once, and used them for the testing of two smart-home platforms. In the future this use of scenarios could also be applied to other applications of public-health engineering, such as the development of smart systems to supply potable water, remove solid and liquid waste, or introduce new systems for a reduction of energy use by buildings.

During product development, the use of our PHM will limit the need for interviews, questionnaires, or focus groups with users. This is a benefit for smaller projects in particular. Interviews, questionnaires, or focus groups with end-users might still be needed in a later phase of product development to focus on specific sub-groups of the 65-85yrs age category. Also, the method only addresses the most common situations. For instance, Alzheimer disease is not addressed, since it does not occur often in relation to the other disabilities in the Netherlands according to Deeg[16]. Also, the outcome of the PHM addresses a set of situation that might occur, but does not indicate whether or not these situations will actually occur. Furthermore, the matrix for selecting the scenario-element 'user' and 'user activity' is based on lifestyles and health information from the Netherlands. Finally, the scenario generated suggests which functionalities might be needed, but does not address the products that provide these specific supports.

Although we have focused on the Dutch population in this research, the PHM is also applicable to populations in other regions. The daily activity patterns used in our study apply to European regions as well[39]. For other regions it is recommended to collect a new set of daily activities. Health information has more regional variations[16]. In addition to the Netherlands, published worldwide health-profiles are available from the World Health Organization[50], and local organizations, such as the Network of Public Health Observatories in case of the UK[17].

Further research is still needed to improve the validity and usability of the PHM. Since only a physician and a physiotherapist judged the matrix, validation is also needed by psychologists, ergonomists, as well as end-users. Furthermore, not all limitations are applicable in all situations, due to differences among persons, in seriousness of the disease, and the stage of the disease. Also, the usability of the PHM will be improved by creating a website or mobile app that requests a health condition of a user and provides the circumstances that require assistance. This can be used to either test a design, or to guide the design process. In addition the PHM could further be developed into an ontology model to ease its linking to other AAL ontologies, such as universAAL's ontology model[48].

Our PHM will help the development of smart systems for older people, to come to products and technologies that are able to fulfill the needs of the older adults, thus postponing the need of long-term care. It provides insight in this field for developers to arrive at a widespread introduction of smart-homes for older adults that may live independently for an extended period of time.

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Appendix 4-A: *Scenario generation matrix showing the relationship between restrictions (ICF)[14,15] and common daily activities[39,40]. Restrictions that are relevant for a specific activity have been marked. Restrictions that are addressed by one of the 74 projects of the first three calls of the Ambient Assisted Living Joint Programme[41], have been marked with a darker color*

ICF	Preparing meals	Housekeeping	Care	Nutrition	Sleep & rest	Social activities	Mental activities	Physical activities	Listening	Watching	Organization of daily life
	Cooking Serving Cleaning up	Cleaning Laundry Gardening Routine maintenance	Personal hygiene Medical care Helping others to eat Being in company Dressing	Eating Drinking	Sleeping Resting Going to bed / getting up	Have a conversation Getting connected Receive visitors	Desk work Entertainment	Sports Hobbies Entertainment Practicing profession	To media To persons	Reading Media, in general	
BODY FUNCTIONS											
B1: MENTAL											
b114											
b117											
b1262											
b130											
b1300											
b1301											
b1302											
b134											
b1340											
b1341											
b1342											
b1343											
b1344											
b140											
b144											
b152											
b160											
b1601											
b1602											
b1603											
b164											
b1641											
b1642											
b1645											
b167											
b172											
b176											
b180											
b1800											
B2: SENSORY FUNCTIONS AND PAIN											
b210											
b230											
b265											
b270											

***Appendix 4-A (continued):** Scenario generation matrix showing the relationship between restrictions (ICF)[14,15] and common daily activities[39,40]. Restrictions that are relevant for a specific activity have been marked. Restrictions that are addressed by one of the 74 projects of the first three calls of the Ambient Assisted Living Joint Programme[41], have been marked with a darker color*

ICF	Preparing meals	Housekeeping	Care	Nutrition	Sleep & rest	Social activities	Mental activities	Physical activities	Listening	Watching	Organization of daily life
	Cooking Serving Cleaning up	Cleaning Laundry Gardening Routine maintenance	Personal hygiene Medical care Helping others to eat Being in company Dressing	Eating Drinking	Sleeping Resting Going to bed / getting up	Have a conversation Getting connected Receive visitors	Desk work Entertainment	Sports Hobbies Entertainment Practicing profession	To media To persons	Reading Media, in general	
B3: VOICE AND SPEECH											
b310											
b320											
b330											
B4: CARDIOVASCULAR, HEMATOLOGICAL, IMMUNOLOGICAL AND RESPIRATORY SYSTEMS											
b455											
b4550											
b4551											
b4552											
B7: NEUROMUSCULOSKELETAL AND MOVEMENT-RELATED											
b710											
b7102											
b715											
b720											
b730											
b740											
ACTIVITIES AND PARTICIPATION											
D1: LEARNING AND APPLYING KNOWLEDGE											
d110											
d115											
d160											
d163											
d166											
d170											
d172											
d175											
d177											
D2: GENERAL TASKS AND DEMANDS											
d210											
d220											
d230											
d2301											
d2302											
d2303											
d240											

Appendix 4-A (continued): *Scenario generation matrix showing the relationship between restrictions (ICF)[14,15] and common daily activities[39,40]. Restrictions that are relevant for a specific activity have been marked. Restrictions that are addressed by one of the 74 projects of the first three calls of the Ambient Assisted Living Joint Programme[41], have been marked with a darker color*

ICF	Preparing meals	Housekeeping	Care	Nutrition	Sleep & rest	Social activities	Mental activities	Physical activities	Listening	Watching	Organization of daily life
	Cooking Serving Cleaning up	Cleaning Laundry Gardening Routine maintenance	Personal hygiene Medical care Helping others to eat Being in company Dressing	Eating Drinking	Sleeping Resting Going to bed / getting up	Have a conversation Getting connected Receive visitors	Desk work Entertainment	Sports Hobbies Entertainment Practicing profession	To media To persons	Reading Media, in general	
D3: COMMUNICATION											
d310											
d315											
d320											
d325											
d330											
d335											
d345											
d350											
d355											
d360											
D4: MOBILITY											
d410											
d415											
d420											
d430											
d440											
d445											
d449											
d450											
d455											
d460											
d465											
D5: SELF-CARE											
d510											
d520											
d530											
d540											
d550											
d560											
d570											
D6: DOMESTIC LIFE											
d620											
d629											
d630											
d640											
d649											

Appendix 4-A (continued): *Scenario generation matrix showing the relationship between restrictions (ICF)[14,15] and common daily activities[39,40]. Restrictions that are relevant for a specific activity have been marked. Restrictions that are addressed by one of the 74 projects of the first three calls of the Ambient Assisted Living Joint Programme[41], have been marked with a darker color*

ICF	Preparing meals	Housekeeping	Care	Nutrition	Sleep & rest	Social activities	Mental activities	Physical activities	Listening	Watching	Organization of daily life
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d650											
d660											
d669											
D7: INTERPERSONAL INTERACTIONS AND RELATIONSHIPS											
d710											
d720											
d730											
D8: MAJOR LIFE AREAS											
d859											
d860											
D9: COMMUNITY, SOCIAL AND CIVIC LIFE											
d920											
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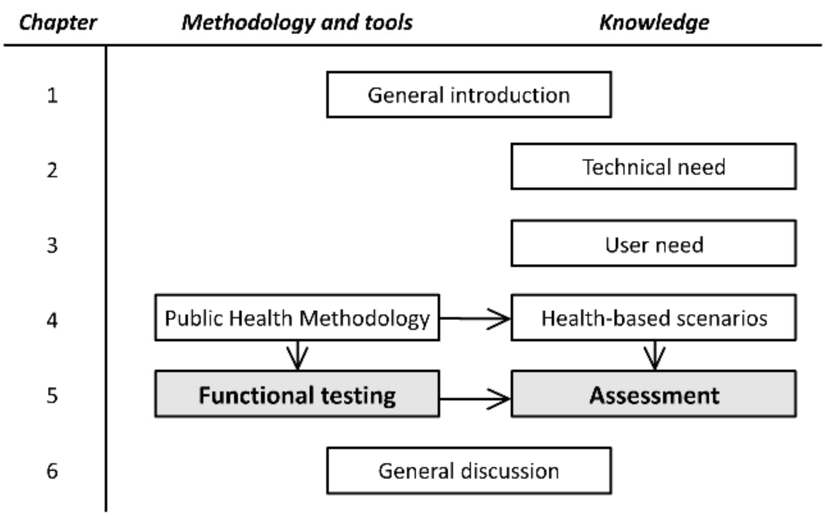
Chapter 5: Functional testing and assessment



In Chapter 3 we demonstrated the need for platforms from an end-user's point of view. In Chapter 4 we defined a range of requirements for platforms with the help of scenarios. In this chapter, we address the question of how platforms can be tested on these requirements and how today's platforms perform.

To this end we propose a testing method for platforms. We used the scenarios that are defined in Chapter 4 as test cases, and we will explain how platforms can be tested with the use of simulations. We then used this method to test two platforms (universAAL and the combination of Universal Plug and Play (UPnP) and the Digital Home Compliant) for their suitability for aging-in-place.

Assessing smart-home platforms for Ambient Assisted Living (AAL)*

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Abstract
Smart-home platforms support applications, services, and devices for Ambient Assisted Living (AAL). The developers of those platforms commonly focus on technological requirements only, without having a clear understanding of end-users such as older adults living independently. Moreover, since there are no functional testing methods for AAL platforms, we introduce a testing methodology for smart-home platforms and use it to test two platforms for their suitability: the universAAL platform that is based on an ontology model, and the 'Universal Plug and Play' (UPnP) platform in combination with 'Digital Home Compliant' (DHC) framework (first version), both using fixed terminology and descriptions. We first developed a comprehensive overview the support older people may need from a smart home. We then developed scenarios that cover many of those needs and used the scenarios as test cases in functional tests in a simulation environment. The results show that 4/5 of the smart-home applications in the AAL scenarios will not work without a platform extension. This demonstrates the importance of these extensions. Therefore, the use of an ontology model for platforms is advisable because of its quick and easy adaption to new devices and services, needed for the worldwide rollout of smart-homes for AAL.

Keywords: smart-home, platform, Ambient Assisted Living, assessment, functional testing

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Introduction

Ambient Assisted Living (AAL) is gaining importance; an increasing number of older people result in a growing demand for assistance at home and smart-care services. However, the available number of care staff is shrinking[1]. AAL may supply the required assistance by developing technologies to support older people to continue to live independently in their own environment (aging-in-place). AAL is a clear target of Ubiquitous Computing and Ambient Intelligence (AmI)[2]. Ubiquitous Computing and AmI may improve health, safety, and well-being, with functionalities such as social gaming, improved communication, fall-detection, telecare, health monitoring, burglar alarm, to name but a few.

