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'Progressing lifetime communities through Universal Design'

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Investigation of the Universal Design of Fall Detection Technologies in the Smart Home and their Impact on Lifetime Communities

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Final Report

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1. Executive Summary

The theme of the National Disability Authority's Research Promotion Scheme in 2017 was progressing lifetime communities through a Universal Design lens. In response to this theme, an investigation into the Universal Design of Fall Detection Technologies and their impact on lifetime communities was undertaken.

Our population is ageing. In the European Union as a whole, people aged 65 and over accounted for 19.4% of the population in 2017 and this is predicted to increase to 23.9% by 2030 (Eurostat, 2017). As a result of the population movement between age groups, the old-age dependency ratio in Ireland is projected to increase from an EU low of 20% in 2015 to 28.7% in 2030 (Eurostat, 2018). This will likely increase demand of care and support services.

Smart technology can help and support us in our daily activities. Smart technology refers to electronic devices that can be worn or are embedded in our environment. Smart technology consists of sensors as well as computing and networking capabilities to connect them to each other or to computer servers and cloud systems. Examples of smart technology include smart phones and smart watches, smart speakers such as Amazon's Alexa, home automation systems that allow us to remotely control our heating, home or building security systems, or recent technologies such as robotic lawn mowers or vacuum cleaners.

Smart technologies used in the home related to the risk of falling are particularly relevant to older people and persons with disabilities. Falls experienced by older people can have life changing consequences including serious injuries, disability, psychological consequences and even death. On average one in three older people fall every year and two-thirds of these fallers will fall again within six months (Health Service Executive et al. 2008). Falls also present a significant financial burden on the healthcare system with an estimated annual cost of falls and fractures of €402 million to the economy in Ireland in 2007 (Gannon, O'Shea & Hudson, 2007).

There is great potential for smart technologies to assist older people and persons with disabilities to live more actively and independently. However, these assistive technologies need to be better integrated into everyday life activities and meet optimal design principles, such as Universal Design. The challenge for smart technologies is to adapt to community settings, where people from all ages and abilities come together. Communities that promote living together across ages and abilities, so called lifetime communities, can foster healthy and successful ageing. The aim of this research was to study the potential that smart technologies have in supporting people to live actively and independently both at home and in the community, with a particular focus on Fall Detection Technology, the design of this technology, and their impact on lifetime communities.

The objectives of the project were:

1. to assess the impact of falls on both people at risk of falling and their families and carers and the need for Fall Detection Technologies

2. to investigate the design state of fall detection solutions and services through a Universal Design lens

3. to understand how this technology can impact and support lifetime community initiatives.

This was carried out by reviewing and analysing the literature and existing Fall Detection Technologies and sourcing primary data from key stakeholders in Ireland.

The literature and technology review provides the reader with an overview of selected design principles for products and services that are more user centred and inclusive. A review of smart home technology and Fall Detection Technologies available in Ireland and current advances in the field is presented. The concept of lifetime communities, their developments and the Amicitia lifetime community exemplar are outlined.

Primary sourced data was gathered through engagements with individuals and groups from various different backgrounds. This included 35 meetings or visits with 64 stakeholders as well as individual semi-structured interviews with a further 67 participants from 9 different participant categories. The research findings are based on this primary source evidence on the role and design of Fall Detection Technologies and their impact on lifetime communities from the perspective of the stakeholders themselves.

The literature and technology review highlighted the extent and benefits of smart home technology, provided an overview of wearable and ambient Fall Detection Technologies, and analysed commercial fall detection systems available in Ireland. The review pointed to the fact that while many new and sophisticated Fall Detection Technologies offer great promise, many are at a low maturity level and have not gone much beyond the research laboratory.

The research findings revealed that Fall Detection Technology was useful, can mitigate physical harm due to long lies and reduces danger of falling by alerting care givers of a person moving. It can reduce the emotional consequences of falls by providing reassurances to people who have fallen and their caregivers. Fall detection can also have a positive effect on lifestyle by allowing persons at risk of falling to maintain independence for longer. For example, vulnerable adults were able to move out of residential care settings back into the community reducing their social isolation.

However, the findings also revealed some weak adherence of fall detection products and systems to the Principles of Universal Design that demonstrated how accessible, understandable and easy to use features benefit users. It was found that while available technology is simple and intuitive to use, some users were unsure about its functioning in all cases. Some users also worried about access to Fall Detection Technology due to costs in particular. The findings also pointed out that some users felt a stigma of vulnerability wearing Fall Detection Technologies, while others pointed to inflexibilities and raised concerns about privacy. Limitations such as accuracy and battery life were raised as other issues.

The research also assessed the impact of Fall Detection Technology on lifetime communities. The research provides insight into the social impact of Fall Detection Technologies on a community. People at risk of falling can be supported to live independently and be active in their community. However, there is also a social responsibility required for Fall Detection Technologies to work effectively. To provide adequate support to people at risk of falling, Fall Detection Technologies need to be integrated into informal or formal care networks. The literature review highlighted a significant positive economic impact to provision of these services in an integrated and inclusive lifetime community. The report concludes with a vision of what a smart lifetime community might look like in the future and how seamless fall detection services could be achieved.

2. Introduction

2.1 Context

The potential of smart technologies to help and support us in our daily activities has long been identified. In 2000 it was predicted that "in the next very few years, the intelligent house will have become, if not integrated into normal life for all income groups, then at least a common, well-understood and desirable consumer good" (Edge, Bruce and Dewsbury, 2000, p.6). Some smart technologies, such as the smartphone have become ubiquitous. In 2017, 90% of all adults in Ireland had a smartphone, while in the 65+ group ownership was 80% (Howard, 2017). Smart home technologies encompass a wide range of technological devices including motion sensors for security, smoke and carbon monoxide detection devices for safety, heating control systems, entertainment and information systems and assisted living technologies such as fall detection and bed occupancy monitoring devices.

However, the uptake of smart home technologies has been rather low outside niche markets, despite its obvious potential to assist people with a range of everyday tasks. Smart home technologies related to the risks of falls are particularly relevant to older people and persons with disabilities. Falls experienced by older people can have life changing consequences. Older people can suffer serious injuries, disability, psychological consequences and even death following a fall. The risk of falling increases with age. On average one in three older people fall every year and two-thirds of these fallers will fall again within six months (Health Service Executive et al. 2008). Falls also present a significant financial burden on the healthcare system. It was estimated that the annual cost of falls and fractures was €402 million to the economy in Ireland in 2007 (Gannon, O'Shea and Hudson, 2007).

Demographics are also changing. In the European Union as a whole, people aged 65 and over accounted for 19.4% of the population in 2017, which is predicted to increase to 23.9% by 2030 (Eurostat, 2017), while the overall population of the EU is projected to increase by only 3%. As a result of the population movement between age groups, the EU old-age dependency ratio is projected to increase from 28.8% in 2015 to 39.1% by 2030, while in Ireland the projected increase is from an EU low of 20% in 2015 to 28.7% in 2030 (Eurostat, 2018). Therefore, as our population ages the number of falls and injuries in this age group will continue to increase, thus putting tremendous strain on our health services and communities.

In order for people to participate actively and remain living in their communities, it is important that their communities meet the needs of this ageing population. There is tremendous potential for smart technologies to assist older people and persons with disabilities to live more actively and independently. However, these assistive technologies need to be better integrated into everyday life activities. When used in a smart home environment, assisted living technologies need to work seamlessly with other smart home technologies that may be used by people of different ages living in the same home. They also need to support mobility outside of the home in order to support older people and persons with disabilities to engage within the wider community. The challenge for smart technologies is to adapt to community settings, where people from all ages and abilities come together. Communities that promote living together across ages and abilities, so called lifetime communities, can foster healthy and successful ageing (Maltz et al, 2014; Austin et al, 2005; Bedney, Goldberg and Josephson, 2010).

Lifetime communities are created through the design of their environment, civic engagement as well as the social and technological support services provided to people in need. Many communities nationally and internationally are striving to meet these challenges and opportunities, one such example in Ireland is the Amicitia initiative. Amicitia is a hybrid social enterprise, which delivers technology and social supports to build smart, sustainable communities (Amicitia 2018).

However, in order for smart technologies to work well within the context of lifetime communities, the technologies need to offer support and adapt their behaviour across all age and ability levels. It is well understood that poor design has a major impact on access to and adoption of both new and existing technologies and services by the general public and in particular by older people and persons with disabilities. Following Universal Design principles can greatly address many of these difficulties.

There are a number of national and international initiatives which set out legislation, standards or guidelines for the design of the built environment, websites, products, services and systems. These include Access and Use Building Regulations (DEHLG, 2010), Digital Single Market policy on Web Accessibility (European Commission, 2012), Universal Design Principles (CEUD, 2017a), the European Telecommunications Standards Institute 's interoperability of smart electrical home appliances based on the SAREF standard (European Commission, 2015), and the International Electro-technical Commission's standard SyCAAL, which will enable usability, accessibility and interoperability of AAL systems and services (IEC, 2018). The regulatory environment, economic benefit of quality design and the desire of people to enjoy active, healthy and fulfilling lives point to a significant role for well-designed smart technologies in the realisation of lifetime communities.

2.2 Aims and Objectives of the Research

The aim of this research is to study the potential that smart technologies have in supporting people to live actively and independently both at home and in the community, with a particular focus on Fall Detection Technology and their impact on lifetime communities. The research provides the reader a discussion which brings together insights gained from the literature and technology review with an interpretation of the research findings.

The research provides the reader with a **literature** and **technology review** of some of the key areas related to the design of Fall Detection Technologies and its impact on lifetime communities. An overview of design methods and principles, in particular Universal Design, is presented. These methods and principles are aimed at providing products and services that are more user centred and inclusive across a broad range of ages and abilities.

The main concepts of smart home technology are outlined. This includes a brief introduction into this sector's development, current research with an emphasis on assisted living technologies, what the current limitations of the technology are and how it is developing within the context of the Internet of Things. The potential of Fall Detection Technologies is highlighted. This includes a summary of how falls impact both the person and healthcare system. The research provides a literature and technology review of current technologies that detect falls, not only the research that is being done in this field but also which technologies are commercially available in Ireland and their main properties.

The concept of lifetime communities is introduced. This explains what a lifetime community is, examples of lifetime communities, how smart technologies are used in lifetime communities and an overview of the Amicitia lifetime community exemplar.

This research provides **primary source evidence** by gathering data, through a series of stakeholder engagements with individuals and groups in Ireland. Themes were generated from this data and findings presented. The key aims of the stakeholder engagement are:

1. to assess the impact of falls on stakeholders in order to understand their need for Fall Detection Technologies.
2. to investigate the design state of fall detection solutions and services through a Universal Design lens to understand how Fall Detection Technology can impact and support lifetime community initiatives.

The findings of the research are interpreted in a discussion chapter and put into a technology, design, and lifetime community context. The discussion looks at the impact of Fall Detection Technologies from a social, economic and lifetime community perspective. The report concludes with a summary and a vision of what future smart lifetime community might look like in which smart technology seamlessly supports older people living on their own within the community.

3. Literature and Technology Review

In this section a review of relevant scientific literature and selected technologies related to smart home technology, fall detection and lifetime communities is provided. The technology review includes a brief overview and introduction to general product design methods and the principles of Universal Design. The concept of a smart home and associated technologies are then presented, followed by an overview of Fall Detection Technologies for older people and persons with disabilities.

The overview on fall detection and alerting covers both current research directions and generally available technologies. Fall detection and alerting technologies are important as the impact of falls on individuals and the community can be life changing. Both smart home and Fall Detection Technologies are discussed within the concept of lifetime communities. The benefits of smart technologies in conjunction with lifetime communities offer people of all ages and abilities life enhancing benefits and can reduce health care costs through concepts such as connected health.

As the research space in these three areas is large, the review was limited to the most recent and most significant literature in the scope of the project's research due to space constraints with search terms summarised in Appendix 1a. An overview of the main commercially available Fall Detection Technologies including a summary of their functions is also provided.

3.1 Design Methods and Principles

Smart technology devices have become increasingly part of our everyday lives. Products such as smart phones, smart watches, smart speakers and smart TVs are examples of such increasingly popular devices. A key factor in their success is not only the technology inside but often more their design appeal. Apple's products demonstrate how well designed smart devices sell in a competitive market. Good design is both aesthetically pleasing and functionally successful for everyone in need of the technology.

There are many **methodologies** and approaches used to design products and services such as; Instructional Systems Design, Agile Design and System Thinking with Participatory Design and Design Thinking being particularly important.

Participatory Design actively involves all stakeholders (e.g. service providers, developers, end users) in the design process. This helps ensure that the resulting design meets users' needs. Also known as co-design, it can be applied to both the design of new products and the improvement of existing products and services (Wilkinson and De Angeli, 2014).

Design Thinking can be successfully employed to achieve user-centric designed products and services. Design thinking is a person-centred, iterative design process (Tschimmel, 2012). It is an application design process where creative solutions are generated to solve difficult problems. A Design Thinking workshop first empathises with the user, next defines clearly the user problem, ideas for solutions are then formed, prototyped and tested in an iterative manner. Although, the origins of the concept of design thinking are not new, it has gathered more exposure and adoption by some or the world's largest corporations and leading academia in recent years.

While design methodologies describe the process of designing a product or service, there is also a need for design principles which describe properties required of product or service. Clear design definitions and **principles** promote greater awareness, facilitate discussion, enable implementation and lead to development of better methods for design (Persson et al. 2015).