The required technologies face numerous challenges. The diversity in needs and aspirations is extensive and includes leisure as well as homework and medical care. Acceptance and adoption of new technologies may also be a problem[3]. Moreover, the needs of older people may change fast depending on the rate of health decline. Satisfying needs and aspirations of older adults can be complex. Solutions may vary from simple monitoring services to advanced in-home interventions or instructions guiding the user carrying out a task[4]. If you add this to the diversity of home-environments it is clear that AAL smart-home systems should be customizable, distributed, and heterogeneous[5].

The complexity of such smart-home systems calls for the integration of technologies from several domains by a dedicated middleware framework[6,7]. Such a framework provides a uniform platform to serve and to integrate heterogeneous devices and services. It has been shown that a uniform platform is required to arrive at a widespread introduction of AAL systems[7,8]. Functions of such a platform vary from dealing with complex heterogeneity problems, to providing the support for context awareness[9]. Despite the fact that platforms are considered from a pure technological angle, the requirements for platforms are mostly defined by the needs of the end-user.

Scenarios are useful tools to understand the needs and aspirations of end-users, and they are often employed in the development of AAL technology. Scenarios enable developers of AAL technology to focus more on the value for end-users than on the core technical workability[10]. All user requirements should be understood during the development of a platform, since the range of functionalities that can be offered by the smart-home system will be dominated by the architecture of a smart-home platform[11]. Unfortunately, developers of platforms commonly focus on technological requirements only, without having a clear view on end-users[12]. The scenarios that are incorporated in the development are rarely based on empirical data. A complete set of scenarios that cover all user requirements is needed. A theoretical background should be established for the creation of such a set of scenarios[13].

Functional testing can be used as a tool to assess the ability of smart-home platforms to support the needs and aspirations of end-users. It aims to validate the correct operation of a system with respect to its functional specification[14]. As with mathematical functions, one or more outputs are created on the basis of the function's behavior and input(s). Services of smart-homes (that have a Service Oriented Architecture) can be seen as functions with an abstract input and output (e.g. an input can be a fall detection at home, the output could be a call for help)[15]. The main aim of functional testing of a smart-home is to provide requests to the service and then to analyze the received responses[16].

The aim of this paper is to introduce functional testing for smart-home platforms and to assess two platforms for their AAL suitability. We propose to use scenarios as test cases and simulations to run the tests. Test results will show whether the smart-home devices, applications, and services that people need to age-in-place (now and as new products become available in the future) fit with the platforms that are developed today. This will give insights into how the platform handles the information exchange for the devices, applications, and services.

The paper is organized as follows: related work is presented in the next section, followed by a section that introduces the two platforms we tested. We then introduce functional testing for smart-home platforms, followed by the test results, while discussion and conclusions form the last section.

Related work

It is common practice to test a developed platform for smart-homes, but most developers validate their platform with an experimental implementation and a limited number of applications. For example, Parra et al. tested their peer-to-peer smart-home architecture using a proof-of–concept prototype based on a set of 5 peer devices[17]. Perumal et al. introduce a platform to improve smart-home interoperability, and tested their solution with a gateway that interoperated with two different sub-systems and did some performance testing[18]. Alonso et al. presents the SYLPH platform that integrates dynamic and self-adaptable heterogeneous Wireless Sensor Networks, and deployed a WSN infrastructure for testing and evaluating this platform[19].

Testing methods for smart-homes have been developed, but up to now they are not dedicated to smart-home platforms for AAL or aging-in-place. For example, Conejero et al. proposed a model for reusable tests to evaluate smart-homes. However, the model is designed to test fully developed smart-home systems and therefore less suitable to test smart-home platforms in early stages of development[20].

Furthermore, research on the requirements of the older end-user does exist, but often focuses on specific Assisted Technology or parts in smart-homes. User requirements that are only related to the platform are rarely investigated[12]. For example, Hensel and Courtney did research on older adults in relation to home telehealth technologies, but focused only on the obtrusiveness of information-based assistive technologies[21,22]. Whereas Demeris did several studies on older persons' needs for smart-homes[23–25], but did not address user requirements for smart-home platforms. Van Hoof et al. provided the requirements and expectations of end-users, their relatives and health care workers for AAL-technologies, with a primary focus on health care in The Netherlands[26].

Using simulations for testing purposes has also been discussed in the literature[10]. For instance, Davies and Callaghan[27] presented a review of virtual worlds and discuss the creation of an artificial control system for simulated humans. Using simulations as a tool in smart-home development has been described by Conte et al.[28]. They proposed a framework for the simulation of home-automation usage to optimize the system's performance. However, using simulations for functional testing of smart-homes does not appear in the literature.

Platform selection

In this section we discuss the platforms most suitable for testing. The main purpose of a smart-home platform is information exchange between heterogeneous devices. An important aspect of sharing information or knowledge is how pieces of information are declared and labeled for correct interpretation, and how to access these pieces of information (the lexic, syntactic and semantic representation of information). In this context, two groups of platforms can be recognized: those with a semantic system or ontology model, and those with fixed terminology and descriptions. For our assessment, we selected one platform of each group, in order to get insight into how these platform's basic distinctions impact their suitability for AAL.

The first group of platforms uses a model (ontology or semantic network) that represents the knowledge that is shared on the platform. When an information bit is correctly placed in the model, any device on the platform should be able to access, understand, and interpret it. Developers are not free to use their own terminology, but are obliged to use the model. Some platforms allow extending this model, so developers can add their own application. These platforms are commonly designed to allow sharing of these extensions to make applications by different new developers (or vendors) compatible. Currently, extensive research is done in this field, and initiatives like The Semantic Web[29] are promising.

Platforms in the second group have fixed protocols that define variables and data types, but also fixed standards on how to access information (i.e. fixed names of services, actions, and arguments). When the predefined protocols and standards are not sufficient for a particular application, developers are free to use their own set of names for variables, data types, services, and actions, to label and access the knowledge that is exchanged on the platform. The developed application will only be compatible with another application when the developers define the terminology in a protocol and the developer of another application is aware of the existence of the protocol, and can access and apply it. Commercial platforms often work this way. Vendor locks are a common feature of these platforms and this is a serious obstacle for adding new and varied devices.

The RAALI project (Roadmap AAL Interoperability) identified 54 different platforms that are suitable for AAL and are already commercially available or still in development (October 2012)[30]. In 48 cases detailed description of these platforms could be traced. Of these 48 platforms, 8 are using an ontology model semantic framework (e.g. universAAL[31], openAAL[32], OASIS[33], HYDRA[34]). The majority (42) is based on a form of fixed protocols (e.g. IP-Symcon[35], mBS Smart Home SDK[36], OpenRemote[37], UPnP[38], openHAB[39]). The availability of the platforms, in terms of downloading the software, documentation, and available support, differs among the platforms. To improve the feasibility of our assessment we chose two, one for each category, on the basis of availability, detailed description, and available support.

Of the platforms that use an ontology model, we selected the universAAL platform[31] for our assessment. The development of the universAAL platform is part of the Ambient Assisted Living Joint Programme[40] funded by the European Commission. We chose this platform for our assessment because of the availability of the software, manuals, and documentation, but also because the universAAL platforms will be developed especially for AAL services and devices. It is built upon OSGi[41], has several tools (e.g. for context awareness), and has an ontology model that can be extended at will. This platform is still under development. We used version 1.2 of the middleware, and employed the ontology model as it was on October 26, 2012.

From the platform that use a fixed terminology, we selected the Universal Plug and Play (UPnP) platform[38], due to its availability (several implementations exists, we used the Cling software stack[42]) and because it is commonly proposed as a platform for smart-homes (e.g.[43,44]). Compared to universAAL, it has a more peer-to-peer approach and it has not been developed especially for AAL. UPnP uses HTTP over UDP and was initially designed for network services like data sharing, communications, and entertainment. The UPnP forum has developed specifications for a number of applications domains, called “Device Control Protocols”, in which interfaces of applications are defined, in terms of names for services, actions and variables. Third parties sometimes define their own protocols in frameworks. We decided to use one of these frameworks, the Digital Home Compliant framework (DHC)[45,46]. DHC employs UPnP in its first version, and Devices Profile for Web Services (DPWS) in its second version to create a platform for service robots and home automation interoperability (the second version of the DHC architecture also considers other smart devices, as smart appliances, smart cars, or smartphones). The different DHC services will allow a manufacturer to implement the communication between robots and the digital home, security and privacy, localization, and collaboration between devices. We chose to use DHC since service robots and home automation have a large potential for numerous robotic projects for AAL (e.g. the CompanionAble project[47]). We chose to use the first version of DHC because at the time of the development of this research the second version was only specified and not yet implemented. Indeed the second version of DHC is already a mix between both categories chosen here, because DHC-Intelligence has its own ontology distributed description of devices.

Functional-testing methodology

The outline of our method is as follows: we first created a comprehensive overview of the support older people might need from a smart-home. These types of support determine the services, applications, or devices needed in the smart-home. We then created scenarios that cover a large number of needs and aspirations. Once a complete set of scenarios was available, it was used as a set of test cases for the functional test. To do so, we created an execution environment for the tests, consisting of a simulated environment containing a user, a physical environment, and the supporting smart-home system. The platform to be assessed was then added to the smart-home system and functional tests were performed for each scenario. Platform assessment was based on the results of the tests and the implementation log of the platform. The method is specified in the activity diagram (Figure 5.1).

Needs of older people

The support needs of older people are basically defined by what people like to do, but are unable to because of health-related restrictions. To get a complete overview, we need a comprehensive set of limitations induced by age-related diseases and disorders, as well as a set of daily activities performed at home. With the aid of so-called health-profiles[48] and the International Classification of Functioning, Disability and Health (ICF)[49] we could collect 118 limitations for Dutch adults 65-85 years of age. We compared and combined these restrictions with 31 common daily activities as reported by The Netherlands Institute for Social Research[13,50].

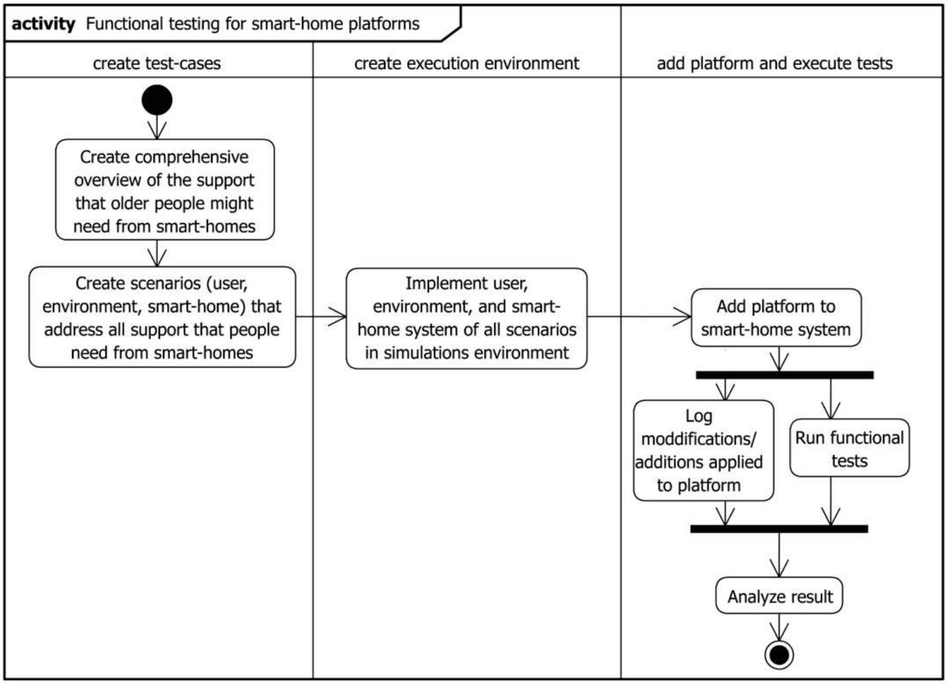

Figure 5.1: *Activity diagram of the method for functional testing of smart-home platforms*

This combination of restrictions and activities provides an overview of the type of support that may be required in a smart-home in the Netherlands. It determines the technology needed in a smart-home to support AAL, and thus what is needed from the platform.

Scenarios

Scenarios are hypothetic but concrete descriptions of the use of a product[51]. A scenario usually exists of a user of a product, an action that the user wants to perform, the product, the targeted use, and a (non-) physical environment. In the case of smart-home products for AAL, a scenario defines what the older person needs from the system at a given time, how this need is met by the smart-home, and under what circumstances (external variables) the need should be satisfied. We used 10 previously created AAL scenarios that cover many of the types of support required by older people[13] (Table 5.1).

Table 5.1: *Overview of 10 AAL scenarios consisting of a daily activity performed by an older person, and the person's limitations influencing the activity. The combination of both results is the support that a smart-home should provide*[13]

no.	Daily activity	Limitations	Support
1	Serving a meal	Muscle power of limbs, available energy, physical endurance, mobility of joints and bones	Transport hot pan with spaghetti from cooker in kitchen to table in dining room
2	Home cleaning	Maintaining attention, memory, vision, organization of activities	Guide user in cleaning dwelling: monitor usage of dwelling, advise user on what, how, and when to clean
3	Providing medical care	Memory, vision, organized thinking, organizing of activities	Guide user in taking correct drug and dose
4	Getting & consuming a hot drink	Getting out of a chair, walking, sensing temperature	Assist user in getting cup of tea; warn user when tea is too hot to drink
5	Going to bed	Maintaining sleep pattern, energy, vision, carrying out daily routine	Assist user in getting to bed on time, brush his/her teeth, find way to his/her bed, turn lights on/off when needed
6	Receiving visitor at entrance door	Standing up, walking, cognition, thinking, memory	Assist user in answering front door: invite someone in, open/ close entrance door
7	Using a dictionary	Maintaining attention, memory, thinking	Assist user with using reference book: locating correct book, helping searching in book
8	Sporting	Exercise tolerance, energy, sensitivity for high temperature and humidity, looking after one's own health	Monitor user while s/he is working out: prevent unhealthy conditions by maintaining healthy indoor climate, advise user to speed-up or slow down when needed
9	Playing a video game	Vision, hearing	Help user with picking the right Wii game, compensate for hearing problems when playing game
10	Watching television	Maintaining attention and focus, muscle power, energy, drive	Improve user experience when watching television show

The scenarios have three main components: (i) the user, (ii) an environment, and (iii) a system to support the user. The user is defined based on a combination of one or more restricted and activities (e.g. the difficulty of lifting heavy objects, and the activity of moving a heavy pan from the kitchen to the dining room). The environment is an aging-in-place setting that is adapted to the activity that the user intends to perform (e.g. a kitchen and dining room). The services, applications, and devices of the system are selected so the user is assisted with the activity (taking a heavy pan from kitchen to living room) and consist of normal and futuristic technology (e.g. a service robot that transports the pan).

In our 10 scenarios, the smart-home that supports the older person was created in such a way that a large diversity of devices was covered (see Appendix 5-A). Devices that are futuristic, currently not realistic, or not yet commercially available, were also included.

Simulations

We used simulations to perform the functional test for two reasons. First, using virtual devices instead of real devices improves the feasibility of the tests given the large range and complexity of devices needed in the scenarios (Appendix 5-A). Some devices are available off-the-shelf (e.g. microphones), others are still in development (e.g. 3D radar systems), or must be custom-made (e.g. transport robots). In these simulations, the devices existed only virtually and their development required only a limited amount of resources.

A second reason for using simulations is that we could exclude variables that did not (or hardly) influence the results, but that would disturb the tests. In other words: we could simplify the environment, user’s behavior, and devices, where this did not influence the final results of the tests. For instance, there are many variables that determine whether or not an older end-user interacts well with the technology (e.g. in the case of a graphical user interface: light conditions, layout of the interface, etc.). In a simulation we can eliminate these issues, and assume that the interaction of the end-user with the technology is ideal. In the real world, as we know, this is often far from true. For functional tests of the platform it is not important *how* a user interacts with the technology, but only *that* there is an interaction. Furthermore, our devices were also assumed to be ideal: when, for example, a sensor measures a value, it is not important *how* accurate the

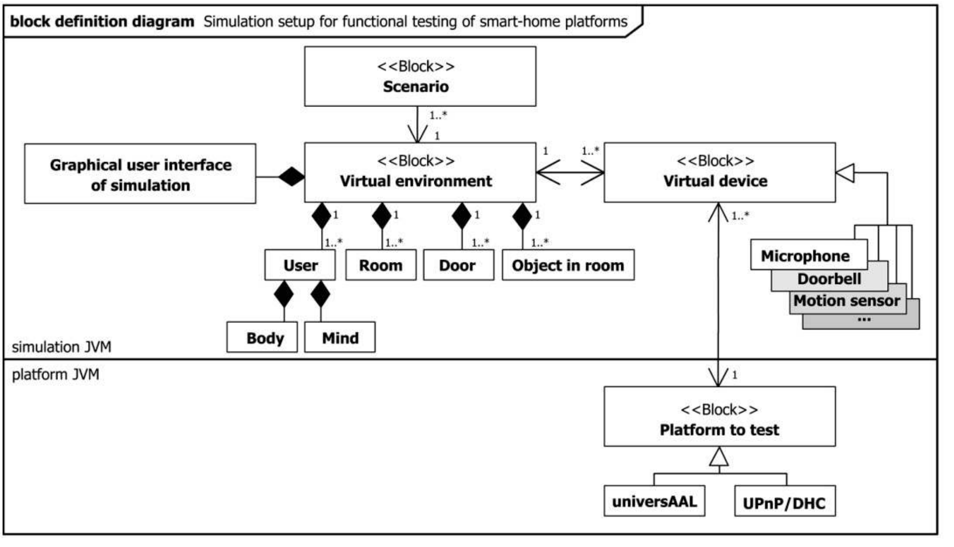

Figure 5.2: *Block definition diagram of the simulation setup. The smart-home platform and the simulation environment run on separate Java Virtual Machine (JVM). In this study, we tested the universAAL platform and a platform that is a combination of 'Universal Plug and Play' (UPnP) and 'Digital Home Compliant' (DHC)*

measured value is, but just *that* there is a measured value with a certain resolution. The purpose of the simulations is not to simulate the real world as good as possible, but rather to address all functionalities that are required from the platform.

We implemented a simulated environment in Java that consisted of three components (Figure 5.2). The first component was the (virtual) physical home-environment (e.g. rooms, doors, and furniture) including a user with a physical body and a mind that determining the user's behavior. Java3D[52] was used to implement and visualize the physical environment (Figure 5.3). The virtual environment also simulated time. This is done by initiating a new time-step after all elements of the simulation finished their actions of the previous time-step. The second component consisted of the scenarios that define the setup of the environment and the user's behavior. The virtual devices of the smart-home system form the third components of the simulation environment. These devices interacted with the virtual environment on one side, while being connected with each other via the platform on the other.

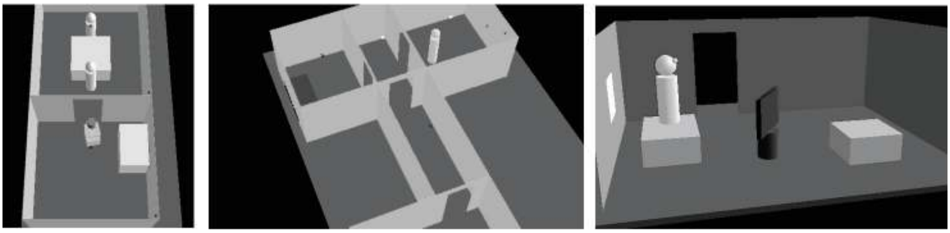

Figure 5.3: *Screenshots of the simulations of the 1st (left), 5th (middle) and 10th (right) scenario. Java 3D was used to implement and visualize the physical environment*

The platform was a real implementation of one of the smart-home platform tested. The platform was running on a different JVM than the simulation environment. The virtual devices of the smart-home system were designed in such a way that all the information needed for its operation was supplied via the platform, so the platform was optimally employed by the devices. The implementation of the 10 scenarios and the simulation environment can be downloaded from www.michielbrink.nl/simulations.

Functional testing and measurements

The main aim of the functional testing of a smart-home is to provide a request to the smart-home services and analyze the received responses[16]. We executed the functional tests by playing each of the scenarios in the simulation environment (e.g. the user calls for help to transport a heavy pan). This generated the requests to the services of the smart-home system described in the scenario. The smart-home system can only execute the correct response, if the system platform provided all functionalities that the smart-home devices required.

We measured two aspects to assess the platforms: (i) an observation of the response of the smart-home system in the tests of each scenario logged in detail and (ii) a log containing all smart-home services and how they were implemented on the platform.

We analyzed two aspects of the smart-home system responses. First, we analyzed whether the response to an action would help the user in performing his/her activity (e.g. transport a pan to the living room). If the action of the smart-home successfully helped the user perform this activity, the smart-home passed the test.

Second, we analyzed if the system behaved as designed, or if the system was unable to do so because of limitations of the platform (e.g. the lack of support for the exchange of complex data, like geometric data). If the smart-home managed to help the user in each scenario, and the smart-home system behaved as designed, we concluded that the platform was able to provide all functionalities needed by the smart-home devices.

From the platform's implementation log we analyzed if the platform was able to support the devices needed for the scenarios, or alternatively if platform adaptations or extension were required. In addition, if adaptations or extension were required, we analyzed whether these would be easily reusable and sharable, so that the devices could be functional on the platform under different circumstances for different developers at different times, with other system configuration. For the universAAL platform, this means extending the ontology, and an assessment of this extension as unequivocal or ambiguous. For the UPnP/DHC platform this means creating particular protocols and specifications.