The **Principles of Universal Design** were developed in 1997 by a working group of architects, product designers, engineers and environmental design researchers, led by the late Ronald Mace in the North Carolina State University (Connell et al.1998). In Ireland, these principles are promoted by The Centre for Excellence in Universal Design (CEUD), which was established by the National Disability Authority (NDA) in January 2007 under the Disability Act 2005 (CEUD, 2017b). In the United Kingdom, a new British Standard on managing inclusive design provides a comprehensive framework to help ensure the needs of persons with disabilities are considered throughout the life of a product or service (BSI 2005).

The Nordic countries are also embracing Universal Design as a framework to design products and services to support people with disabilities and the ageing population. In 2012, they created A **Nordic Charter for Universal Design**:

> "Persons with disabilities often experience the public arenas environments, products and services as poorly-designed to fit their abilities and/or their needs. Together with the demographic changes in the Nordic societies with an increasing number of elderly people, it needs initiatives to improve independence, accessibility and participation in society. A strategy which aims to make design and composition of different environments, products, communication, information technology and services accessible, usable and understandable to as many as possible is Universal Design" (Björk, 2013, p1).

It is useful to view Universal Design at both micro and macro levels. At a micro level, design features or products should be created so that they are be used by as many people as possible. While on a macro level, the designer combines accessible and usable design features, with customisable or adaptable features alongside more specialised design solutions that deal with the most extreme usability issues. By stepping back from the individual features and looking at the product, service or environment as a whole, designers are in a position to investigate alternatives providing equivalent experiences to users of all ages and abilities (CEUD, 2017c).

For designers Universal Design defines seven principles which provide guidance in the design of products, services and environments:

Principle 1: Equitable Use
A design should be useful and marketable to people with diverse abilities. For example, the design provides the same means of use for all users, that is, identical whenever possible and equivalent when not. It avoids segregating or stigmatizing users and provides suitable means for privacy, security and safety equally to all.

Principle 2: Flexibility in Use
A design should accommodate a wide range of individual preferences and abilities. For example, the design provides choice in the methods of its use, such as accommodating right- or left-handed access and use. It facilitates a user's accuracy and precision and provides adaptability to a user's pace.

Principle 3: Simple and Intuitive Use
A design should be easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. For example, the design eliminates unnecessary complexity. It is consistent with user expectations and intuition. The design arranges information consistent with its importance and provides effective prompting and feedback during and after task completion.

Principle 4: Perceptible Information
A design should communicate necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities. For example, the design allows for the use of different modes (pictorial, verbal, tactile) of presentation of essential information. It provides adequate contrast between essential information and its surroundings, maximising "legibility" of essential information. It provides compatibility with a variety of techniques or devices used by people with sensory limitations.

Principle 5: Tolerance for Error
A design should minimise hazards and the adverse consequences of accidental or unintended actions. For example, the design arranging elements to minimize hazards and errors, providing warnings of any hazards and error and providing fail safe features.

Principle 6: Low Physical Effort
A design should allow efficient and comfortable use with a minimum of fatigue. For example, the design allows a user to maintain a neutral body position. It requires only reasonable operating forces. It minimises repetitive actions or sustained physical effort.

Principle 7: Size and Space for Approach and Use
Due consideration of this principle ensures that the appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility. This includes that the design provides a clear line of sight to important elements for any seated or standing user. It accommodates variations in hand and grip size. The design provides adequate space for the use of assistive devices or personal assistance.

From micro to macro, Universal Design has implications for the design of any single feature of a product, service or environment but similar approaches are also termed as inclusive design, accessible design or design for all. Universally designed technologies and environments provide comfort, adaptability and flexibility that can help to reduce human life cycle impact and encourage residents' participation in the community (Kadir and Jamaludin, 2013).

In the following, an overview of smart technologies with an emphasis on fall detection and prevention technologies is presented within the context of the home and community settings.

3.2 Smart Technologies

Technology is becoming more and more significant in our daily lives and communities. Within the context of this study, smart technology refers to electronic devices, which are worn or are placed in the environment. These devices have embedded computing, networking and sensing capabilities. They execute software that processes sensed data from the environment or person with which they are connected. This software can make devices adapt and react to changes in external conditions.

Internet, mobile and broadband communication technologies are facilitating the development of new products and services. The Internet of Things, which can be defined as the connection of computing devices embedded within our physical environment to the Internet, is one of the latest aspects of smart technologies. The Internet of Things is contributing to the development of smart communities by providing data on what is happening in the community and its environments. Cloud computing, together with the advances in data analytics and artificial intelligence, offers insights from this data which can enable community stakeholders to innovate new services that improve their daily lives (Lea, 2017).

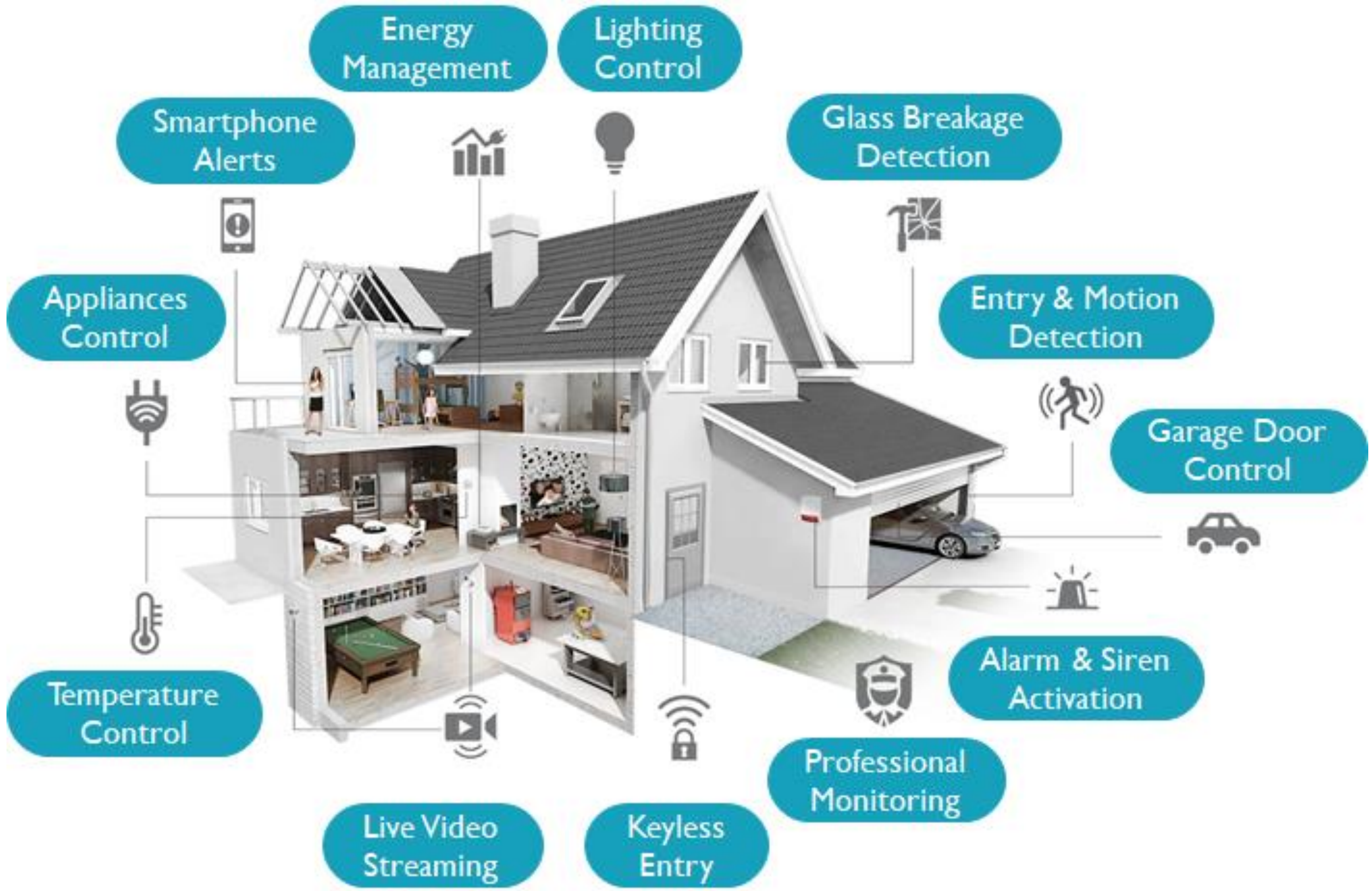


Figure 1: The ABC's Smart Home Technologies, (Corvello, 2017)

Smart Homes

A smart home uses home automation technologies and other connected, ambient electronic technologies that allow the home and its contents (including its occupants) to be monitored. This technology can assist the occupants in many daily tasks and can often be controlled automatically or remotely via a user's smartphone or computer. Li, Da-You and Bo defined a smart home as a *"dwelling incorporating a communications network that connects key electrical appliances and services, and allows them to be remotely controlled, monitored, or accessed"* (Li, Da-You and Bo, 2004, p. 659). More recently the monitoring of occupants' activities and health has also become part of smart home technology.

A smart home typically consists of a base unit, often called a smart home gateway or smart home hub, which connects to a large number of devices using both wireless and wired communications technology. These devices can sense physical parameters, detect events and control appliances within the home. Monitoring sensors (temperature, light, smoke and carbon monoxide sensors) and event detection sensors (intruder, fall and water detection) can be connected to a home gateway. Actuators can control various elements of the home, for example, switching lights on/off, opening doors or turning on/off appliances (Chan et al., 2008; Alam et al., 2012). Figure 1 shows the breadth of smart home technologies ranging from entertainment to comfort, to security management and access control.

Emergence of Smart Home Technologies

Smart home and home automation technologies have been an active area of research and development for over 50 years. Early commercial products emerged first in the 1960s that offered simple local monitoring functions for temperature, gas and security. In the mid-1970s smart homes technology became more widely implemented, due to the emergence of communication network technology, which allowed automated devices such as switches and appliances to be connected via powerline communication (Hallak and Bumiller, 2016). With advances in microelectronics and computing in the early 2000s, research has increasingly focused on using sensors, electronic devices and artificial intelligence software to make home environments smarter (De Silva, Morikawa and Petra, 2012; Nakamura et al., 2015).

There is now a trend towards Internet of Things based services for smart homes. Smart objects and devices are becoming more available on the market and are increasingly being used in consumers' households. Over the past few years many of these devices offer 'out of the box' connectivity to the Internet, such as the Amazon Alexa smart speaker or the Philips Hue smart lighting system (Stojkoska and Trivodaliev, 2017). These Internet of Things services can be linked with smartphone applications which allow occupants to control their homes remotely.

Occupants can be given advice assisting them with health matters or managing energy consumption and the security of their home (Alaa, 2017).

Design and Potential of Smart Homes Technologies

The design of smart home technology has also advanced with time, improving the usability of this technology. A recent review considered software applications to help control smart homes (Caivano et al., 2018). Caivano at. al. conducted an extensive literature review that identified 12 software systems that currently allow general users, not just computing experts, to program and configure home automation systems. The criteria the authors applied relate to software usability rather than traditional product design principles. The review found that all but one scored high in ease of device control, while most allowed flexibility in device management. Fewer supported interoperability with services already used by the end-user. Less than half facilitated integration with other smart devices produced by other manufacturers. The authors then selected 3 tools from the identified 12 for an experimental analysis of their usability with a range of users between 19 and 60 years of age and identified 10 design guidelines for similar software technologies.

While there also is evidence that involvement of the community - including family members or older adults and other stakeholders - is important for the success of smart homes and home health-monitoring technologies, such an inclusive approach is not yet adhered to sufficiently to realise the full impact of the technology (Reeder et al., 2013). There is potential for smart home technology to address the needs of its occupants, in particular the needs of older people and persons with disabilities, to live more independently. Smart home technology can empower older people and persons with disabilities to control their homes by means of technology which they might not otherwise be able to do (Demiris, 2009; Demiris et al., 2008; Lê, Nguyen and Barnett, 2012). This can include the use of smart phones or tablets as touch interface devices. Smart speakers such as Amazon's Alexa or Google Home can provide voice interfaces to control the home. As smart home technology becomes more prevalent, there will likely be an increased focus on usability to make the technology more intuitive to use.

Entry into the smart home and healthcare market by the likes of Google, Apple and Amazon suggest a further convergence and potential for a more person-centred approach to the design of services. A recent study by Deloitte (Taylor, 2015) indicates that mobile platforms and the integration with smart home technologies offers more personalised care and improved communication with end users, leading to improved care services. These commercially available smart home hub devices use voice recognition software to facilitate the control of other devices in the home through normal human speech. This increases flexibility and simplicity of use of smart homes and reduces the physical effort required. However there are some concerns around equitable use, from the hearing/vocally impaired to differences in gender efficacy (for example, picking up male voices better). Also the costs of these technologies varies and this can pose limits on their equitable use.

A further challenge for smart home technologies is interoperability. While there are a wide range of devices available to manage entertainment, energy, security and healthy living aspects of a smart home environment, only those that are part of a particular manufacturer's ecosystem will work well with that manufacturer's smart home hub. For example, smart devices designed to work with Apple's HomeKit smart home software platform are not compatible with the Google Nest thermostat or security cameras systems. This severely limits the equitable use and flexibility of devices that are outside a particular manufacturer's ecosystem. Manufacturers, policy makers and open source software developers have recognised this. Industry initiatives, such as the **Open Connectivity Foundation** (OCF, 2018), are trying to develop interoperability technologies that allow smart devices from multiple manufacturers work within the same smart home environment. Open source efforts such as OpenHAB are alternatives to commercial offerings aimed at overcoming smart device and service interoperability problems. The European Commission has also launched an initiative in conjunction with the **European Telecommunications Standards Institute** (ETSI) to develop interoperability of smart electrical home appliances based on the SAREF standard (European Commission, 2015). However, the penetration of these interoperability initiatives into the actual end user space has so far been limited.