Results

Each of the 10 scenarios could be completed by both universAAL and UPnP/DHC platform. A total of 61 devices and services were used in the scenarios performing 88 actions. Some devices were used in multiple scenarios. On average, each scenario employed 10 devices (Appendix 5-A).

To improve the feasibility of the simulations, we skipped some device implementation actions. This was because they involved the same interaction with the platform as previous implemented actions. The following implementations were skipped: the service robot in the fourth scenario for the UPnP/DHC platform (this would require the same interaction with the platform as for the robot in the first scenario), the return of the television-mover to its original location (scenario 10), and the action to restore the status of windows (open or closed) to their initial status (scenario 10).

The smart-home system behaved in all resulting scenarios according to its design for both platforms. This means that the platforms were able to provide all functionalities needed by the smart-home devices, such as discovery of devices on the platform, to subscribe for events (where needed), to publish and receive events, and to request and provide information. However, the universAAL platform needed an extension for 67 of the 88 actions, and the UPnP/DHC platform for 73 of the 88 actions (Appendix 5-A).

This means that the universAAL platform supported 24% of all actions outright. This included actions related to the physical (geometrical) world, like databases that hold information about the layout of the home. Also easily measurable units (like mass and temperature) and media (audio and video) were defined concepts in universAAL.

The ontology model of the universAAL platform allowed for easily added extensions in 61 out of 88 cases (69.3%). The connection of these actions with the existing ontology model was straightforward. Implementing extensions for the remaining six actions (6.8%) was more complex since there were no close related concepts of these actions in the ontology; i.e. there was more than one approach to extend the ontology for these actions. If developers used different approaches, multiple concepts of one action would be added to the ontology and this would diminish the reusability of that action. These more difficult extensions were related to user-profiling, medical prescription, and images (Appendix 5-A).

The UPnP platform (without DHC) supported 9% of required actions outright, such as media services (e.g. audio and video). In combination with DHC the percentage rose to 17%. The additional actions are related to robotic applications. The remaining 83% of the actions required additions to the UPnP/DHC platform.

Examples of devices that were not specified by either universAAL, or UPnP/DHC include human localization with infrared cameras (e.g.[53]), speech recognition (e.g.[54]), applications related to user-profiling[55] (e.g. the database that contains the cleaning preferences of the user), home appliances (e.g. the coffee machine), or specific smart devices such as the smart bookcase or the medicine cabinet.

We noted several non-platform related issues during the implementation of the scenarios. We did not include sufficient devices and services to determine if a user is cleaning (scenario 2). We used sensors to measure the use of the water tap, motion, and location of the vacuum cleaner, but these were not enough to recognize a cleaning activity. Also, in order to work properly, many devices need to know their location in the home, but most of these devices would not be able to provide this information. For example, it was simple to request a cup of tea via a touch screen (scenario 4). However, the location of the touch screen, and therefore the location of the user that requests the cup of tea, is normally not known. We chose to use the motion sensors in the rooms to determine the user's location. The drawback is that this only works when there is only one person is present in the home.

Discussion

In this study we started with health-profiles of older people to come to an overview of all forms of support that may be required by older people when they age-in-place. We used scenarios and simulations to assess two platforms on their suitability to support an older person at home.

After some extension or additions both platforms appeared suitable for an AAL implementation of the 10 scenarios. However, only about one fifth of the actions of the services and devices were supported by the platforms outright. Below follows a discussion on the feasibility of the required platform extensions.

universAAL

For universAAL the required extensions involve only extending its ontology model. The model is used to exchange information. It gives meaning to a value, and defines the relation between pieces of information (a chair is a piece of furniture, a physical entity, which has a shape and a location). A custom ontology could easily be created or extended. A developer of a device would have to define the purpose of a new device using the existing ontology. For example, a developer of a CO_2 sensor defines that the device is a (predefined) type 'Sensor' with a (predefined) 'PhysicalLocation', and provides a (predefined) 'Measurement'. The measurement has a (predefined) 'Unit' with a (predefined) 'MeasurableDimension' that is called 'CO_2'. Any other device that would need a measurement for CO_2 on a certain 'PhysicalLocation', would not need to know about the specific CO_2 sensor. Instead, it could just ask the platform for a 'MeasurableDimension' 'CO_2' on a 'PhysicalLocation'.

A total of 72% of all actions could easily be added to the ontology in this way. These ontological additions did not require any practical decision on how to construct this new ontology; it was straightforward. The extensions of the ontology were added to the overall universAAL ontology, so the concepts of these defined actions could be used by any other device, without the need for additional knowledge or information.

A total of four actions (5%) were harder to add to the ontology: (i) exchange of images, (ii) a query on the time of day that the user is willing to perform some cleaning activities, (iii) a query on how much time after a cup of coffee the user wants to start cleaning, and (iv) the exchange of a prescription for drugs. These concepts can in principle be added to the ontology in different ways, and discussion would be needed to decide how best to include them in the standard ontology model of the universAAL platform. For example, an image file could be added with the concept of 'EndPoints': the image is then be downloaded from a HTTP server. Alternatively, images could be exchanged over the platform by sending a base64-string. These decisions should be made centrally, to prevent inconsistency in the ontology model.

UPnP and DHC

UPnP works with predefined syntactic interfaces. The UPnP Forum[38] standardized several device control protocols with specifications of how a UPnP device of a certain type should name its services, actions, and variables. In our test, UPnP/DHC (as is) failed to support 83% of the 88 actions. The developer needed to choose for each new device how it will be supported. This choice includes the semantics of services, actions and variables, and also custom data types and data serialization.

For example, when UPnP has to implement a database service that provides a list of rooms in the home (relevant to all scenarios except for 3, 7, and 10), the developer has to decide how rooms are represented. By contrast, when an ontology model is available for Room, it already includes Location, Name, and Shape. The UPnP specification defines no framework for custom data types, so the result will be made complex with different frameworks used by the various developers of devices and services. Developers often use single strings for transporting semantics they consider necessary for their particular needs. The location and dimensions of a room can be transported by, for example, a string that contains eight coordinates (one for each corner of the room) which could look like this: “$(x_1,y_1,z_1),(x_2,y_2,z_2), \ldots,(x_n,y_n,z_n)$”. Alternatively, one coordinate and three lengths can be used too (x, y, and z as the dimensions of the room). In our case, DHC specified how a room is represented (location, shape, etc.). However, other complex data structures, like a medicine prescription, have not been specified by DHC. UPnP allows for constructing these data structures in many different ways (e.g. “(name medicine, dose-per-time, times-a-day)”), which makes creating a uniform medicine-prescription service enormously challenging.

This problem is also recognized by other researchers. Solutions are sought using the Semantic Web[29] and Web Ontology Language (OWL)[56], but these solutions have often a limited focus, such as the transfer of audio and video (e.g.[57]). For the use of UPnP for AAL, extensions for all technological domains should be available, in the same way that DHC addressed the robotics domain. DHC already includes all functionalities that were required to support the robotic related devices in the 10 scenarios.

Consequences for AAL

A platform that supports a broad range of applications is important to arrive at successful AAL for several reasons. Firstly, older people need a broad range of support applications at home[7]. Secondly, a widely used platform is a necessary precondition for the future growth of the market in AAL products and services[58]. Thirdly, AAL services often require information from multiple devices. In our study, all 61 devices in the 10 scenarios needed information from other devices. AAL services can therefore only be developed when the engineer knows that the platform supports a combination.

The design of the two platforms supported about 20% of the required devices outright. For other platforms on the market or in development, this percentage is not expected to be any higher. Most platforms focus on a specific application domain (e.g. building or home automation, such as OpenRemote[37]), focus during their development on a limited number of use-cases or scenarios (e.g. the Netcarity project[59]), or are purely middleware and do not intend to define information models or protocols for applications (e.g. OSGi[41]). In all cases the required flexibility of platforms should preferably focus on uniformity of procedure when adding new devices, rather than on continuously providing new complete sets of device protocols.

A model describing the information that is exchanged via the platform is crucial. A vendor lock of devices, more likely in UPnP-like platforms, inhibits developers to use each other's information, and knowledge of what the information stands for. The ontology model of the universAAL platform includes this common understanding and this is an important advantage for any platform to be suitable for AAL. Other platforms with a comparable ontology approach include OASIS[33], PERSONA[60], and SENSEI[61].

Further research

In this study we focused on the functional suitability of platforms for AAL. There are several other factors of a platform that can influence its suitability. Among them are the adaptability of a platform, costs, reliability, safety and privacy issues, and the technical performance of platforms. Also, as we have seen, new devices and services need further development in order to complete the simulated scenarios.

Furthermore, although we created a comprehensive overview of the wide range of the user's limitations and requirements, we could only test 61 devices. Also, since the devices greatly influence the test results it is advisable to perform more tests with a different set of devices.

Although our methodology has global applications the scenario we used were derived from observations of older Dutch adults 65-85 years old. Daily activity patterns used in our study apply to the whole European region[62], but the health information has a more limited regional validity[48]. Published worldwide health-profiles are available from the World Health Organization[63], and local organizations, such as the Network of Public Health Observatories in case of the UK [64].

Finally, we recommend validating the simulations with real tests later in the development process of platforms.

Conclusions

We describe a functional testing method for smart-home platforms. This method consists of the use of scenarios as test cases for functional tests in a simulation environment. We successfully created 10 AAL scenarios where support is provided by smart-home devices, applications and services, ranging from leisure to housework and care, required by older people when they age-in-place.

The result of such a functional assessment would guide the further development of platforms to arrive at a platform that supports all required functionalities. Extended platform versions of universAAL and UPnP/DHC are able to support the required devices, applications and services. The extensions needed for the UPnP/DHC platform include specifying semantics and creating custom data types. Extensions for the universAAL platform include customization of the platform's ontology model, which allows for the addition of these extensions in a constructive and sharable way in order to foster reuse by other smart-home systems.

The importance of this reuse of platform extensions is the fact that 4/5 of the smart-home applications in the AAL scenarios will not work without an extension of the platform. The use of an ontology model for platforms is advisable because of its quick and easy adaption to new devices and services, needed to the worldwide rollout of smart-homes[7].

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Appendix 5-A: *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	**Service**	**Supported by**					
		universAAL			**UPnP/DHC**		
		Outright	**Addition**		**UPnP**	**DHC**	**No**
			Easy	**Hard**			
IN 8 OUT OF 10 SCENARIOS							
Scenarios: Serving a meal (1), Home cleaning (2), Providing medical care (3), Getting & consuming a hot drink (4), Going to bed (5), Receiving visitor at entrance door (6), Using a dictionary (7), and Sporting (8)							
Broadcast audio stream on a location	Speaker	X			X		
Convert text into spoken words	Speech synthesizer module		X				X
IN 7 OUT OF 10 SCENARIOS							
Scenarios: Serving a meal (1), Home cleaning (2), Getting & consuming a hot drink (4), Going to bed (5), Receiving visitor at entrance door (6), Sporting (8), and Playing a video game (9)							
Provide names for all rooms in the home	Floor plan database	X				X	
Provide route in coordinates from point A to B		X				X	
Provide geometry of all rooms in the home		X					X
Provide geometry of all walls in the home		X					X
Provide order of rooms to go from point A to B			X				X
IN 5 OUT OF 10 SCENARIOS							
Scenarios: Serving a meal (1), Home cleaning (2), Going to bed (5), Receiving visitor at entrance door (6), and Using a dictionary (7)							
Provide audio stream of sound on a location	Microphone	X			X		
Recognize spoken words	Speech recognition		X				X
Recognize location of spoken words			X				X
IN 4 OUT OF 10 SCENARIOS							
Scenarios: Home cleaning (2), Going to bed (5), Receiving visitor at entrance door (6), and Playing a video game (9)							
Display text on television	Television		X				X

Appendix 5-A (continued): *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	Service	Supported by					
		universAAL			UPnP/DHC		
		Outright	Addition		UPnP	DHC	No
			Easy	Hard			
IN 3 OUT OF 10 SCENARIOS							
Scenarios: Home cleaning (2), Going to bed (5), and Sporting (8)							
Sense presence of a someone in room	Motion sensor	X			X		
Scenarios: Serving a meal (1), Getting & consuming a hot drink (4), and Receiving visitor at entrance door (6)							
Provide locations of all people in room	Infrared camera		X				X
Scenarios: Serving a meal (1), Getting & consuming a hot drink (4), and Watching television (10)							
Provide geometry of non-moving objects in room	3D radar system	X					X
IN 2 OUT OF 10 SCENARIOS							
Scenarios: Home cleaning (2) and Going to bed (5)							
Indicate water running from tap	Water-flow sensor	X					X
Switch lights on/off at specified location	Lighting service	X					X
Scenarios: Receiving visitor at entrance door (6) and Playing a video game (9)							
Provide video stream	Video camera	X			X		
Scenarios: Sporting (8) and Watching television (10)							
Open/close window	Window	X					X
IN ONE SCENARIO ONLY							
Scenario: Serving a meal (1)							
Get assignment to pick object X up at location Y	Robot transporter		X			X	
Get assignment to drop object X off at location Y	Robot transporter		X			X	
Provide coordinates of object on cooker	Smart cooker		X				X

Appendix 5-A (continued): *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	**Service**	**Supported by**					
		universAAL			**UPnP/DHC**		
		Outright	**Addition**		**UPnP**	**DHC**	**No**
			Easy	**Hard**			
Scenario: Home cleaning (2)							
Advise user on cleaning activities	Cleaning-adviser service		X				X
Provide location of vacuum cleaner	Vacuum-cleaner localization		X				X
Display text on display screen	Text-display		X				X
Indicate use of coffee machine	Coffee machine		X				X
Provide user's preferred time of the day for cleaning	Cleaning-preference database			X			X
Provide user's preferred time between coffee & cleaning				X			X
Scenario: Providing medical care (3)							
Measure weight	Scale	X					X
Guide user in selecting correct medication	Medicine-selector service		X				X
Provide position of medicine in cabinet	Smart medicine-cabinet		X				X
Provide list with all medicine in cabinet			X				X
Provide list with all positions of objects (medicine) in cabinet			X				X
Report when medicine-cabinet is opened/ closed			X				X
Display images on screen	Display			X	X		
Provide weight of pill	Medicine database		X				X
Provide images of medicines				X			X
Exchange prescription information to other services	Medicine prescription database			X			X

Appendix 5-A (continued): *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	**Service**	**Supported by**					
		universAAL			**UPnP/DHC**		
		Outright	**Addition**		**UPnP**	**DHC**	**No**
			Easy	**Hard**			
Scenario: Getting & consuming a hot drink (4)							
Provide location of hot fluid	Infrared camera	X					X
Provide temperature of hot fluid		X					X
Report when hot fluid is moving		X					X
Bring drink to user on request	Service robot		X			X	
Warn user when attempting to drink hot fluid	Hot-fluid warning service		X				X
Allow user to order drink	Touch screen		X				X
Scenario: Going to bed (5)							
Provide channel that is selected on television	Television	X					X
Switch off television			X				X
Guide user to bed	Bed-guiding service		X				X
Provide all appointments of user	Agenda		X				X
Provide required sleep duration	Sleep-pattern database		X				X
Provide duration of user's previous night sleep			X				X
Provide television programming	Television guide		X				X
Display text messages on mirror	Smart mirror		X				X
Convert text into speech	Smart radio alarm		X				X
Report someone's presence in bed	Bed sensor		X				X
Scenario: Receiving visitor at entrance door (6)							
Play audio on television	Television	X			X		
Play video on television			X		X		

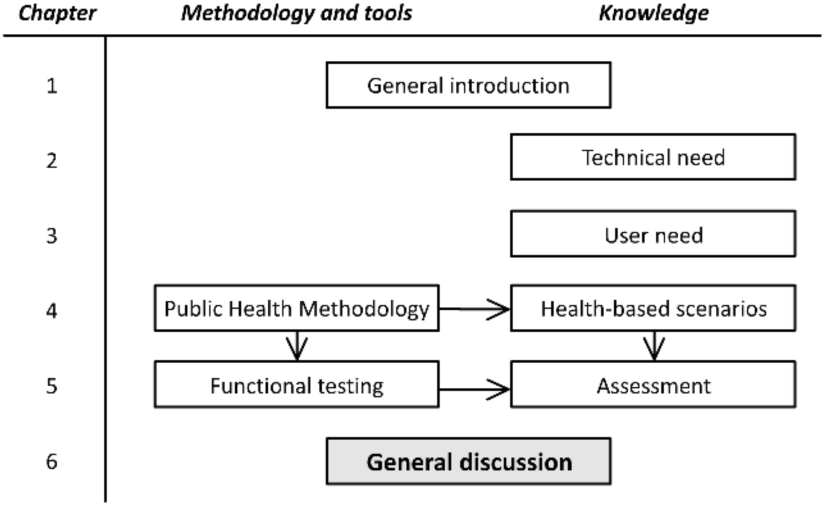
Appendix 5-A (continued): *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	Service	Supported by					
		universAAL			UPnP/DHC		
		Outright	Addition		UPnP	DHC	No
			Easy	Hard			
Mute television	Television		X				X
Help user to decide who is allowed into the home	Access-control service		X				X
Open/close entrance door	Door		X				X
Lock/unlock entrance door			X				X
Provide weekly performed user activities	Activity database		X				X
Report ringing doorbell	Doorbell		X				X
Scenario: Using a dictionary (7)							
Help user in searching in books	Book-search service		X				X
Locate specific book in book case	Smart book case		X				X
Locate all books in book case			X				X
Highlight location of book			X				X
Provide information on type of book	Book-database		X				X
Locate word in dictionary			X				X
Report book going in or out book case			X				X
Scenario: Sporting (8)							
Provide ambient air temperature	Thermometer	X			X		
Provide heart-rate of user	Heart-rate sensor	X					X
Monitor workout of user	Workout-monitor service		X				X
Report user is doing workout exercises	Movement sensor		X				X
Provide ambient air humidity	Hydrometer		X				X
Provides ambient CO_2 level	CO2 sensor		X				X

Appendix 5-A (continued): *Services and actions executed by a simulated smart-home systems pertaining to the 10 selected scenarios and the support given by universAAL and UPnP/DHC platforms. For universAAL, we indicated if the action was supported by outright, easy to add to universAAL's ontology, or outside the scope of current ontology (hard). For the UPnP/DHC platform, we indicated if the action is specified by UPnP, DHC, or not specified (No). Scenarios are fully explained in Table 5.1*

Action	Service	Supported by					
		universAAL			UPnP/DHC		
		Outright	Addition		UPnP	DHC	No
			Easy	Hard			
Provide maximal air temperature that is healthy for user	Health-profile database		X				X
Provide maximal air humidity that is healthy for user			X				X
Provide maximal CO_2 level that is healthy for user			X				X
Provide maximal heart-rate that is healthy for user			X				X
Scenario: Playing a video game (9)							
Display images on television	Television			X	X		
Show game-cover on television that is pointed at	Game-cover enlargement service		X				X
Show subtitles on television of a spoken text	Subtitle-service		X				X
Provide images of game-covers	Game-cover database		X				X
Scenario: Watching television (10)							
Provide sound level of a location	Microphone	X					X
Move television to another position	Television-mover robot		X			X	
Rotate television			X			X	
Provide information on the television program that is watched by user	Television		X				X
Improve experience for user when watching television	Experience-enhancer service		X				X
Provide coordinates on the position of the user's head	Video camera		X				X

Chapter 6: General discussion



Based on the needs and aspirations of older people, integration of smart-home technology in building design, construction, and maintenance is needed for successful aging-in-place. As we have seen, this calls for a universal software platform (Chapter 2 and 3). The platform should support all technology that might be needed by older people at home, in public buildings, in offices and nursing homes, now and in the future. These needs can be defined by scenarios that are based on a combination of health-related limitations and daily activities (Chapter 4).

Functional tests show the suitability of platforms for aging-in-place, using scenarios as test cases, and simulations to perform the tests (Chapter 5). An assessment of two platforms show that extendibility of the platforms, for instance through ontology, is crucial when creating a platform that is suitable for aging-in-place. Although its ontology is not yet complete, the universAAL platform is meeting this requirement. However, a number of questions still remain unanswered in this research.

6.1 Scenarios

The scenarios that were created for this thesis have limited diversity. A much greater diversity of scenarios should be created to capture all required assistance for the target population. In this thesis we have focused on the most common diseases of Dutch older adults in each health profile, excluding less common diseases. Our group incorporates 5 out of 8 diseases that have a prevalence of the highest category (5.8% to 1.7%), and 4 out of 10 diseases from the highest but one category (1.7% to 0.58%)[1].

A set of 31 daily activities were used to create the scenarios. However, each activity consists of multiple subactivities that could also require particular assistance. These subactivites are not included in our scenarios. Including the subactivities in the scenarios would tailor them more specifically, and therefore make them more useful[2]. Also less common (or less daily) activities should be included in the scenarios in the future (e.g. accidents), to cover a wider range of required assistance. Another limitation: we have focused on The Netherlands, and Asian countries for example will have different health profiles, limitations, or daily activities that should be added to the PHM databases.

The scenarios created for this thesis will have to be updated in the future: the devices and services that are used in the scenarios are selected based on the technology that is currently available (82%) as well as technology that is expected to be available in the near future (like specific service robots, 18%). When new technologies emerge that act or react differently, platform requirements could change. Think for example of biomechanical applications or nano-materials that may call for more complex data types, like DNA for a biomechanical application. These would require an updated set of scenarios.