In 2014, the EU-FP7 project **UniversAAL** launched an open platform that provides a standardised approach for easy and economic development of Ambient Assisted Living (AAL) solutions. This has potential benefits for end users by making new solutions affordable, simple to configure and deploy. The UniversAAL platform sets out to assist the solution providers by making it easier and cheaper to create innovative AAL services or to adapt existing ones (Ferro, 2015). While these initiatives are laudable, uptake has been limited and existing smart home technologies do not comply with these standards.

The **International Electro-technical Commission** (IEC) is creating a standard called SyCAAL. It has a vision of Active Assisted Living that takes account of the evolution of the market. It will foster standardisation which enables usability and accessibility of AAL systems and services. It will enable cross-vendor interoperability of AAL systems, services, products and components and will address systems level aspects such as safety, security and privacy (IEC, 2018).

From the perspective of personal health, smart home technologies can also be used to monitor activities of daily living, cognitive decline and mental health and heart conditions for all persons with complex care needs. The convergence and connectedness of new technologies is seen as an enabler to a fully integrated care environment (Taylor, 2015). However, the Technology Readiness Level (TRL) (DOE, 2009) for home health monitoring technologies intended for older adults with complex needs is generally low (Lapierre et al. 2018). TRL is widely used to measure a technology's progress from scientific discovery or early development to commercial product or service and is measured in 9 levels. TRL-1refers to early development, e.g. a basic discovery, TRL-4 refers to testing of a small scale prototype of technology and TRL-9 refers to a market ready product.

While smart home technology has the potential to support an ageing society - as well as persons with disabilities - to live independently for longer, the full extent to which smart home and home health monitoring technologies help people with health issues and improve health-related quality of life has not yet been fully evaluated (Liu et al. 2016; Peek, Aarts and Wouters, 2017). There is therefore a need for more evidence based research to demonstrate the effectiveness of these technologies.

For smart home technology to be fully effective, the design of this technology needs to be part of the overall design process of a home. There are guidelines for inclusive design of homes based on the principles of Universal Design (CEUD, 2015) and the benefits of inclusive design of smart homes is well recognised (Dewsbury, 2000; Pennick, Hessey and Craigie, 2016). However, few homes are designed from the beginning with the installation of smart technologies in mind. This approach leads to suboptimal use of smart home technology and limits its full potential.

3.3 Falls and Fall Detection Technologies

Falls among older people and persons with disabilities is a major health issue. The risks and consequences of falls on those who fall, their families, carers and communities can be considerable. Technology can play an important role in detecting and reducing the consequences of falls.

The Consequences and Risk of Falls

Falls can lead to a decrease in quality of life and greater reliance on family and carers and can have life changing consequences. Older people are most likely to suffer serious injuries, disability and death following a fall as well as psychological consequences (HSE, NCAOP and DHC, 2008). In Europe, 30% of people aged 65 years and over fall each year, with one in five of these requiring medical attention and one in ten suffering fractures (Towner and Errington, 2004). One third of domestic fall injuries occur in wet conditions (Rosen et al. 2013). Recent research has also highlighted a sharp increase in falls in women in midlife (Peeters et al. 2018). Falls also have a large economic impact on healthcare services. It is estimated that the annual cost of falls and fractures in Ireland will rise to over €2 billion by 2030 (Gannon, O'Shea & Hudson, 2007).

The **Strategy to Prevent Falls and Fracture in Ireland's Ageing Population** (HSE, NCAOP and DHC 2008) sets out goals to increase awareness, develop comprehensive services and create a safer environment to help prevent falls. It also recognises a role for assistive technologies and recommends the exploration and establishment of the benefits of assistive technology in the design of housing for older people.

As the population ages it is important to encourage greater physical activity and to mitigate against the risks of falling. Studies show that older adults who are physically active have better cognitive function and functional health and a lower risk of falling. Despite this, two-thirds of the Irish population aged 50 years and older report low or moderate levels of physical activity (Donoghue, O'Connell and Kenny, 2016). There is some evidence that wearable devices can help encourage older individuals to lead healthier and safer lives, for example by reminding them to become active during periods of inactivity or by providing health related information. (Tedesco, Barton and O'Flynn, 2017).

The Need for Fall Detection Technology

Fall risk can be reduced with regular physical activity (Morris et al. 2016) as well as accurate fall risk assessment (Palumbo et al., 2016). Wireless sensor technology has been developed by researchers in Ireland to support fall risk assessment (Kinesis, 2018). However, while a range of health and education initiatives and some technologies exist that assist in the prevention of falls, there is still a need for Fall Detection Technologies in the home and community as the risk of falling cannot be entirely eliminated. Should a fall occur it is important that help is at hand, as quickly as possible, if required.

Fall Detection Technologies also assist in preventing long lies. A long lie is the consequence of falling and not being able to get up for a long time. Fall Detection Technology can help prevent long lies by raising alerts that someone has fallen. There is on average a 15% likelihood of a long lie resulting from a fall for those aged 65 years and over (Bloch, 2012; Tinetti, Liu and Claus, 1993; Wild, Nayak and Isaacs, 1981). It is also reported that half of the seniors who fall cannot get up on their own and a lie time of more than 72 hours increases their mortality by 67% (Gurley et al. 1996). Detecting falls quickly can reduce the fear of falling and other consequences including reduced physical activities, lower social contacts, depression and low quality of life (Scheffer et al. 2008).

A recent study of an automatic fall detection device investigated the economic impact of a device that can reduce long lies (O'Dwyer and Murphy, 2018). In Ireland the average cost of falls is €13,809 per person. A cost benefit analysis of a wearable automatic fall detection device which can be used both in the home and in the community was carried out. Net benefit is estimated by comparing costs with and without the device. The incremental net benefit varies depending on how effective the device is at alerting a carer to assist a faller and thus avoid a long lie from the fall. This study showed that if such a device was adopted by all older adults, the average cost of falls in Ireland would drop to €7,373 per person, even if the device was only 50% effective. The total resulting net benefit calculated for the 2016 population of Ireland is €823 million, assuming 100% update and retention of the device with a just 50% effectiveness. A 75% effectiveness of the fall detection device increases the net benefit to €1,431million.

The Components of Fall Detection System

Fall detection and alerting technologies are used both in indoor environments as part of smart home technologies and in outdoor environments. A fall detection system typically consists of one or more of a variety of detection sensor technologies to detect a fall event and a central decision making and alerting unit, which alerts caregivers. The sensors can be either worn on the person or are ambient in the building. They are connected to the central unit via a communication network using either a wireless communication system (typically for wearable sensors) or a wired communication system within the detection space. The central unit typically uses telecommunication networks such as a landline phone connection or a mobile cellular service to raise an alert. A range of recent studies have attempted to review the current research literature in this space and provide a discussion of Fall Detection Technologies (Khan and Hoey, 2017; Alaa et al. 2017; Lapierre et al. 2018).

Fall Detection Technologies can be grouped into three categories (Mubashir, Shao and Seed, 2013): wearable, ambient and camera based technologies. For the purpose of this report, we consider camera based technologies as ambient, as they are installed in the environment. In the following, recent research on and commercially available Fall Detection Technologies are reviewed under either Wearable Fall Detectors, that is, devices that are worn on the person, and Ambient Fall Detectors - devices that are embedded in the environment.

Wearable Fall Detection Technologies

Wearable Fall Detection Technologies can be grouped into those that are required to be operated manually and those that function automatically. Some manually operated wearable panic button alarms are for use only indoors in the home, while others can be used outside in the community. The user can trigger an alert manually by pressing a button on the device. This alert is sent directly, or through a 24 hour monitoring station, to the user's family or carers (Delahoz and Labrador, 2014). In Ireland, the Senior Alert Scheme run by Pobal provides wearable annual alarm to people aged over 65 living alone (Pobal and DHPCLG, 2016).

Automatic fall detectors do not require the person who has fallen to press a button. Some can only be used indoors, while other use mobile phone communication to allow the device to work outdoors. These devices measure either the human posture or motion related characteristics (velocity, movement direction) to infer a fall from a detected event. Among these approaches, the main technologies are accelerometers, gyroscopes and pressure sensors (Igual, Medrano and Plaza, 2013). Recent research has shown that a combination of multiple sensors produces the best fall detection accuracy. For example, studies have shown that pairing accelerometer and barometer improves detection accuracy by 11.6%, sensitivity by 22.5%, and specificity by 5% (Bianchi et al. 2010). Pairing accelerometer and gyroscope improves accuracy by 2.6%, sensitivity by 5%, and specificity by 2% compared to using accelerometers alone (Bourke et al, 2016).

There is a range of commercially available wearable fall detection devices. Philips Lifeline, Medical Guardian and MobileHelp are some of the leading providers (Medical Alert Advice, 2018). Some of these devices are for use only in the home, while others can be used outdoors.

Automatic fall detection can also be provided as an additional feature to the multifunctional smartphone and smartwatch. These applications leverage the inbuilt accelerometer and gyroscope as well as the computing capabilities of the smartphone to detect falls. Recent developments in smartwatch technology also offer automatic fall detection functionality. While these studies show great potential, there is also a recognition of the current limitations of the smartphone as a fall detection device, primarily due to its large form factor and short, less than one day, battery life (Igual, Medrano and Plaza, 2013).

Dedicated wearable fall detection devices are of a size and shape that can be worn on the wrist, as a pendant around the neck or clipped onto a belt or pocket. Some devices raise an alert if the device is not being worn. This allows a family member or carer to remind the person at risk to wear the device. The battery lifetime of wearable devices varies greatly. Those devices that provide automatic fall detection or function outdoors give greater flexibility in use but generally require nightly recharging, while the battery for push button alarms for the phone can last up to two years (Medical Alert Advice, 2018). This wearable technology is generally simple and easy to use and requires little physical effort.

However, the most critical requirement of any wearable fall detection device is that the person at risk of falling is actually wearing the device. This may not always be followed by older people due to forgetfulness, carelessness, stubbornness or lack of understanding of risk (Bentley et al, 2014; Fisk, 2003). As an example, one study reports that out of a population of people over 90 years old that own a panic button system, 80% do not press the button, simply because they were not wearing the device when the fall occurred (Fleming and Brayne, 2008; Mager, Patwari and Bocca, 2013). Due to this reason, research on ambient fall detection systems has been gaining popularity. However, a key question is how to get older people to wear fall detection devices regularly. Among the answers are questions around the design such as more intuitive use, more useful, e.g. more functions beyond fall detection, more tolerant to error, and more desirable design.

For a summary of the functional features of various types of commercially available wearable Fall Detection Technologies, see Figure 2.

Ambient Fall Detection Technologies

Unlike wearable sensors that can be used both indoors and outdoors, ambient sensors work mainly indoors because the infrastructure has to be set up in the occupied space before use and they tend to have a limited range. However, of those elderly people who live independently, about half of the falls occur inside their own homes (Day, 2003) which indicates the need for reliable indoor fall detection systems. Ambient Fall Detection Technologies can be grouped into those that

- require a person to raise an alarm manually
- automatically detect movement or lack of movement to assess the risk of a fall occurring or having already occurred
- automatically detect the occurrence of a fall (Mubashir, Shao and Seed, 2013).

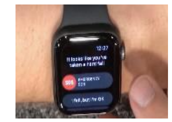
The most common ambient Fall Detection Technologies are the pull cord and strip alarms. These types of alarms are generally installed in the bathroom and provide a mechanism for the user to call for assistance if he/she has had a fall. The pull cord alarm triggers an alert when the cable is pulled. The cable is often a bright colour to make it easier to see in low lighting environments. The strip alarm can be cut to a suitable size and installed around the corners so that the full surface area of the bathroom is covered. Thus user pushes the strip alarm to raise an alert. The strip alarm is usually placed at a low level on the wall so that a user can reach the alarm easily if they have suffered a fall.

The risk of a fall can also be raised by monitoring movement. Movement might indicate a risk of falling and lack of movement might indicate that a fall has occurred. A pressure sensor mat can be placed under the mattress on a bed or on the floor next to a bed or under a cushion on a chair. This will trigger an alarm when the person at risk of falling gets out of the bed or stands up from the chair. The alarm calls will be raised immediately or if they do not return within a set timeframe. Movement can also be monitored by the integration of motion sensors in a smart home. While this technology is often used for security purposes, it can also be used to detect the movement of people at risk of falling. Passive Infrared (PIR) sensors can be fitted in selected areas of the home to detect movement. PIR sensors detect movement of heat (body heat) to infer movement of a person. An alarm can be raised if a person at risk of falls attempts to get out of bed, up off a chair or leave a room. Systems can also be integrated with lighting control, that is, when a person gets up, the light turns on.

Some ambient technology can automatically detect a fall. While considerable research is ongoing, this technology is not generally commercially available. Computer vision based fall detection approaches have been shown to have the highest accuracy among ambient technologies (Mubashir, Shao and Seed, 2013). This technology analyses images taken by cameras to detect falls. However, they have drawbacks especially with regards to wall penetration, darkness and smoke, and suffer from privacy concerns (Palipana, Pietropaoli and Pesch, 2017). Radio frequency based wireless technologies including Doppler radars can be used to detect a fall. Radar based fall detection uses signal processing to interpret the Doppler characteristics of a person's radar signal based on the nature of the person's movement. Radar based fall detection is a proven technology. It is non-obstructive, non-intrusive, insensitive to lighting conditions and preserves privacy and safety (Amin et al. 2016). It has been shown to be quite accurate but is expensive and has a short range.

Recent research is also being carried out on the analysis of other wireless technologies to detect falls. Standard Wi-Fi based fall detection approaches are quite new compared to the rest of the fall detection sensors. Wi-Fi hardware is not expensive and is already in place in most homes in the form of a wireless router providing Internet access to occupants. This technology can capture the characteristics of movement and a fall similar to radar with good accuracy using similar signal processing algorithms and techniques. Therefore, this technology has great potential in detecting falls in the home due to its wide availability and low cost (Palipana et al. 2017).

The development of Fall Detection Technologies is advancing but much of the ambient technologies remain in the research space with low Technology Readiness Levels (Lapierre et al., 2018). Most research studies have evaluated their approaches in laboratory settings only and have not used people at risk of falling in their evaluation (Mubashir et al., 2013; Pang et al. 2018). Little research and development in this space considers inclusive design approaches such as co-design with end users of such technologies (Thilo et al. 2016). This limits their accessibility, equitable use and flexibility of use. Chapter 5 provides evidence of user experience in Ireland with Fall Detection Technology presented through the lens of some of the Principles of Universal Design.

	Manual Panic Button		Automatic Fall Detection			
	Home Device	Community Device	Home Device	Community Device	Smart Phone	Smart Watch
						
Push Panic Alarm	✓	✓	✓	✓	**x**	**x**
Movement Detection	**x**	**x**	✓	✓	✓	✓
Automatic Fall Detection	**x**	**x**	✓	✓	✓	✓
Location Identification	**-**	✓	**-**	✓	✓	✓
Indoor Home Use	✓	✓	✓	✓	✓	✓
Outdoor Community Use	**x**	✓	**x**	✓	✓	✓
Multi-functional Use	**x**	**x**	**x**	**x**	✓	✓
Duration of Use (battery life)	1-2 years	1-2 days	1-2 years	12-18 hours	12-18 hours	12-18 hours

Note: ✓ **:** full functionality, **- :** partial functionality, **x :** no functionality

Figure 2: Functional Features of Wearable Fall Detection Devices

	Manual Alarms		Movement Detection		Fall Detection		
	Pull Cord	Strip Alarm	Pressure Sensor	Motion Sensor	Vision Fall Detection	Radar Fall Detection	Wi-Fi Fall Detection
							
Push Panic Alarm	✓	✓	x	x	x	x	x
Movement Detection	x	x	✓	✓	✓	✓	✓
Automatic Fall Detection	x	x	x	x	✓	✓	✓
Location Identification	✓	✓	✓	✓	✓	✓	✓
Indoor Home Use	✓	✓	✓	✓	✓	✓	✓
Outdoor Community Use	x	x	x	x	x	x	x
Multi-functional Use	x	x	x	✓	x	x	✓
Duration of Use	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited

Note: ✓ **:** full functionality, **x :** no functionality

Figure 3: Functional Features of Ambient Fall Detection Technologies

For a summary of the functional features of commercial and research prototype ambient Fall Detection Technologies, see Figure 3. For a non-exhaustive list of current suppliers and retailers of Fall Detection Technologies in Ireland see Appendix 1b.

3.4 Lifetime Communities

Emerging smart technologies offer the prospect of new and more efficient health and care services for older people and persons with disabilities living in their homes and communities. However, the business and service models needed to deliver these are complex. Understanding the dynamics of communities is essential in the development of these models. This section of the study presents examples from Ireland and around the world reviewing different approaches to lifetime communities. Smart technologies are enabling these communities to provide better integrated, more efficient and accessible primary care services and some examples of those are given.

Emergence of Lifetime Communities

Lifetime communities or 'Communities for a Lifetime' is a relatively new concept. It was first introduced in Florida in the United States in 1999. For the purpose of this study a lifetime community is comprised of both the physical infrastructure of a community, as well as, the health, social and technological support services in that community. The objective of a lifetime community is to foster healthy and successful ageing across the lifespan. Lifetime communities benefit all residents including younger adults, working families, people with temporary or permanent disabilities and older adults alike. These communities act as a framework to help communities for the future (Minnesota Department of Human Services, 2018a).

Lifetime communities aim to be good places for residents to grow up and grow old in. In a lifetime community, community sector leaders build places that support health and vitality for residents and the community as a whole through collaborative action and strategic planning. Fostering communities for a lifetime can be an important tool to prepare any society for a growing age population (Minnesota Department of Human Services, 2018b).

The goals and objectives of lifetime communities originally established in the United States of America are similarly matched in other regions across the world which are seeking innovative solutions to support their growing and ageing populations. In the United Kingdom for example, the National Health Service is working with a number of housing developments across England to shape the health of communities and to rethink how health and care services can be delivered. The **Healthy New Towns** programme was launched in 2015 with demonstrator sites chosen from across the UK (NHS, 2018).

In the Netherlands, the **Buurtzorg model** has achieved considerable success by enabling people with care needs to live independently in their communities. The Buurtzorg team considers the client, their living environment and the people around them to build a solution involving the client and their formal and informal networks. Self-management, continuity, building trusting relationships and building networks in the neighbourhood are all core principles of the model. This person-centred model has proved to be very successful in the Netherlands (Olsen, 2016). However, the application of the Buurtzorg model to healthcare systems and communities in other countries needs to be demonstrated (Kreitzer et al., 2015).

Policies supporting Lifetime Communities

Cities of the Nordic countries recently collaborated to produce a white paper outlining their shared vision for what a sustainable city is in a Nordic context. This white paper builds on the **Nordic Charter for Universal Design** (Björk, 2013), with inclusive planning processes using checkpoints to ensure that the interests of the entire population are considered in the design of physical environments and their amenities. The white paper also incorporates the UN's **Sustainable Development Goals** and indicates nine practices or outcomes required for a truly sustainable city. The nine principles are

1. Inclusive
2. Healthy
3. Resilient
4. Compact Green
5. Mobility
6. Circular Economy
7. Low Carbon
8. Smart
9. Design (Borges et al. 2017).

Challenges arise when trying to scale these policies and processes and translate them into local contexts. In an effort to overcome this, organisations are building collaborative global networks and supporting communities to ensure that good design is a core part of their planning process.

The **Global Alliance on Accessible Technologies and Environments** (GAATES) is the leading international organization dedicated to the understanding and implementation of accessibility for sustainable built, social, ICT and virtual environments and to promoting the **Guiding Principles of the United Nations Convention on the Rights of Persons with Disabilities** (CRPD) as adopted in December 2006 (GAATES, 2018). This includes architectural design, infrastructural design, transportation systems, habitat, and electronic information and communication technologies; so that everyone, including persons with disabilities and older persons are able to fully participate and contribute to society (Delta Centre, 2013).

In Ireland, HSE strategies reflect lifetime community activities. **Time to Move on from Congregated Settings** is a strategy for community inclusion from Health Service Executive. It supports people with disabilities to move from large institutions (congregated settings) to their own homes in the community. (HSE 2011). The **Integrated Care Programme for Older People** (ICPOP) and the National Clinical Programme for Older People (NCPOP) are leading out on the development of cohesive primary and secondary care services for older people. The programme is currently implementing, testing and monitoring integrated service developments for older people in across a number of pioneer sites. It is evaluating this implementation so that lessons learned may be extended nationally. The objective of the programme is to improve the quality of life for older people by providing access to integrated care and support that is planned around their needs and choices, supporting them to live well in their own homes and communities (HSE, 2016).

The **Age Friendly Ireland Cities and Counties** Programme is run throughout Ireland. This programme aims "*to create the kinds of communities in which older people live autonomous and valued lives*" (Age Friendly Ireland, 2016, p.11). Activities are designed around the World Health Organisation Age Friendly Themes:

- Outdoor Spaces and Buildings
- Housing
- Social Participation
- Transportation
- Respect and Social Inclusion
- Civic Participation and Employment
- Communication and Information
- Community Support and Health Services (Age Friendly Ireland, 2018a).

The programme is run by city and county-based alliances, chaired by a high-ranking local authority representative. The alliances involve senior decision-makers from the public, commercial and not-for-profit organisations. The views, interests and needs of older people are at the core of all decisions. Older people exercise a strong, guiding influence on age friendly local development in each local authority. It is a programme that facilitates multi-agency cooperation in finding new, innovative low or no-cost ways to make our communities better places for people to grow old in. Each Age Friendly City and County develops an **Age Friendly Strategy** for its particular region in consultation with its stakeholders (Age Friendly Ireland, 2018b).

Use of Smart Technologies in Lifetime Communities

Smart technology can play an important role in the success of lifetime communities. A smart community creates an ecosystem made of stakeholders including the public, community groups, businesses and local authorities. It leverages new technologies to improve quality of life and efficiency of services to meet the needs of the community. Smart communities recognise the importance of citizen engagement to understand better their needs and also to enable people in the community to improve their daily lives and community themselves. Despite the potential and promises of connected health in particular, they are said to be at risk of digital exclusion (Fleming, Mason and Paxton, 2018). To remedy this, research suggests that user centred design, training and community engagement tailored to include the specific needs of older people is needed (Wandke, Sengpiel and Sönksen, 2012).

The **NHS Healthy New Towns** demonstrator in Darlington, UK highlights the growing importance of technology as part of the long-term care solution. This demonstrator brings together clinicians, community representatives, care providers, technology and digital innovators as well as health and social care commissioners to 'rethink' how health, wellbeing and care services can be delivered. It aims to maximise independence and lifestyle choices by building smart houses in neighbourhoods with built-in monitoring and information access. The development of a local innovative digital health system will allow phone line, app and internet-based digital technology to be linked to GP and hospital record systems. This will improve planning and predictive modelling of the population requirements. It will use 'big data' available from health, social care and local authority organisations to establish effective data sharing, identify those at risk of developing long-term conditions and frailty, and predict population needs to improve commissioning (NHS, 2018).

Technology can also be used in novel ways to nudge people towards healthier lifestyle choices by providing rewards for regular exercising. In Japan, the fastest ageing country in the world, there is a movement to create a sustainable, prevention-oriented society in which people can lead happy and healthy lives regardless of the population's advancing age. The **Smart Point Project** engaged people over 40 years of age in six participating cities and monitored activity achieved through regular exercise. People received points for participating in the health promotion programs. The points earned through the programme could be exchanged for Ponta points (another reward point system with cards that can be used nationwide), community certificates or social contributions (donations). Of the approximately 12,600 participants, 76% were people with no interest in exercise at the beginning of the project. The effect of ongoing exercise on the health of the participants was clearly demonstrated by reduced medical costs including a reduction in the number of falls due to increased physical activity (Yuka, 2017).

In general, smart technologies for assisted living and connected health are not widely adopted in Ireland. Previous analysis by the National Disability Authority suggests that Ireland has an underdeveloped assistive technology infrastructure in comparison with other countries such as Norway, Denmark, the Netherlands and Germany (NDA, 2012). The reasons are wide ranging and include accessibility difficulties, cost of the technology and lack of grant-aided funding. Difficulties in getting the technology to work reliably for non-technology experts and a fragmented technology landscape where one smart home technology does not work with another are among the contributing factors (NDA, 2018). These difficulties limit a broader adoption of a range of potentially complementary technologies. A recent report researching **Assistive Technology for People with Disabilities and Older People** outlined concerns about the current service provision of assistive technologies. It pointed out that the system is fragmented and under-resourced to meet emerging changes (DFI and EI, 2016).

However, there are a number of encouraging examples of smart solutions developed for lifetime communities in Ireland. Homesafe is an established solution which provides advanced technologies to care for the elderly in their own home, with 24 hour sensor monitoring, health monitoring technologies and a 'friendly call' service (Homesafe, 2018). Another emerging technological solution is Carefolk, an integrated care platform for professional and family care teams, which provides tools to allow them to share information and coordinate care in a secure easy-to-use environment (Carefolk, 2018)

The **Great Northern Haven** development in Dundalk, County Louth is one example in Ireland where technology is used to enable independent living and enhance quality of life of its residents. The need for this housing development was identified during the consultation process conducted during the preparation of the **Louth Age Friendly County Strategy**. Agencies worked together to deliver an innovative solution which supports older people to continue to live independently in their own communities. It is located strategically beside a Primary Health Care Unit, Council offices, leisure centre, social welfare office, church, pharmacy and bus stop. This is a flagship project for County Louth as Ireland's first 'Age Friendly' County, and for the Netwell and CASALA research centres (Age Friendly Ireland, 2018c).

The charity ALONE supports older people to age at home in Ireland. It is also developing a smart technological solution aimed at the needs of older people. In 2017, it started a pilot of the **BSafe Assistive Technology** in a number of homes of older people. BSafe will provide individualised packages of Ambient Assisted Living Devices and wearable devices. It will also provide the BWell app and tablet for older people. BWell focuses on aspects of social interaction in an older person's life including their mental, emotional and physical health. The older person records their activities, reviews their data, manages their appointments and medications as well as, communicates with their support networks. The BFriend app is available to ALONE staff and volunteers who work directly with older people. This allows both staff and volunteers to log their visit details, ensure quality of service with a history log, and keeps volunteers and staff safe through location sharing during visits (ALONE, 2017).