Furthermore, scenarios could be made more realistic to gain more accurate results. This could include realistic user behaviors as described in the literature[3,4], and a refinement of realistic interaction between user and the user-interfaces of technologies. In particular older users' attitude and acceptance towards technology (e.g. robotics) could be included[5,6]. Furthermore, the building-environments could be improved by making them more realistic with the use of game engines[3], or even active 4D CAD models in a Building Information Model (BIM)[7].

Finally, we designed the scenarios in such a way that all technologies must be supported by the platform. This might be best for testing the platform, however this does not mean that it is also best from a usability and utility point of view. In some situations a user will be better supported by purely mechanical solutions, or an electronic solution that is not connected with the platform. One should keep this in mind when using the scenarios for other purposes than testing platforms.

6.2 Enrichment, prevention and care

The research in thesis is limited to compensation for limitations of older adults and providing assistance to them. Scenarios for personal fulfillment, prevention and care need testing as well. By doing so, all four main goals that are defined by Gerontechnology are addressed[8], leading to a more comprehensive set of scenarios to assess platforms for aging-in-place.

Personal fulfillment, pleasure, leisure, and creativity play a central role in human culture and an individual's development. Research has shown that participation in a simple cultural fun program increased health rating, decreased the number of doctor visits, decreased number of falls, improved mood, and stimulated other activities[9]. Therefore it is important that smart-buildings also support leisure activities, like easy access to media, games[10], and sports[11]. These activities should therefore be included in the scenarios for platform testing.

Preventing loneliness, diseases, and trauma caused by accidents, also has a huge positive impact on someone's wellbeing. Here the role of the smart-building could consist of support for social inclusion by robots[12], early detection of diseases by monitoring[13], or technological support for fall prevention[14], but also detecting falls to prevent further subsequent physical and psychological trauma[15,16]. In addition, guaranteeing a healthy indoor climate from the earliest age will prevent sensitization and symptom development of allergies caused by mites and fungi that flourish in damp indoor spaces[17].

Care at home in the form of telehealth, telemedicine, and telecare is often suggested as a way to support aging-in-place, to enhance quality of life, and to decrease the workload for professionals. Although empirical evidence is missing[18], and implementation faces many bariers[19], this development is still pursued and more applications become available[20]. A platform should therefore be able to support these new technologies.

6.3 Platforms

Although we have shown that at least two platforms theoretically seem suitable for aging-in-place, other platforms should also be evaluated using the testing method that we have introduced. A comprehensive overview of the suitability of platforms for aging-in-place could then evolve. To facilitate this process the simulation software and a manual can be downloaded from www.michielbrink.nl/simulations.

In our platform-assessment we focused on the difference between a platform with a semantic system or ontology model (universAAL platform), and one with fixed terminology and descriptions (UPnP/DHC platform). When testing other platforms it may be useful to focus on a specific technological aspect, and select platforms accordingly. For instance, one could focus on centralized vs. distributed intelligence[21], the use of software agents[22], or Web Services[23]. This would gain insights into the (dis)advantages of technological aspects of platforms for aging-in-place.

There are many open-source platforms that could be tested: the RAALI project identified 54 different platforms that are suitable for Ambient Assisted Living (October 2012)[24]. However, only 10 platforms have made their software available; have recently (past 2.5 years) updated their software; and focus on more than one application. These platforms include universAAL[25], openAAL[26], HYDRA[27], MundoCore[28], openHAB[29], openUCR[30], OSAMI[31], IP-Symcon[32], mBS Smart Home

SDK[33], and OpenRemote[34]. Except for universAAL, that was tested, all other 9 are still awaiting assessment.

6.4 Assessment

Apart from using the simulation environment for platform assessment, it could also be suitable as a tool to assess the compatibility of a service (or application) and a platform. Vendors of smart-home products could use the simulation environment to verify whether their product is suitable for the available platforms.

Platform assessments are currently limited to *function* testing, although *performance* is also important for the suitability of platforms for aging-in-place. With software performance testing, platforms can be tested on aspects such as responsiveness, stability, reliability, resource usage, and scalability[35,36]. In addition, a benchmark can be developed to compare platforms. Extensions of the simulation environment would be needed to meet these requirements.

In addition, non-technological requirements are important for the suitability of platforms for aging-in-place. These include the influence of a platform on organizational aspects such as the total costs and the maintenance of a system, but also aspects related to the end-user’s acceptation, use, and privacy issues[37]. These aspects are outside the scope of this research, but that does not mean they are of lesser importance than technological requirements.

For example, the acceptance and use of the technology by the end-user is important for the success of smart-homes for aging-in-place, and much research has been conducted in this field, for instance on acceptance of robots by older people[6]. The acceptance and use can be described by the Unified Theory of Acceptance and Use of Technology (UTAUT), formulated by Venkatesh et al[38]. This model describes four key constructs and four key moderators (gender, age, experience, and voluntariness) that define the user’s intentions to use technology and subsequent usage behavior (Figure 6.1).

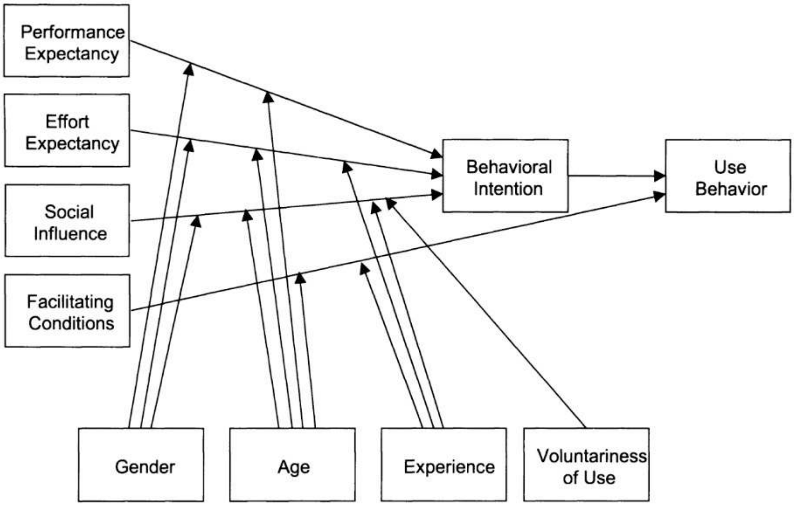


Figure 6.1: *The Unified Theory of Acceptance and Use of Technology (UTAUT) model. The behavioral intentions and use behavior are determined by four key constructs (left) and four key moderators (bottom). Source: Venkatesh et al*[38]

A platform plays a role in three of those constructs. Especially the construct 'performance expectancy' (the degree to which an individual believes that using the system will help him) is highly influenced by the offered functionality of the platform. 'Effort expectancy' (the degree of ease associated with the use of the system) is indirectly related to the platform's offered functionality, since it is the platform that determines whether an easy-to-use interface is supported or not, as we have discussed in a previous publication[39]. Furthermore, the role of a platform is minimal for 'social influence' (the degree to which an individual perceives that important others believe he or she should use the new system), while 'facilitating conditions' (the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system) is again highly influenced by a platform. It is therefore important to assess platforms on 'performance expectancy', 'effort expectancy', and 'facilitating conditions' in the future to improve the acceptance and use of smart-homes.

6.5 Implementation in practice

The practical implementation of software platforms comes with new challenges. When more smart-home applications and services become available, more decisions in the design of a smart-home for aging-in-place need to be made. Building professionals should understand the needs of the older user before a smart-home can be designed.

The Public Health Method (PHM) described in Chapter 4 can be used by construction professionals to gain understanding of older adults' needs, and customize the design of a building to the needs and limitations of older people. Today, the construction industry uses participatory research methods and meetings or focus groups with end-user experts to gain understanding of the older end-user. Compared to these methods, PHM would be more structural and easier to use for constructions professionals.

Use of PHM could be especially interesting for MEP engineers (Mechanical and Electrical engineering and Plumbing), also referred to as building services engineers, who are responsible for the inclusion of services in a building to make it a healthy, safe, and pleasant environment for the inhabitants. Older people have a different health profile compared to younger ones[40]: they have a higher morbidity of chronic diseases and age-related inflictions. This changes their perception of a healthy, save, and pleasant built environment. The services that MEP engineers design must therefore change in aging societies.

PHM use

PHM could be of use for MEP engineers when it is implemented in a software tool, for instance a website or mobile app. The website or app would requests of the MEP engineer to provide a user's health condition and will then supply all circumstances that require some sort of assistance in the built environment. These could be used to either test a design, or to guide the design process. When needed, the circumstances could be used as a basis for scenarios. The website or app would implement PHM by combining limitations of common diseases (as defined by the ICF) in a database with the daily activities that people perform in the building.

The required customization of the building design derived from PHM could increase the complexity of the design and may increase the design costs, since most of this must be done manually. Incorporation of PHM in a Building Information Model (BIM) could resolve this issue. Currently BIM is mainly used for inter-operability, integration, model-based communication, and collaboration in building projects, using passive 3D models[41]. In this form, BIM is useful to validate the design for its suitability to support the user with a given health condition. Active 3D models, and even 4D (including time as a dimension) have the potential to utilize both automated design and changes over time[42]. Ideally, the PHM would automatically apply required modifications in the design.

Limitations of PHM

PHM needs several extensions before it is suitable for practical implementation. Firstly, PHM is now limited to daily activities in homes, so the measures used for the design of a house will help the older inhabitant to perform their daily activities. However, support for non-daily activities might be vital under some circumstances, think of help during an emergency situation (e.g. fire). Therefore, PHM should be extended for these non-daily activities. For MEP, additional activities would be needed for offices, public buildings, nursing homes, and hospitals.

Secondly, while PHM will indicate the need for support, it does not offer the solution. Many assistive technologies exist, and for an effective use of PHM by MEP, we suggest to extend the PHM website or app with available assisted-technology solutions. Research is still needed to investigate the effectiveness of most solutions. Outcomes of these researches should also be included in the website's database.

Thirdly, PHM needs expansion to implement needs related to personal development and satisfaction, accident prevention and engagement, and care support and organization in the building design. For example, based on a user's health profile, one could derive the support for care and organization of care that is required. These could be translated into events to take place in the building, and can be added to the circumstances or scenarios that are generated by the PHM.

Implementing solutions

The solutions that are needed to support older adults in buildings are diverse and include relatively simple solutions (e.g. avoiding the use of thresholds in a house), but also more complex solutions like Ambient Intelligence (AmI) applications[43] that can be integrated in smart-homes or intelligent buildings[44]. New ICT will be required, such as more advanced Building Automation System (BAS), or software platforms for smart-homes. This means that the expertise of the MEP engineer will need to be expanded with AmI technologies such as installation of AmI hardware devices, but also the deployment of AmI software.