Other **initiatives** have also been launched recently in an effort to better integrate technology and social supports. **Health Innovation Hub Ireland** (HIHI, 2018) facilitates and accelerates the commercialisation of innovative healthcare solutions, with a particular focus on Engaging Positive Ageing (DBEI, 2018). The Enterprise Ireland **Small Business Innovation Research** (SBIR) programme enable public sector bodies to connect with innovative ideas and technology businesses so that they provide innovative solutions for specific public sector challenges and needs. In 2017 Cork County Council set the challenge for innovation to support older and vulnerable people to be and feel secure in their own homes (Enterprise Ireland, 2017).

Amicitia Exemplar

Amicitia is a socially inclusive, shared value social enterprise based in Athenry, Co. Galway. Amicitia introduces a new model of social enterprise that puts the community at the heart of the enterprise and builds on the social values of Amicitia's trading subsidiary Independent Living Ireland (Amicitia, 2018; Independent Living Ireland, 2018a). Amicitia is currently in the first phase of these efforts and has introduced a redistributive economic model which shares resources equitably across society, creates training and employment opportunities for the most disadvantaged and connects community groups across new resilient networks. Independent Living Ireland generates profit through the sale of many of the smart home and assistive technologies detailed in chapter 3 to clients such as hospitals, nursing homes, disability care organisations and individuals living independently in the community. These profits are redistributed to support community development projects.

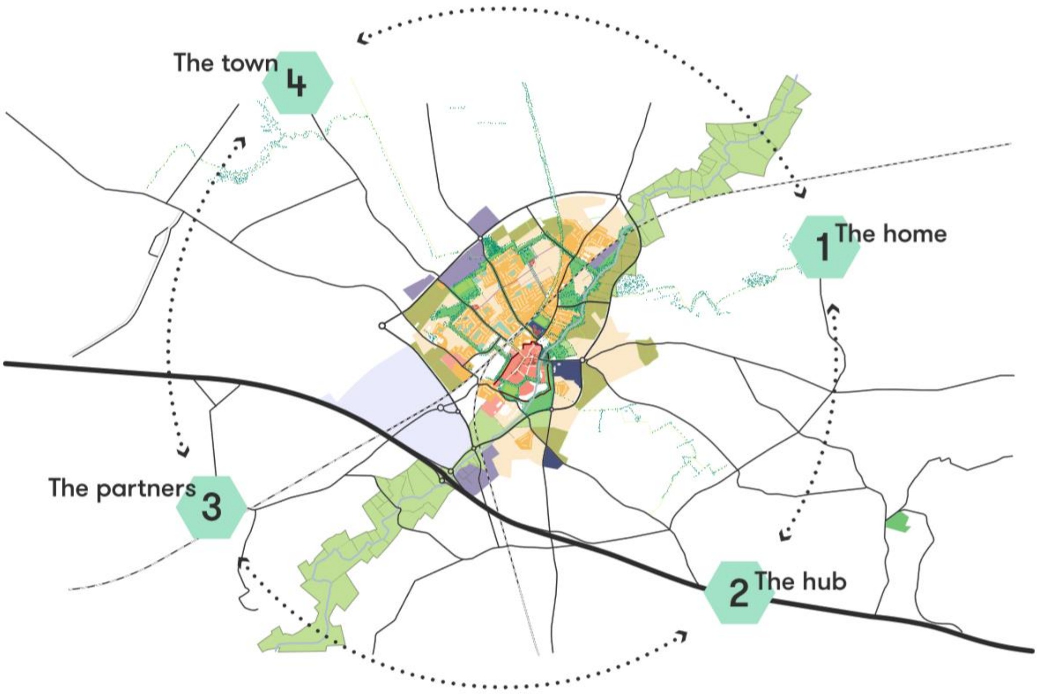


Figure 4: Amicitia Vision for Lifetime Communities

Amicitia's vision for a lifetime community aims to connect older and vulnerable people living in their own homes to both a social hub located in the town and the wider town community with support from its partners, as illustrated in Figure 4. It is expected that the implementation of an Amicitia lifetime community model will vary from town to town depending on the existing services in that town. The Amicitia model is an iterative process and expands with each new project and partnership.

The Home

In an Amicitia lifetime community it is envisaged that older or vulnerable people living independently in their own home will be supported by smart home and assisted technologies. Alerts raised by these support technologies will be answered by their family members, neighbours or volunteers in the hub or wider community. Technology (including Fall Detection Technology) can improve health and wellbeing while also providing safety and security in and around the home. These interventions help older people and those with disabilities to age in place with local community support.

Amicitia recognises the importance of ageing in place. In 2017, the Amicitia project Cairdeas, designed in partnership with Dutch design agency dmau, was one of five commended entries in the Homes for Smart Ageing Universal Design Challenge (HSAUDC, 2017; Amicitia, 2018). This challenge aimed to encourage innovation in the design and delivery of housing solutions for older people to implement Action 2.19 of Rebuilding Ireland (Government of Ireland, 2016).

Amicitia is currently developing a technology platform, the Ami Platform, which builds on and extends the features of existing smart technologies by leveraging next generation 'Internet of Things' applications. This technology aims to support older people and people with disabilities with some of their daily life activities. A prototype of the Ami Platform is currently being tested in Mitchelstown, Co. Cork. It is developed in partnership with Friendly Call Cork and the Nimbus Research Centre in Cork Institute of Technology and supported through a Small Business Innovation Research grant by Cork County Council, Enterprise Ireland and Health Innovation Hub Ireland. The platform is currently at Technical Readiness Level (TRL) 4. The platform was co-designed with the members of community through design thinking workshops. Wearable and ambient Fall Detection Technologies are included in the project. These technologies can be used both in the home and the community.

The Hub

Amicitia considers that technology is only one element of a lifetime community. With an increasingly elderly population, many rural towns in Ireland face the challenges of finding adequate care for older people. Amicitia believes a social hub strategically placed in a town will begin to put in place structures to address these challenges. Social supports are key to the sustainability of the model and these are coordinated through Amicitia's social hub. The hub facilitates social interaction and help reduce loneliness and isolation felt by many older and vulnerable in the community. The home is connected to a hub in the centre of the town. This hub can be a repurposed shop space ideally linked with a garden area. The space connects local care networks and volunteer response services to provide an extra layer of support for those living independently.

Amicitia's first social hub opened in Athenry in September 2015. This hub includes gardens, markets and space for the community to host workshops and events, including arts and craft workshops, community gardening, a sustainable energy network and a small-scale plastics recycling initiative. These workshops and activities are fully inclusive and are open to all members of the community regardless of age or ability.

The Partners

Amicitia aims to support and collaborate with partners in each new town to develop a new lifetime community. Amicitia relies on a diverse group of partners to improve its technical systems, develop its community projects and enhance its social business model. These include Independent Living Ireland, Friendly Call Cork, Health Innovation Hub Ireland, Nimbus Research Centre, Athenry Community Council and Cork County Age Friendly programme.

The Town

The connected home and community social hub supported by a community development platform can regenerate the rural town and improve the public realm. Older people and people with disabilities have easy access to vibrant townlands with community support networks stretching to the hinterland.

In 2019, Amicitia along with the Athenry Community Council were awarded funding through LEADER to implement this project in the town of Athenry. Public consultation on this began in February with members of the community asked to contribute their ideas to reimagine the public spaces of the town with a view to making them more inclusive and age-friendly. Results of this study will be published towards the end of 2019 and will include a short documentary to support community efforts to access finance and realise some of the ideas suggested through the public consultation process. Amicitia takes a holistic approach to the needs of older people and people with disabilities.

Amicitia Model

Amicitia has developed a model that recognises the interplay between the enterprise and social elements, Figure 5.

1. **Sensors** and machine learning algorithms support those in need in their homes by detecting falls, bogus callers or changes in routine which may signify health problems.

2. **Social** isolation and loneliness are alleviated through friendly call and other community-led services such as dementia tea mornings.

3. Technology and the hub help to coordinate **care networks** including first-responder services.

4. A blockchain-based **rewards** system encourages volunteering based on the Japanese model of Fureai Kippu (Hayashi 2012).

5. Participatory projects and online civic **participation** tools engage the wider community and build intergenerational links to support health and wellbeing.

6. A redistributive economic model creates **shared-value** in the community and supports people from socially disadvantaged groups into employment.

7. **Partner** networks are key to growing and scaling the project.

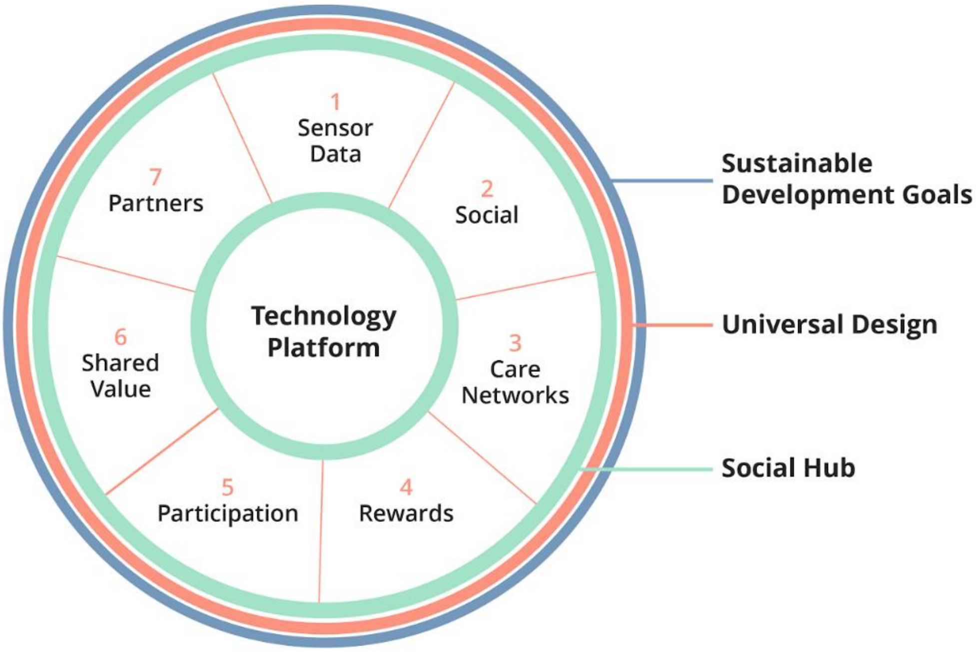


Figure 5: Amicitia Model for Connected Communities

Amicitia is guided by the Principles of Universal Design in an effort to design their technology and community projects using inclusive participatory processes. Amicitia is also guided by the **United Nations Sustainable Development Goals** (SDGs) (UN, 2015). In 2015, countries adopted the **2030 Agenda for Sustainable Development** and its 17 interconnected Sustainable Development Goals. To achieve the goals there is a whole-of-government implementation plan where all Ministers retain responsibility for implementing the individual SDGs relating to their functions (DCCAE, 2018).

A central impetus of the Agenda is to ‘leave no one behind’. This aligns closely with the Principles of Universal Design and means that all people everywhere, regardless of their individual circumstances or characteristics, must be included as active participants in the journey to 2030 (Richardson, 2017).

3.5 Conclusions

Design methodologies such as Participatory Design or Design Thinking set out the steps to achieving a successful design (the how). While Design Principles set out what is required of a successful design (the what). **Universal Design** (UD) offers seven principles that can guide designers in the development of products that are more equitable, flexible, simple and more intuitive to use, communicate information in a more perceptible manner, exhibit more tolerance to error, require lower physical effort and are optimised in size and space for their use. UD is increasingly being embraced in the design of products and services for older people and people with disabilities. Several countries are putting policies in place for product and service design that embraces UD.

At the same time we see that **Smart Technologies** are becoming increasingly pervasive in our lives. This includes smart homes technologies, ranging from smart energy management, to smart security, entertainment, to assisted living. Many of the consumer electronic companies are now offering products in this space including voice controlled smart home hubs from Amazon, Google, Samsung and Apple.

Fall Detection Technologies form part of a range of smart technologies and can be divided into wearable and ambient technologies. Falls are a major health risk for older people and people with disabilities. The detection of falls and the immediate alerting of care givers that someone has fallen are key to reducing the negative impacts of falls. A review of the scientific and technical literature was carried out to discover recent developments in Fall Detection Technologies. The review and analysis of existing Fall Detection Technologies was formulated through both the participating researchers’ knowledge and through examining product literature. The analysis referred to the Principles of Universal Design.

The review found that the development of existing Fall Detection Technologies does not appear to systematically incorporate the Principles of Universal Design. Furthermore, advanced Fall Detection Technologies currently under development within the research community exhibit low levels of maturity. Many Fall Detection Technologies operate in silos as they do not work with other smart technologies or integrate with specific smart home environments. The level of automatic fall detection is limited in commercially available technologies.

A **Lifetime Community** is a novel concept that supports healthy and happy ageing within a community context. Smart technologies can play a significant part in supporting lifetime communities by providing community members with mechanisms for effective communication, interaction and living assistance. However, current smart technologies including Fall Detection Technologies are not well integrated into this concept. They also do not integrate well with existing health care services.

4. Data Gathering and Analysis Methodology

The data gathered as part of the research was mainly of a qualitative nature and required a methodology for the research to be carried out. The Braun and Clarke thematic analysis method offers a suitable framework (Braun and Clarke, 2006). Data was gathered through semi-structured interviews with 67 individual participants and unstructured meetings with 64 community stakeholder participant. All data gathered was codified from which themes were generated and key findings identified in response to the objectives of the research.

4.1 Methodology for the Stakeholder Engagement Strand

The main objective of the stakeholder engagement strand was to gather data based on experiences of stakeholders in Ireland focused on

1. The impact of Fall Detection Technologies on people at risk of falling and their carers from a stakeholder perspective.