In contradiction to current smart-phone applications, where apps are easily installed, an AmI building has a system configuration ill suited for immediate installation. One does not know what services, interfaces, and devices will be available in the future (while a smart-phone will always have a touch screen, microphone, speaker, etc). This means that, in the near future, the configuration of an AmI building will partly remain a manual process. And this “manual” process will be incorporated into the activities of the new MEP engineer in the design process of a building. This means that the building will not only be physically designed, but the software will be ‘designed’ (or developed) alongside the physical design process, using for instance a Scrum development method[45]. As developments continue, the software deployment of the system will be increasingly automated, but especially the first generation of widely applied AmI systems will need a proper manual deployment. When the whole building design process is automated, the preparation of the software can also be automated.

Although it is the responsibility of the new MEP engineers to design buildings that are suitable for older people, it is unlikely that MEP engineers will develop the software to innovate network technologies and AmI hardware devices. This will be done by the current suppliers of network technologies and the ICT or electronics industry. This could be in the shape of an extension of smartphone and tablet functionalities.

6.6 Impact on society

With the results of this study and the research that is still to be conducted in the future, we hope that the development of platforms will be better guided, to arrive at smart-homes suited for aging-in-place. PHM may provide smart-home designers and MEP engineers an overview of the support that the home environment should provide. This overview will help them to design smart-homes that fit the needs for assistance required by the older end-user. By using the functional testing method, platform developers can assess their platform at an early stage of development, to arrive at a platform that suits all applications required by older people.

A good platform is important for the success of smart-homes for aging-in-place. Firstly, a platform boosts technological development, since developers do not need to start from scratch each time they develop a smart-home application[46]. Secondly, new and more advanced applications will be possible, since a platform provides easy access to all available information. This is important, since older people require more smart functionalities than are now available on the market[47]. Smart 'behavior' of a home starts with the availability of information: the home should *know*, before it can *act* smartly. And, thirdly, widespread introduction of smart-homes requires a uniform platform[37]. Once a platform becomes standard, fewer resources are needed for development of technologies, more applications become available, and competition between vendors may lower the prices for products.

For example, the existence of a uniform platform would be indispensable for the development of products and services for fall prevention, detection, and management[48]. There is a great need for these types of devices, since in The Netherlands most accidents at home are due to falling[49]. However, to prevent or detect a fall, a complex system is required that needs information from various devices, like cameras[50], smart-floors[51], wearable sensors[52], accelerometer[53], and acoustic sensing[15]. A platform is therefore necessary to integrate the devices. Furthermore, a uniform platform will increase the success of such products or services, since sensors from various vendors can be combined. Moreover, when more information is available through the platform, prevention, detection, and management can me more sophisticated.

The development of a uniform platform will influence Politics, Economics, and Sociology (together with Technology four elements of the PEST-analysis[54]). Greater availability and cheaper smart-home applications would mean that more people would be able to live independent in their own homes; a desired political outcome. This will help alleviate the upcoming shortage of professional and family care. An economical impact would be the growth of the smart-home market, and a social impact would imply a potential higher quality of life for older people and a higher availability of workforce for other sectors than care.

Our effort to guide the development of smart-homes will hopefully contribute to suitable smart-homes for aging-in-place, which will be a necessity in an aging society.

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Summary

In this thesis software platform requirements for aging-in-place are explored and two platforms are assessed for their suitability.

Aging-in-place has been defined as living independently and healthily in your own environment as long as possible, postponing or preventing institutionalization. The need for aging-in-place will increase in the future due to recent demographic changes. In many societies the number of older people increases while the available personnel and family members to take care of people decreases. Aging-in-place would be a solution and can be achieved if Information and Communication Technology (ICT) is used to support older adults at home.

The concept of aging-in-place is connected in this study to smart-homes, i.e. homes equipped with technology that provides support. Smart-homes consist of devices like sensors (e.g. microphones or thermometer) or actuators (e.g. an automatic door or a service robot) that communicate with each other over a network. By exchanging and sharing information, services and devices cooperate to support the user of the smart-home. Examples of these services and devices include social gaming, tele-care, health monitoring, and fall prevention, detection and management.

A software platform is used to integrate the technology of a smart-home. For example, if the user requests to turn on the lights through a user interface, this command will be shared by the platform with a lighting service so the lights will come on. Platforms typically consist of middleware (software that provides easy access for devices), semantics for identifying both services and variables, and tools (for example algorithms that are able to make intelligent decisions). From a technological point of view, platforms are indispensable for the development of smart-homes for aging-in-place. Platforms are the point of departure for the development of a wide range of smart-home products and devices.

In recent literature the development of a platform is discussed overwhelmingly as a technological issue. Consequently, platform development is currently based on technological requirements only and does not include the end-user needs. The architectural design of the platform has a large influence on the delivered functionalities of the smart-home system. Because platforms of the future are being developed today, it is necessary to gain insights whether platforms are suitable to support what is needed by the older end-user. Therefore, we address in this thesis the following questions: (i) why is there a need for a platform , (ii) does the older person who ages in place benefit from the usage of a platform in his/her smart-home, (iii) what is expected from such a platform now and into the future to be suitable for aging-in-place, and (iv) do state-of-the-art platforms meet these expectations, and how can we test this.

Technology needs a platform

Older people that age in place can be supported by home automation, robotics, assistive technology, geriatric telecare and telemedicine (Chapter 2). However, most of these products and services operate on a stand-alone basis. This means that they do not cooperate in supporting the older adult, do not exploit each other's resources, but also may even be (unintentionally) mutually obstructive. This may result in inefficient and unreliable technology and is a huge barrier for successful aging-in-place.

In order to improve the efficiency and reliability of the technology to support aging-in-place, products and devices should be integrated. Integrating different technologies is a multidisciplinary technological challenge that will require advanced and modern ICT. A good software platform can deliver the required level of integration and interoperability to increase the quality of life of older adults and decrease the healthcare burden in aging societies.

The user needs a platform

In Chapter 3 the conclusions of our analysis of 23 smart-homes for aging-in-place on smart-home projects are presented: platforms are not only desired from a technological viewpoint, but also the user's viewpoint. The extent of smart-home systems' relevance for different levels of the Maslow deficiency needs is investigated, as well as the corresponding level of integration of smart-home systems.

Only those smart-home systems that are capable of a high level of integration support all 5 Maslow's levels of deficiency needs: (i) physiological, (ii) safety - related, (iii) social, (iv) esteem-related, and (v) self-fulfillment or self-actualization. To arrive at this level of integration, a universal platform is required supporting all the technology that is needed to support older people at home. This fits in with the vision of the Ambient Assisted Living Open Association (AALOA): using a platform that integrates many devices so they act as one device that provides all required functionality.

Public Health Methodology (PHM)

PHM is the subject of Chapter 4. Scenarios were chosen to capture the support required by older people when they age-in-place. These scenarios are based on a combination of defined relevant health-related limitations, and on daily activities that people perform.

Health-related limitations are collected in two steps: first health profiles were analyzed that define the health condition of our target group (Dutch people, aged 65-85 years, living independently at home). Secondly, the International Classification of Functioning, Disability and Health (ICF) was used to identify the limitations that are associated with a health condition. A total of 118 health-related limitations were identified.

Common daily activities of older people at home were retrieved from studies of the Sociaal Cultureel Planbureau (SCP). These activities are clustered in 31 common daily activities.

By combining all limitations with these daily activities a complete overview was created of the support that older people might require when they live at home independently. For aging-in-place, technology must be able to provide all the required support. Platforms will therefore have to be compatible with all required forms of technology.

To apply these requirements, we chose to create scenarios, which consisted of:

- A user and his/her limitations;
- An activity that the user wants to perform;
- A physical setting in which the activity is performed (the home); and
- The technology (devices, applications, or services) that supports the user in doing his/her activity.

Ten scenarios were created that cover most combinations of limitations and activities of older people that live independently at home in the Netherlands. These 10 scenarios were used to check a platform's suitability for aging-in-place.

Assessment of platforms

The assessment through scenarios of platforms for their suitability for aging-in-place is the subject of Chapter 5. Functional tests were used to assess whether platforms support the technology that is required for aging-in-place. The scenarios were used as test cases for functional tests. The great variety of combinations of environmental conditions and devices in the scenarios called for a simulation with virtual devices.

The simulations consisted of the following components:

- A virtual environment (rooms, doors, furniture, etc.) with virtual users;
- A scenario that directs the behavior of the environment and the user;
- Virtual devices that obtain information from the environment (sensors), or influence the environment (actuator, like a robot), and are connected to the platform; and
- A real (implementation of a) platform, that connects all devices, and provides all functionalities that the devices need to support the user.

In a virtual simulation environment, 2 platforms were tested: the universAAL platform, and the Universal Plug and Play (UPnP) platform in combination with the Digital Home Compliant framework (DHC). The latter (DHC) uses UPnP and is designed as a platform for service robots. Functional test using the 10 scenarios were performed. These included 61 devices that are able to perform 88 different actions that the smart-home must perform to support the user in the scenarios.

Extended platform versions of universAAL and UPnP/DHC were able to support the required devices. The universAAL platform supported 21 of 88 actions (24%). The remaining 67 actions required platform extensions. This included customization of the platform's ontology model, allowing extensions in a constructive and sharable way in order to foster reuse by other smart-home systems. The UPnP/DHC platform was capable of supporting 15 out of 88 actions (17%); here, the needed extensions required specifying semantics and creating custom data types.

Reuse of platform extensions is an important feature, since on average 4 out of 5 of the smart-home applications in the scenarios will not work without a platform extension. The use of an ontology model for platforms is preferable because of its easy adaptability to new devices and services. Therefore the universAAL platform is better suited to support aging-in-place as compared to UPnP/DHC.

Limitations and future research

Implementation of the study result in practice, limitations of the study, and follow-on research are discussed in Chapter 6. The use of PHM in the construction industry to design buildings suitable for aging societies is discussed. Constraints of this study are the still limited number of assessed platforms, and the number and narrow scope of the scenarios. More platforms should be tested using more and divers scenarios. It would also be fruitful to perform other types of tests, since functional testing only was conducted as part of this study. In addition a wider use of our assessment method (PHM) should be further explored in order to apply MEP (Mechanical & Electrical engineering and Plumbing) to the aging society.

Conclusion

This study has shown the needs and requirements for platforms in smart-homes that support aging-in-place. The innovative use of the ICF, health profiles, standardized daily activities, scenarios, functional tests, and simulations have hopefully laid a most-needed basis for the future, successful development and roll-out of housing concepts for older adults.

Samenvatting

Dit proefschrift betreft de analyse van platforms voor hun geschiktheid om te gebruiken bij het langer zelfstandig laten wonen van ouderen.

Door de vergrijzing van de samenleving neemt het aantal ouderen toe dat niet meer zelfstandig in hun eigen, oude, huis kan blijven wonen. Hierdoor stijgt de vraag naar personeel voor verpleeg- en verzorgingshuizen, terwijl tegelijkertijd de beroepsbevolking krimpt. Er zijn slimme technieken nodig die er voor zouden kunnen zorgen dat ouderen wél langer zelfstandig en gezond in hun eigen woning kunnen blijven. Smart-homes zijn een veelbelovende toepassing op dit gebied. Een smart-home bestaat uit een huis of appartement, toegerust met een set sensoren (bijvoorbeeld een thermometer of microfoon) en actuatoren (bv. een automatische deur of service robot), die verbonden zijn in een datanetwerk. Sensor en actuatoren werken samen om de dagelijkse activiteiten van de bewoner te faciliteren.