2. The current design state of fall detection solutions and services as seen by the stakeholders themselves.

3. How Fall Detection Technologies impact and support lifetime community initiatives.

Based on this objective, the team identified important key stakeholder groups, such as people who are at risk of falling, including older people, and their informal care group of family, friends and neighbours. It also included formal care givers and healthcare professionals who support those at risk of falling. Other stakeholders considered to have valuable insights were people who understand the technologies and trends underpinning fall detection, as well as, people who understand how lifetime communities work in practice. This presented a detailed map of stakeholder groups and personas relevant to the research as can been seen in Table 1.

	Category	**Representative Personas**
A	**Person at risk of falling**	Older people with limited mobility at risk of falling Older abled-bodied person at risk of falling Persons with disabilities at risk of falling
B	**Informal Carer**	Informal Carer of an older person at risk of falling Informal Carer of a person with disabilities at risk of falling
C	**Formal Carer**	Carer in Home Support Service Carer in Residential or Congregated Settings Nursing Assistant in Hospital Setting

D	**Healthcare Professional**	Nurse Occupational Therapist Physiotherapist Doctor
E	**Retailer**	Retailer of Fall Detection Technologies
F	**Researcher**	Assistive Technology Researcher Fall Detection Technology Researcher Older Person Healthcare Researcher
G	**Designer / Innovator**	Technology Designer Town Planner Healthcare Innovation Specialist Technology Innovation Specialist
H	**Lifetime Community**	Community Group Worker Community Support Worker Community Development Worker
J	**Local Authority**	Age Friendly Programme Staff Business Development Staff

Table 1: Stakeholder Categories and Personas

Based on these personas, a strategy was developed for the engagement strand which included semi-structured interviews with individuals and unstructured meetings with key stakeholder individuals and groups. The semi-structured interviews concentrated on the impact of Fall Detection Technologies on people at risk of falling and their carers and the current design state of fall detection solutions and services. While the unstructured visits and meetings with individuals and groups were considered more suitable for gathering data on the emergence of lifetime communities in Ireland and the role of technology in these communities.

While participants' anonymity has been maintained, the category of each participant can be identified and the data of each participant has been recorded individually. A participant's data is identified by participant ID made up of a prefix, which refers to the category of that participant and a suffix, which is an anonymised identifier in that category. For example, Participant A05 is a person at risk of falls and Participant C02 is a formal carer. Anonymised details of the participants can be found in Appendix 2.

Interviews with Individuals from Key Stakeholder Groups
Semi-structured interviews were carried out with 67 individual participants from 7 different categories as set out in Table 2. The interview protocols on Fall Detection Technologies were developed appropriate to various different stakeholder groups. The language used in the interviews was simple and accessible to everyone. The first question was used as a 'warm-up' to get the

participant accustomed to the interview process and to ensure they are comfortable with talking to the interviewer. This was followed by a series of general questions on routine, community life, familiarity with fall detection solutions, perspectives on current problems and future possibilities. Each participant was asked at the end of the interview if they wished to add anything else, this allowed for the participant to raise issues not covered in the interview protocol. For further details of the interview protocols, see Appendix 3.

The participants were interviewed at a place convenient to them. The researchers spent some time ensuring the interviewee was comfortable and ready to talk before commencing the interview. Interviews were carried out in accordance with the approved project Research Ethics Guidelines, see Appendix 4. Participants were advised of the purpose of the research, what was involved in taking part, how participants were selected, and the voluntary nature of participation. The confidentiality of their data, any possible risk or disadvantage to them and the benefits of the research was also outlined. Interviewed participants signed the Project Consent Form prior to the interview being carried out, see Appendix 3b.

Semi-structured interviews were carried out during either via face-to-face meetings or telephone conversations. A researcher interviewed each participant, with a second researcher attending where possible to take notes. Telephone interviews and some face-to-face interviews were also audio-recorded with the agreement of the participant. The recordings were then summarised and written notes were produced by the researcher.

prefix	category	number
A	Person at risk of falling	19
B	Informal Carer	19
C	Formal Carer	10
D	Healthcare Professional	10
E	Retailer	5
F	Researcher	3
G	Designer / Innovator	1
	total	**67**

Table 2: Semi-structured Interview Participants

Visits to and Meetings with Community Stakeholders

A series of visits and meetings with active lifetime community programmes were organised with 64 participants from 9 different categories, as set out in Table 3. The Amicitia exemplar provided access to a wide variety of stakeholders which allowed the researchers gain insight into various different smart technologies and the role of technology to support lifetime communities. This included visits to lifetime communities developing technology solutions in the built environment using commercial products. Observation and shadowing of participants in lifetime community was also undertaken as they co-designed community support technological solutions in group settings. Data was captured by the researchers following these meetings and visits with a series of reflections based on their observations of these communities. The reflection data was peer reviewed by the research group to minimise bias.

prefix	category	number
A	Person at risk of falling	9
B	Informal Carer	5
C	Formal Carer	3
D	Healthcare Professional	7
E	Retailer	1
F	Researcher	2
G	Designer / Innovator	6
H	Lifetime Community	22
J	Local Authority	9
	total	**64**

Table 3: Participants from Lifetime Community Visits and Meetings

4.2 Methodology for Data Analysis Strand

The data from the stakeholder interviews, meetings and visits was documented. This was collected and managed under the project's ethical framework. **Thematic analysis** on this data was conducted using Braun and Clarke's flexible methods applied in six stages. This methodology positions the researcher at the heart of the process and data from stakeholder help to reveal unifying patterns and ideas across core themes:

1. Familiarisation with the data: The project team went over the interview transcripts or recordings a number of times to familiarised themselves with the content and characteristics of the data. This process was repeated until all persons involved in the coding felt that they had become immersed and intimately familiar with the content.
2. Generating initial codes: The project team identified features of the data relevant to answering the research question. Using this first set of codes generated by the research group, all data pertaining to each was identified and extracted from the transcripts. This process was repeated for each data item. Data relating to the same codes was then collated together.
3. Generating themes: Through a revision of the codes developed in the previous step themes were generated. This involved a process of sorting the codes based on significant patterns of meaning.
4. Reviewing themes: After the generation of the first round of themes, these were reviewed and checked against the data set to determine if they told a true, convincing story of the data that answers the research question at hand. Related themes were merged, and others were broken down into sub themes. This process continued until it was felt that the themes accurately reflected the narrative of the data.
5. Defining and naming themes: A detailed analysis of each of the final themes was developed. The scope and focus for each theme was defined, as well as a theme name.
6. Producing the report: The final phase involved weaving the analytic narrative and data extracts, while contextualizing the analysis in relation to existing literature.

This was carried out as an iterative and reflective process that developed over time with discussions moving back and forward between each strand of the research. Several revisions were carried to ensure the stability of the emerging picture.

4.3 Limitations of the Study

There were a number of limitations and difficulties experienced during this study. While there are many examples of Fall Detection Technologies available on the market, the researchers found that most participants at risk of falls and their carers had experience only of a limited number. They were therefore unable to give opinions on the full range of the technologies available. The researchers had to rely on the expertise of other researchers and retailers for opinions on the less commonly used technologies.

Observations of people at risk of falling using available Fall Detection Technologies would have assisted in the understanding of the assessment of design of these technologies. However such observations were not feasible during the timescale of this study. This was due partly to the fact the many interviews were undertaking in community rather than home settings. Also by their nature falls are unplanned events and so it was not possible for the researchers to observe the technology functioning in a real situation. The researchers therefore relied on the reported opinions and experience of stakeholders.

As with most research studies, the researchers would do some things differently if embarking on this study again. The interview protocol could have been more focused. Interviewees tended to want to talk more about what they were familiar with and less about Fall Detection Technology. Much of the data documented for the stakeholder engagements, while interesting, was not directly relevant to the research questions in this particular study. This resulted in additional time and effort required to analysis the data.

Another limitation of a study is a fast developing technology landscape. This study refers to technologies at a particular point in time. The technology landscape can change very quickly. Indeed new Fall Detection Technologies have emerged during the course of this study while others have left the market.

5. Findings

In this chapter the findings of the analysis of data gathered from formal semi-structured interviews as well as from stakeholder meetings and visits to several emerging lifetime communities in Ireland are presented. The findings are based on an analysis of data using the methodology described in Chapter 4. For thematic maps generated from the data gathered from stakeholder engagements, see Appendix 5.

The findings identify that falls and fear of falling is a real issue for participants. Fall Detection Technology is found to play an important role within a network of care supporting older people and those with disabilities at risk of falling. However, participant's experience of technology also points to a range of problems with design, functionality, and use of such technologies. Participants also identify some examples of integrated Fall Detection Technologies that support lifetime communities.

5.1 The Role of Fall Detection Technologies

Participants highlighted both causes and consequences of falls. Health issues, both physical and cognitive, can lead to people falling. Environmental causes in the home and community were also raised as causes for falls. Consequences of falls include physical harm, emotional issues and lifestyle changes. Significant fear of the consequences of falls was also expressed by many of the interviewed participants.

As outlined in Chapter 3, a variety of Fall Detection Technologies are commercially available in Ireland including wearable technologies such as the panic button alarms, automatic fall detectors, and ambient technologies such as pull cords, strip alarms, bed/chair occupancy monitors and home occupancy sensors. The Fall Detection Technologies most often reported by participants were the panic alarm button and the pull cord.

Many participants agreed with the usefulness of wearable manual panic alarm buttons in the home environment for both raising alerts after a fall but also for other events such as bogus callers (Participants A03, A04, A07, A10, A15, A19, A22, B02, B03, B05, B12, B14, H04). However, more sophisticated technologies are also available but are in less use. Participant E05 described a smart home system:

> We have developed of a range of sensors connected to a platform. They are placed around the house. They work in the background. They give us information, like if there is no movement in the house for a period of time or if someone wandered out the door in the middle of the night when they shouldn't if they have dementia and they are mixing up their days and nights, the platform alerts the family or the carers.

Physical Consequences of Falls

The consequences of falls include physical harm as a result of falls ranging from cuts and bruises to broken limbs and other serious injuries requiring hospitalisation, long-term physical effects resulting in risk of further illness, as well as the physical effects to carers. Participant A12 detailed injuries her friend had suffered when she fell:

> She landed on her eye which was badly damaged. It was bruised for two weeks.

Participant B12 reported her aunt's injuries:

> She fell in the kitchen and broke her hip. She was in hospital for a long time after that.

Participant B03, a healthcare assistant, reported:

> The aftermath of a fall is what is most dangerous, because hospitalisation leads to infections. Deterioration can be really fast after an older person is hospitalised.

The use of technology, such as the panic alarm button, can reduce the physical harm of a fall significantly such as **reducing long lies**. For example, participant B14 described her father's use of his panic alarm:

> He wears one on his wrist all the time, as he lives alone. Very recently, he has had two falls. One when he was coming out of the house and he toppled. He was on the ground and couldn't get up. He activated the alarm. I was called and came over to him to help. He was very lucky because there was no one due to call until the following morning. He would have been there outside on the ground all night, if he didn't have the alarm.

Movement sensing devices are used to **raise alerts** that a person has moved out of a bed or chair and could be at risk of falling (Participants B14, C01, C02, C03, C06). Devices also extend to professional care environments with participants reporting on the use of pull-cords and strip alarms in bathroom facilities in nursing homes and residential units in the community. The usefulness of bed/chair occupancy sensor technology was recognised by some participants, particularly those working in nursing homes, to **highlight potential risk** of falling.

Participant D05 recommends those technologies for some of her clients:

> I have recommended sensors for patients with dementia to alert their carers when they get up at night or when the get off the chair.

Participant C01, a health-care assistant working within a nursing care home, who described the bed / chairs occupancy sensor technology as:

> lifesavers … we wouldn't manage without it.

Emotional Consequences of Falls

The emotional effects of a fall can cause considerable stress for both the person who fell or is at risk of falling and their family/carer. Falls often lead to significant lifestyle changes. Participant A17 mentioned

> I'm very nervous of falling in the shower.

Participant A18 explained:

> I'm afraid of being stuck alone at home due to the consequences of a fall.

Participant B14 outlined her worries about her father, who had fallen twice in recent weeks:

> I worry constantly.

However, Fall Detection Technology can **reduce fear of falling or of falling again**, for example participant A10 finds that her panic alarm "provides great reassurance", and participant E01, a retailer of the panic alarm system says that:

> The panic alarm gives peace of mind and reassurance for our clients.

Participant E05 quoted one customer who has smart technology installed at home, saying:

> I salute the motion sensors every morning because the people in the monitoring station know I'm OK … the system gives me that extra bit of safety and security and for me that is very important.

Fall Detection Technology can also **reduce concern and anxiety of family and carers**. Participant B14 feels less stressed that her father is wearing a panic alarm button:

> knowing that my father wears a panic button is a great relief.

Impact on Lifestyle Changes

A number of lifestyle effects were reported for both people who fell and their families. The immediate consequence for many participants after falling was a change to their activities of daily living and to their lifestyle more generally. A fall can also have an impact on a carer's daily life. This is particularly relevant to informal carers, who are often fitting in the care of a friend or relative around their own career or other responsibilities. Participant B02, who cared for her elderly mother-in-law explained:

> She wouldn't light the fire in her sitting room for fear of falling into it. She didn't use the room for the last eight or nine, maybe ten years of her life.

Participant B05, speaking about her mother, said:

> She broke her arm. She still has no use of that arm. It had a huge impact on her life as she isn't able to do anything for herself anymore. She requires someone to be with her all of the time ... She used to be upstairs but now her bedroom has been moved downstairs due to her poor mobility. When she needs to go downtown, like to the doctors, she has to use a wheelchair so she doesn't move out as much as she used to. She used to go shopping every Thursday but not anymore.

Participant E05 described the impact Fall Detection Technology such as the panic button has on one of his customers to help her **maintain independence** as she lives alone:

> I'm thinking of one woman back the road. She wouldn't live in the house without it and it is only a social alarm.

Fall Detection Technologies have also been installed in homes as part of the integration of vulnerable adults and adults with disabilities from residential care to independent living accommodation in the community (Participants D10, D15, D16, E01, E02) helping with **reducing their social isolation**.

While the adoption of ambient motion monitoring appears to be limited, some participants recognised that it is very helpful in detecting change in patterns in the routine of occupants and that gives reassurance to the person at risk (Participants E01, E05, G02, G03, H21).

5.2 Vignette

The following is a fictional representation of our findings encapsulating many of the problems faced by older people living alone. It is one story which reflects the challenges of caring for older people in the community and highlights the present state of technology in this network of care.

> Angela is 76 and has lived in her home in a rural community all of her married life. Her husband, Sean, passed away two years ago. She has two sons, who live away from the area with their young families and one daughter, who is in Australia. Her sons call to visit as often as they can and Angela is thankful that she has the support of her neighbours when she needs it. Since she

has retired from her work as a teacher, Angela has kept up an active role in the community by taking part in the active retirement club and volunteering in the local charity shop.

Angela's confidence was rocked by a recent fall in her home. She was coming down the stairs early on a dark winter morning when her foot got caught on a mat and she fell over by the front door. It was not until the postman arrived later that morning that she was able to call for help. She was brought to the hospital with a fractured hip. The fall made her more aware of living at home on her own and the dangers of falling again. She wants to remain living at home and does not want to have to spend any time in a nursing home.

Her son helped her for a couple of weeks when she returned home from hospital and the occupational therapist arranged for a personal alarm to be installed. The man who came to install the device showed Angela how it operated. While she is reassured by having a panic alarm, she feels a little confused and nervous with technology. She is afraid of setting off the alarm accidentally and she doesn't want to put anyone out by requesting help when it is not required.

Angela also doesn't like wearing the pendant when her neighbours call over as she feels it makes her look vulnerable.

She now uses a walking stick to help her and she can no longer spend time in the garden. She doesn't have the opportunity to spend time volunteering in the charity shop any more as she can't stand for too long at one time. She still takes part in the active retirement group but the less time she spends in the community the more isolated she feels. Her pendant alarm doesn't work away from the home and she is nervous about walking too far in case she trips on the footpaths around her house which haven't been upgraded in sometime.

5.3 The Design of Fall Detection Technologies

Many participants have experience of the panic button alarm and pressure sensor mats. They found these devices generally simple and intuitive to use. Participants reported issues however with the equitable use, flexibility of use and tolerance of error with these and other Fall Detection Technologies. Findings related to other Principles of Universal Design were not observed and so were not considered relevant here.

Simple and Intuitive Use
Fall Detection Technologies such as the panic button alarm and pressure sensor mat were generally considered **simple and intuitive to use**. Participant B03 reports his mother's use of a panic button alarm. He said:

> She did not find it hard to use … it was a straightforward device.

However some **confusion around the use** of panic button alarm was reported by a few participants who were unsure of how these devices function and so are not certain that they will work in all situations, e.g. in the shower (Participants A01, A15). This technology could be **too complex for people with cognitive impairment** such as those with intellectual disabilities or dementia (Participants E02, F02).

It was reported that some residents in care homes use alarms too much or not at all, as they are unsure of how they work (Participants C02, C06) and that others mistakenly believed that they would be charged for using their device (Participant C04).

Equitable Use
A number of issues regarding the equitable use of Fall Detection Technologies was reported by participants. Many participants worry about the **access to Fall Detection Technologies**. They expressed the reluctance of people to purchase devices due to their cost (Participants A10, B09, D02, D04, D08, E05). Other participants pointed out the restriction of the Senior Alert Scheme to older people, which excludes other younger people who could benefit from this technology (Participants D05, E01, E03).

Participant E01, a retailer, feels that:

> The Seniors Alert Scheme offers a good service to elderly people who can get access to it. But what about young people with disabilities or early onset of dementia? There needs to be more support for these groups.

The provision of ambient Fall Detection Technologies in the home was not evident outside independent living accommodation provided for people with disabilities moving from congregated settings supported by HSE funding (Participants E01, E02). This is despite the technology being readily available on the market. Participant E05 described a smart home system that his company has developed:

> We have developed a range of sensors connected to a platform … The smart technologies like ours are out there, but we wouldn't sell as much of it as the panic alarms.

Participants pointed out that wearing a fall detection device highlights that the wearer is vulnerable. Technology that is segregating or **stigmatizing** is off-putting for some users (Participants A15, B03). Some issues with the design of the wearable panic button alarm were reported. The alarm bracelet can pinch a user's skin and be **uncomfortable** to wear (Participant C04). The alarm pendant design makes users worried about wearing it to bed for fear of choking (Participant C04). The Velcro on the bracelet alarm devices can get caught on woolly jumpers (C09).

Some participants requested that the location identification feature be disabled on their mobile devices and only be used if a fall has occurred, as the user didn't not want the movements of the wearer to be **tracked unnecessarily** (Participants B22, B23).

Flexibility in Use
Participants reported a number of issues related to flexibility of use of Fall Detection Technologies. For example, if the faller is **unconscious** or **confused** he/she may not be able to raise an alert on a manual panic button alarm (Participants C05, E01). Some participant said it can difficult to communicate with a family member or call centre operator through the base station or wearable device when an alert is raised. However, if the person is **too far away** for the base station or has a **hearing impairment,** they are unaware that someone is coming to their assistance (Participant A19, B14). One participant was worried how her father, who is hard of hearing, would use the technology (Participant B04).

While the flexibility of some wearable devices to be used outside the home is desirable, the **battery life** of these devices can be very restrictive, sometimes less than 12 hours (Participants A29, E01, E03). These device are often required to be charged every night.

Participant E03 highlighted some of the problems with automatic fall detection devices used in the community:

> The devices are great and have lots of nice features to support people in the community. The battery life is a real let down though. This really needs to be addressed.

Tolerance for Error
Some people at risk of falls **forget to wear** their fall detection devices, which makes them useless if the person does then fall (Participants B02, B08). One family member expressed a desire to know if the person at risk is wearing the device or not, so that they could remind their loved one to wear the device (Participant B21). Another participant expressed the opinion that false reassurance given by a device is worse than having no device at all (Participant B04). Users are afraid of setting off their alarm device accidentally, and so will not wear it (A12, B05, C05, C08, C09).

In one care home, problems were reported with pressure sensor mats which do not function if the **connected box is too far** from the chair (Participant C01). These mats in beds can cause **false alarms** when residents turn in bed or false alerts can be triggered on motion sensors by pets and other family members (Participants C01, C11).

5.4 The Impact of Fall Detection Technologies on Lifetime Communities

The greatest impact of Fall Detection Technologies on lifetime communities, as reported by participants, is the positive social impact. This technology can support people at risk of falling to live in their own homes and be active in a lifetime community. The physical impact on the community varies for differing types of technology. The technological solutions reported by participants are limited in their functionality or accessibility or were are at an early stage of development.

Social Impact on Lifetime Communities

The **risk of falling in the community** has been highlighted by walkability studies carried out in towns as part of the Age Friendly Ireland Cities and County programme (Participants H07, H11, J02, J03, J06). Identified problem include obstacles on footpaths, installation of shelters and timing of pedestrian crossings. Concerns were also expressed by people at risk of falling and their carers. The condition of pavements presenting a trip hazard was pointed out by many participants (Participants A13, A14, A15, A16, A17, B02). Poor accessibility to shops and houses was also reported (Participants A12, A13, A14, A15, A16, A17). Bad weather was highlighted as a risk factor by Participant A18, who recalled:

> The footpath was very icy. I slipped and fell landing on my hands and knee.

Fear of falling in the community has an impact on a person's lifestyle, as pointed out by Participant C01 who said:

> Their fear of falling can lead to them becoming fearful of walking alone.

Following a previous fall Participant A18 said:

> During the recent bad weather, I didn't move out of the house for three days, as I was afraid of falling.

Participant A14 said:

> I'm afraid of going into the city and falling on the footpaths because they are very bad.

Participants reported that they or a person in their care had a wearable panic alarm. (Participants A03 to A11, A14 to A25, B02, B03, B05 to B10, B12 to B20, C02 to C09, C10). This technology supports many older people living alone to **stay living in their own homes** and remain part of their community (Participants A03, A04, A05, A10, A12, B07, B12, B14). Some participants reported an ambient support technology which was used to support people moving from congregated settings to community or **independent living** accommodation (Participants D14, D15, D16, E02). Very few older people have ambient fall detection in their own homes (Participants E02, E05). Many participants in lifetime communities also highlighted the need for Fall Detection Technology to enable older and more vulnerable people be and feel **safer and more secure** in their own homes (Participants G02, G03, G04, H06 to H12, H16, H21, J03 to J08). Family and carers also reported a sense of **peace of mind** and reassurance that the person at risk uses Fall Detection Technology (Participants B14, B12, B21, B22).

The impact of Fall Detection Technologies on **social activity in the community** as reported by participants is varied. While the wearable panic button alarm is widely used, a number of limitations were pointed out. Participant A04 said she wished to "*upgrade her alarm*" to an automatic fall detection device for the extra sense of security. Participant A18 worries about falling in the garden as the alarm doesn't work outdoors. While Participant A13 thinks the device is more for use at home:

> If something happened when you were out, you would get help from someone else.

The ambient Fall Detection Technologies reported by participants by their nature are embedded in their homes and so do not function or support activities outdoors (Participants D15, E02, E05). The Internet of Things technologies being tested by Amicitia can be used both in the home and the community and so support a person at risk to be active in the community. (Participants C14, E02, H07, H21).

Each Fall Detection Technology reported by participants required some level of **community response in time of need**. The Senior Alert Scheme relies on call centres to manage the response to alerts, firstly by trying to make contact with the person at risk through the base station in the home and then if need to alert family members or emergency services (Participants A03, A05, A14, A15, B02, B05, B12, C09, C10). The solution installed to support people moving from congregated setting has care staff close by or on-call when required (Participants D14, D15, E02). The design of the Amicitia platform allows for alerts (including those related to falls) to be responded to by the social hub, a family member, carer or community volunteer, as desired by the person at risk (Participants G02, G03, G04, H06 to H12, H16, H21, J03 to J08).

The **social model** supporting the installation and response to fall technologies solutions as reported by participants was varied. The wearable panic button alarm is supported by the Senior Alert Scheme run by Pobal. The cost of equipment is subsidised and the person at risk or their family member pay a modest annual fee. Some participants were also involved in the provision of these alarms through their work in community groups or as retailers and installers of this technology (Participants B20, D11, E01 to E05). Some participants reported an ambient support technology which was installed to support people moving from congregated settings to community or independent living accommodation (Participants D14, D15, D16, E02). This development was part of the Time to Move on from Congregated Settings strategy which is supported by state funding. Ambient fall technologies have also been installed in private homes, however the cost is entirely borne by the family of the person at risk (Participant E01, E05).

Physical Impact on Lifetime Communities
The physical impact of Fall Detection Technologies on the community differs for the various technologies. The wearable panic button alarm is easy to install. It has a base station that sits in the home connected to a landline or mobile telephone (Participants B14, D14, D15, D16, E02). Existing ambient Fall Detection Technologies described by participants were embedded in the home and required an internet or telephone connection (Participants E01, E05).

The technology that forms part of the Amicitia prototype consists of a base station connected to the Internet and located centrally in the community. The sensors in the homes or those placed in the community communicate directly and wirelessly to the base station. Most sensors are battery operated and so are easily installed or relocated. These sensors however, need to be within a two to five kilometre range of the base station. The range depends on the specifications of the base station and sensors as well as the geographical terrain. It is estimated that hundreds of homes can be connected to the same base station. (Participants E02, H07, H11).

6. Discussion

The discussion presented here brings together insights gained from the literature and technology review with an interpretation of the research findings in a considered view.

6.1 The Range of Fall Detection Technologies

The research conducted investigated what Fall Detection Technologies are generally available or under development. It found that a range of commercial Fall Detection Technologies are in use in Ireland with the most popular ones being those that are available through specific schemes supported directly or indirectly by the state. Fall Detection Technologies can be divided into wearable and ambient fall detection. The most popular wearable technology is the push button alert technology available through the Seniors Alert Scheme to the over 65 age group. Among the ambient technologies in use are the pull cord alarm, strip alarms and pressure matts. The literature and technology review identified a broader range of Fall Detection Technologies beyond those currently in use in Ireland. These range from commercially ready and available technologies to emerging technologies currently under development in research laboratories. The research evidence also highlighted the impact and user experience with Fall Detection Technologies in use in Ireland.

Beyond what is widely in use in Ireland, the literature review identified a much broader range of Fall Detection Technologies both commercially available and under development. A number of wearable fall detection devices are available that automatically detect falls and alert care givers. Some of those have built-in GPS capability to pin-point the location of a fall when the fall occurs outdoors. However, many participants were only familiar with technologies currently in use, such as the wearable manual panic button alarm technology. They were less familiar with newer technologies such as fall detection systems based on smartphones and smart watches or more sophisticated ambient technologies such as camera or radio frequency based systems.