Een smart-home vereist een technisch platform waarop alle apparaten aangesloten worden zodat deze naadloos samenwerken. Dit platform zorgt ervoor dat alle informatie van elk apparaat beschikbaar is voor alle andere apparaten op het platform. Een platform bestaat meestal uit middleware software voor toegang tot informatie. Verder heeft een platform een semantisch framework dat bestaat uit een set benamingen voor de soorten informatie die uitgewisseld worden (bv. de term ‘temperature’ voor een waarde die de temperatuur aangeeft). Tot slot kunnen platforms specifieke gereedschappen hebben, bijvoorbeeld om op basis van slimme algoritmes intelligente beslissingen te kunnen nemen.

Tegenwoordig worden platforms vanuit dit technische oogpunt ontwikkeld, zonder rekening te houden met wat er vanuit de oudere persoon van het systeem (en dus ook het platform) verwacht wordt. Omdat de platforms voor de toekomst op dit

moment ontwikkeld worden, is het noodzakelijk om nu inzicht te krijgen of deze platforms aansluiten bij de wensen en behoeftes van de toekomstige oudere gebruiker. In dit proefschrift geven we hier een beeld van. We bekijken vanuit de behoeftes van de oudere eindgebruiker of (i) platforms echt noodzakelijk zijn, (ii) wat er van een platform verwacht wordt, (iii) of de platforms die nu in ontwikkeling zijn aan de verwachtingen voldoen en hoe we dit kunnen toetsen. Op deze manier geven we richting aan de ontwikkeling van platforms die leiden tot smart-homes voor langer thuis wonen.

Technische behoefte

In hoofdstuk 2 lieten we zien dat er verschillende producten en diensten nodig zijn om ouderen thuis te ondersteunen, zoals domotica, robots, hulpmiddelen voor ouderen en zorg op afstand. Op dit moment werken deze producten en diensten nog onafhankelijk van elkaar. Dit resulteert in een gebrek aan samenwerking en inefficiëntie omdat producten elkaars middelen niet benutten en een lagere betrouwbaarheid omdat services elkaar kunnen tegenwerken.

Om deze problemen op te kunnen lossen, zullen de technologieën van de diverse disciplines geïntegreerd moeten worden. Dit is een complex onderwerp dat geavanceerde Informatie en Communicatie Technieken (ICT) omvat. Een technisch platform kan de functionaliteiten bieden die nodig zijn om de producten en diensten te integreren om zo ouderen thuis optimaal te ondersteunen.

Gebruikersbehoefte

In hoofdstuk 3 laten we met een literatuurstudie zien dat de toepassing van een platform in smart-homes noodzakelijk is als we kijken naar de behoeftes van ouderen. Het is bekend dat de variatie in behoeftes van ouderen groot is. Deze omvatten behoeftes op alle niveaus van de hiërarchische ordening zoals gedefinieerd in de piramide van Maslow. In de literatuurstudie hebben we 23 smart-home systemen voor ouderen geanalyseerd en gekeken naar de relatie tussen (i) de behoefteniveaus waar het systeem aan voldoet en (ii) het technisch integratie niveau binnen smart-home systemen (in welke mate werken apparaten met elkaar samen).

Het is duidelijk dat hoe meer behoefteniveaus ondersteund moeten worden, des te hoger het integratie niveau is. Om het brede scala aan behoeftes te kunnen ondersteunen met smart-homes, is het hoogste niveau van integratie nodig. Het gebruik van een platform in smart-homes leidt tot dit gewenste hoge integratie niveau en is daarmee noodzakelijk voor deze toekomstige woningen.

Een Public Health Methodologie (PHM)

Om te bepalen waar een platform aan moet voldoen om geschikt te zijn voor de oudere gebruiker, introduceren we in hoofdstuk 4 de "Public Health Methodologie", of wel PHM. Met de PHM ontwikkel je scenario's die gebaseerd zijn op openbare gegevens over de gezondheid van een populatie. We hebben de PHM gebruikt om scenario's te maken voor zelfstandige Nederlandse ouderen (65-85 jaar). Veel voorkomende ziektes en aandoeningen van ouderen zijn verzameld met behulp van de zogenaamde gezondheidsprofielen van deze doelgroep. Alle beperkingen die voortkomen uit een ziekte of aandoening (bv. een verminderde capaciteit voor lopen of versjouwen) zijn vervolgens gewonnen uit het International Classification of Functioning, Disability and Health framework (ICF), dat ontwikkeld is door de World Health Organization (WHO). Dit leverde 118 verschillende beperkingen op.

We hebben deze beperkingen vervolgens gecombineerd met een lijst van 31 normale dagelijkse activiteiten (bv. het opdienen van een maaltijd), die zijn verkregen uit onderzoek van het Sociaal Cultureel Planbureau (SCP). De combinaties van beperkingen en activiteiten leidden tot een compleet overzicht van mogelijke vraag naar ondersteuning (bv. steun bij het verplaatsen van een zware pan met spaghetti).

Van een platform wordt verwacht dat alle benodigde technische oplossingen ondersteund worden. Om dit te toetsen, hebben we scenario's gegenereerd op basis van de verzameling benodigde ondersteuningen. Deze scenario's beschrijven een oudere persoon met beperkingen die een dagelijkse activiteit uit wil voeren in een (thuis) omgeving, en een smart-home systeem dat de gebruiker ondersteunt in het correct en veilig uitvoeren van de activiteit. Om platforms te kunnen testen, zijn er 10 scenario's gemaakt die een groot deel van de beperkingen en activiteiten omvatten. Deze dekken ruwweg alle beperkingen en dagelijkse activiteiten van thuiswonende ouderen in Nederland.

Beoordeling van platforms

Met de scenario's als test cases beoordelen we vervolgens de platforms in functionele tests. Het platform plaatsen we in het smart-home systeem dat beschreven is in het scenario. Vervolgens kijken we of het platform alle apparaten van het smart-home systeem ondersteunt zodat zij hun hulptaak kunnen uitvoeren.

Vanwege het grote aantal verschillende apparaten in de scenario's, hebben we alleen simulaties gebruikt om de tests uit te voeren. In deze simulaties bestaan virtuele gebruikers, omgevingen en smart-home apparaten. De virtuele smart-home apparaten zijn vervolgens verbonden met een platform dat draait op een PC. Op deze wijze zijn twee platforms getest: het universAAL platform, en Universal Plug and Play (UPnP) in combinatie met Digital Home Compliant (DHC). Dit laatste platform wordt gebruikt ter ondersteuning van service robots. Om de functionele testen uit te voeren met de 10 eerder ontwikkelde scenario's, zijn 61 smart-home apparaten gesimuleerd die samen 88 verschillende acties konden uitvoeren.

Resultaten van de tests laten zien dat beide platforms uitbreiding nodig hebben om alle apparaten uit de scenario's te ondersteunen. Het universAAL platform ondersteunde 21 van de 88 acties (24%). Om de overige acties te ondersteunen was een uitbreiding van het ontologie model van het platform nodig. Dit model omschrijft alle informatie binnen het platform en definieert verbanden tussen grootheden en is dusdanig opgezet dat uitbreiding een logisch proces is dat eenvoudig door derden kan worden uitgevoerd. Het UPnP/DHC platform ondersteunde 15 van de 88 acties (17%). Omdat het UPnP/DHC platform geen ontologie model heeft, betekende een uitbreiding het zelf definiëren van protocollen die bestaan uit benamingen van services, activiteiten en variabelen, en van geavanceerde data types, bijvoorbeeld geometrische informatie over objecten in een ruimte. Het creëren van zo een protocol kan op verschillende manieren en protocollen dienen als aanvullende informatie bij een platform verstrekt te worden. Uitbreiding is daardoor zeer tijdsintensief.

Omdat voor gemiddeld 4/5 van alle apparaten uit de scenario's uitbreidingen aan het platform nodig zijn, is een ontologie model wenselijk voor een smart-home platform. Het gemakkelijk hergebruiken van uitbreidingen is cruciaal voor het succes van smart-homes, omdat alleen zo de ondersteuning voor het aantal apparaten door een platform kan groeien, zodat een universeel platform kan ontstaan.

Vervolgonderzoek

In hoofdstuk 6 discussiëren we over de toepassing van het resultaat van deze studie in de praktijk, de beperkingen van de studie en benodigd vervolg onderzoek. We laten zien hoe de PHM toegepast kan worden in de bouw als hulpmiddel bij het ontwerpen van gebouwen in een vergrijzende samenleving. Beperkingen van de studie omvatten het gelimiteerd aantal gebruikte scenario's, de beperkte diversiteit in de scenario's en het beperkte aantal platforms dat getoetst is. Het is daarom niet alleen aan te raden om andere platforms te toetsen, maar ook om te werken aan meer scenario's met een bredere scoop. Verder zullen platforms niet alleen getest moeten worden op functionaliteit, maar ook op bijvoorbeeld prestatie.

Conclusie

Met dit onderzoek hebben wij de behoeften en eisen aan platforms in kaart gebracht om te komen tot slimme huizen voor ouderen. Door op innovatieve wijze gebruik te maken van gezondheidsprofielen, de ICF, een standaard set met dagelijkse activiteiten, scenario's, functionele tests en simulaties, kunnen we hopelijk richting geven aan de noodzakelijke ontwikkeling van toekomstige platforms, en hebben we hiermee een basis gelegd voor slimme huizen voor ouderen.

Curriculum Vitae

Michiel Brink was born on 9 July, 1984 in ‘s Hertogenbosch, the Netherlands. He grew up and went to secondary school in Heerlen. Between 2001 and 2005 he studied Applied Physics at the Hogeschool Zuyd in Heerlen. He then enrolled in the MSc Building Services program at the Department of the Built Environment at the Eindhoven University of Technology in Eindhoven. His MSc thesis addressed the use of software agents in home automation. He graduated ‘cum laude’ in 2008. Building on this work he started his PhD in February 2009 at the unit Performance Engineering for Built Environments, at the Department of the Built Environment at the Eindhoven University of Technology.

During his thesis work, he was also assistant treasurer and is currently IT officer for the International Society for Gerontechnology, and was a member of the organizing committee of the ISG*ISARC2012 World Conference. In July 2011 he joined the National Reserve Corps of the Dutch army, where he now has the rank of private first class.

Bouwstenen is een publikatiereeks van de Faculteit Bouwkunde, Technische Universiteit Eindhoven. Zij presenteert resultaten van onderzoek en andere aktiviteiten op het vakgebied der Bouwkunde, uitgevoerd in het kader van deze Faculteit.

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