Sophisticated Fall Detection Technologies such as those based on camera image analysis, radar and other radio frequency technologies such as WiFi signal analysis are not widely used. Their maturity (technology readiness level - TRL) is currently either low (Lapierre et al. 2018), they are expensive and not widely available, or have other problems such as privacy concerns, e.g. image-based approaches. Many new approaches have only been evaluated in laboratory settings, using younger adults staging falls rather than with older adults experiencing real fall events (Pang et al. 2018). These technologies use modern machine learning approaches to detect falls from sensor data. Machine learning algorithms are trained with data gathered from a particular environment. When the environment changes the accuracy of detecting falls may be reduced (Igual et al. 2013; Kahn and Hoey 2017).

While there is a wide range of fall detection and assistive technologies available, the degree of fragmentation in this area is high with many barriers to integration. Interoperability of assistive technologies with other smart technologies within the home is a major problem. As pointed out in the literature review, technologies from different manufacturers generally do not work well together in the same home. For example, Fall Detection Technology from one manufacturer will typically not work with the smart home hub from another manufacturer. Users are required to buy into one smart home ecosystem, which limits the devices and technologies available to them. It is important that new solutions can also integrate well with legacy systems. This is currently not the case. There is a need for standards for such technology to be adopted. Some industry and standards bodies such as the Open Connectivity Foundation with their IoTivity framework (OCF, 2018), the International Electro-technical Council with the SyCAAL standard (IEC, 2018) and the European Standards Institute with the SAREF standard (European Commission, 2015) are now starting to address this. However, real interoperability seems to be still quite some time off.

6.2 The Role of Fall Detection Technology

The research findings showed that Fall Detection Technologies have a positive impact on older people and persons with disabilities as they can mitigate the physical, emotional, and lifestyle consequences experienced by both persons at risk of falling and their care network. Fall detection and alerting can help prevent the faller experiencing more physical harm. For example, raising an alert in a timely manner can prevent a faller lying undetected on the ground for a long time after the fall event. Technologies such as pressure mats can also help to avoid falls by alerting care givers that a person has left a safe place, e.g. chair or bed and is now moving and at an increased risk of a fall event. Fall detection reduces the fear of falling not only among persons at risk of falling but also among the members of their care network. It can also have a positive effect on lifestyle by allowing persons at risk of falling to maintain independence for longer. For example, vulnerable adults were able to move out of residential care settings back into the community reducing their social isolation.

6.3 The Design of Fall Detection Technology

Adherence of both wearable and ambient fall detection products to the Principles of Universal Design is varied and often unsatisfactory. This research found evidence to that effect not only during the stakeholder engagement process but also through the literature research (Thilo et al. 2016). There are some issues with simple and intuitive use of wearable Fall Detection Technologies. However, there are more significant issues with equitable use, flexibility and tolerance to error. Poor design has a major impact on access to and adoption of new and existing technologies.

Simple and Intuitive Use

Evidence from Section 5.3 indicates that while most Fall Detection Technologies are simple and intuitive to use, some users are unsure about how they function. This can lead to the fear that the technology may not work in all situations. It must also be borne in mind that some technological solutions may also be too complex for people with certain disabilities. Technological advances can lead to solutions being introduced that are not well understood by users and not well supported after installation and commissioning. This 'delivery' stage is often viewed as the final 'successful' step rather than the initial stage of operation. This can create the incorrect perception that certain issues are solved.

Equitable Use

Issues with the equitable use of wearable Fall Detection Technologies were also identified. Some participants reported that their device was uncomfortable when worn. Others raised concerns about the safety of devices such as the pendant alarm being around the neck when a user sleeps. There is also the evidence that users' perception of the fall detection services can also be negative. It was pointed out that the wearable Fall Detection Technology can carry a stigma of vulnerability or raises privacy concerns. These problems point to design issues that need to be overcome to improve the adoption of wearable technologies. This could be done through more attractive designs that make it desirable to wear the technology.

Technological advances have led to solutions that are more equitable in use. In the consumer electronics space, wearable technologies are advancing fast. Smartphone are ubiquitous and smart watches are becoming ever more popular. These technologies can also include automatic fall detection functions. The rapid development of the smartphone is the primary driver behind the convergence and connectedness of new technologies. This could be an enabler to a fully integrated care environment. Recent smart watch technologies have much smaller form factor and overcome the bulk problem of a smartphone which was designed more for communications and media consumption. While the small smart watch screen may pose problems for persons with limited dexterity, the fall detection functionality and associated fall alerting is based on software embedded in the smart watch and will work without the person needing to interact with the watch. Smart watches which have attractive design makes them desirable to wear. Some of these devices also support automatic fall detection functionality. Additionally, they also offer other health care and daily life supporting functions built-in.

The cost of assistive technologies was mentioned as an issue during the engagements with participants. Some users were willing to pay more for better technologies and services, such as automatic fall detection and alerting. The cost of ambient Fall Detection Technology is significant. Many ambient Fall Detection Technologies are difficult and expensive to retro fit into existing buildings. Cost was cited as a major factor in preventing adoption of these technologies. This affects the equitable use of the technology across a broad range of users. New technologies that provide much more functionality and can be integrated with smart home, communications and Internet of Things technologies are attractive despite the higher cost.

Flexibility in Use

There are some issues with the flexibility of use of wearable Fall Detection Technologies. Some wearable and ambient Fall Detection Technologies require the person wearing them to raise the alarm manually. This is not possible if the person is unconscious after a fall or has fallen in an awkward position. The inability to cancel an alarm once raised was also cited as a problem affecting its use, as many older people did not want to be a nuisance raising an alert unnecessarily.

Some wearable fall detection devices are also limited to a person's own living environment. The standard panic alarm button is registered with the base station in a person's home and ambient technologies are embedded into the home environment. This means that when a person visits family or friends, they cannot bring those fall detection systems with them. Essentially all ambient Fall Detection Technologies are designed for indoor use and do not function outdoors in the community, which limits their usefulness. This is a significant limitation and prevents many older people or persons with disabilities from going outside.

However, some of the drawbacks of manual alerting have been overcome by automatic Fall Detection Technology, making them more flexible in use. Automatic wearable Fall Detection Technology based on mobile connectivity allow the person at risk to be mobile too, as this technology works both inside and outside the home. This has advantages as users can take the technology with them, which avoids social isolation. With automatic ambient fall technologies the person at risk doesn't need to wear any device at all. The limitation of the battery life of wearable automatic fall detection devices is a major concern.

The literature review identified that the broad range of current Fall Detection Technologies available have varying degrees of accuracy. Tests of commercial automatic Fall Detection Technology revealed accuracy of 70-87%. This means that between two and three in ten falls are undetected or that events were detected as falls when none actually occurred. This accuracy issue may prove problematic for care services using such technology.

Concerns also relate to the environments, where wearable Fall Detection Technologies can be used, such as in wet environments. Some of the wearable automatic fall detection devices as well as many smartphones and smartwatches are not suitable for use in wet conditions. This is a significant disadvantage, considering the high rate of fall injuries which occur in wet conditions (Rosen et al. 2013).

Tolerance for Error

Tolerance of error issues range from user issues to technology problems. Wearable Fall Detection Technologies such as the panic button alarm have design limitations in that they need to be worn in order to be effective. It was reported that many older people often forget to wear the technology or complain about the design. Uncertainty about the accuracy of automatic fall detection is still a concern for wearable technologies. Multiple people in a home or the movement of pets can lead to difficulties with the accuracy of automatic ambient fall detection.

Many, if not all, the elements required to develop successful fall detection solutions already exist or are emerging from ongoing research and innovation, as described in the literature review. The developments in Internet of Thing devices allows fall detection devices to be integrated in a system of 'things'. It cannot be assumed that these solutions will just happen in time. The fact that few new technologies have been tested with older adults adds to the concerns for Universal Design of these technologies. Increasingly, the importance of involving multiple stakeholders in the design of new technological solutions is highlighted (Reeder et al. 2013; Thilo et al. 2016). Person-centric design processes, such as those following Universal Design Principles (CEUD, 2017c) are key to addressing the needs of the user of a product or service, as described in Section 3.1.

6.4 The Emergence of Lifetime Communities

This study also looked at the concept of lifetime communities, liveable places for young and old, and the impact of Fall Detection Technologies on the development of these intergenerational places. The study identified a number of projects in Ireland and abroad that could be deemed lifetime community initiatives. It is clear from the research that many of these projects are in the early and demonstrator phase. This draws interesting parallels with technological readiness level of many new, emerging technologies.

Demonstrator sites such as NHS Healthy New Towns in Darlington, UK recognises the growing importance of technology. It brings together a wide variety of stakeholders to co-design long-term care solutions at a community level. Clinicians, community representatives, care providers, technology and digital innovators as well as health and social care commissioners are tasked with the challenge to 'rethink' how health, wellbeing and care services can be delivered.

In Ireland, public bodies have begun to use Small Business Innovation Research challenges to spark this kind of innovation. Amicitia, a lifetime community initiative, was the winner of one of these challenges in Co. Cork. The challenge sought to explore low cost, innovative and accessible solutions that will help older citizens maintain a good quality of life and remain and feel secure in their home and community. The response to the challenge brought together social enterprise, community, research and innovation organisations to co-design, develop and test a prototype in a typical Irish town. This prototype integrates technology, including Fall Detection Technology, as one part of a wider network of care in the community.

6.5 The Impact of Fall Detection Technologies on Lifetime Communities

The greatest impact of Fall Detection Technologies on a lifetime community is the social impact. These technologies assist people at risk of falling to live at home allowing them to be more independent and play an active part in their community. For example, older people at risk of falling were able to remain living in their homes and vulnerable adults were able to move out of residential care settings into the community which reduced their social isolation. The technology also gives people at risk and their caregivers peace of mind.

The concepts behind lifetime communities are not new or unique. Community and local care networks have played an important part of Irish life for many years. But the emergence of new technologies represents an opportunity to deliver better care in community environments. For example, the Integrated Care Programme for Older People (ICPOP) is developing primary and secondary care services for older people in Ireland to assist them to live well in their own home and community. This positions nursing homes at the last point of care, which is the desire of a large proportion of people.

Alongside the social benefits of Fall Detection Technologies to a lifetime community, there are also social responsibilities. The Senior Alert Scheme requires families, friends or emergency services to respond to the needs of the person at risk. Some independent living accommodation need dedicated care staff either on-site or on-call to respond to alerts. The emergence of lifetime community initiatives such as Amicitia depend on both community and family to support those at risk. Whichever care network is provided it needs to be robust, reliable and sustainable if the person at risk and their caregivers are to have confidence in the fall detection service.

There is an economic impact of Fall Detection Technologies in a lifetime community. There is the obvious economic benefit to supporting people at risk of falling to live independently in their own homes rather than in nursing homes. The provision of Fall Detection Technologies can reduce physical and mental consequences of falling which impacts on the cost of medical care required by the fallers. The economic benefit of reducing long lies is very significant. Even if a fall detection device is only 50% effective, it has been calculated in 2018 that the average cost of falls to the healthcare system in Ireland would drop to nearly half, saving hundreds of millions of euro per annum. These cost savings take into account the cost of both provision of the fall detection device and call monitoring service. There is also a considerable indirect economic impact of people at risk living more independently. For example, a carer is free to work, resulting in greater spending capacity as well as tax revenue.

The physical impact of Fall Detection Technologies also needs to be considered. Some ambient Fall Detection Technologies are difficult to retro-fit into existing buildings and others are not suitable for outdoor usage. Overall, Fall Detection Technologies need to be better integrated with smart home environments to work seamlessly with other smart technologies in a home and across the community. This is currently not the case. Newer Fall Detection Technologies that are part of the Internet of Things require reliable wireless connectivity to a base-station. While some of these base-stations have a range of five kilometres or more, a network of base-stations may be required for a person to seamlessly move within and between communities.

Lifetime communities are also defined by how well their physical environment works, including private home and public buildings as well as the outdoor environment. The design of those have an impact on the risk of falling among people in those environments. There are policies, guidelines and standards at national and international level for the design of the built environment such as the Universal Design Principles as promoted by the National Disability Authority or the Nordic Charter on Universal Design, which also draws on the United Nation's Sustainable Development Goals. The Centre for Excellence in Universal Design also issues technical guidance, for example Universal Design Guidelines for Homes in Ireland (2015) and the Technical Guidelines for In-Home Displays (2013).

6.6 Conclusions and Recommendations

The findings of this research suggest a number of actions that policy makers, care service providers and researchers could take to address some of the issues that have been highlighted.

Access to Fall Detection Solutions for all those at Risk of Falling

There should be more support for people at risk of falling to access appropriate Fall Detection Technologies. The current Seniors Alert Scheme is restricted to those over the age of 65. People with disabilities or those younger than 65 with long-term health conditions would benefit greatly from access to Fall Detection Technology. Similarly, this scheme is restricted to just one type of technology. Different people at risk of falling require different technology solutions. Access to wearable technology with automatic fall detection functionality or ambient solutions could support more people in need. People's needs also change over time and so technological support might need to change or adapt with their needs too. This could be achieved through policy changes and extended financial supports to match technological updates.

Technology Standards and Interoperability
There is a need for standards and improved interoperability across a range of smart technologies such as smart home and Fall Detection Technologies that follow Universal Design Principles. The vision of a seamless fall detection environment within the community requires a range of technologies to work together without error or interruption. Many current technologies operate in their own silos and this limits their uptake and usefulness. Improvements could be achieved through policy changes which encourage adherence to interoperability between, and standards for, these technologies and by adopting a Universal Design approach including the 7 Principles.

Integration of Fall Detection Technology into Care Networks
There is a need for better integration of technology with care networks and healthcare, taking a Universal Design approach. While there is a wide variety of innovative technologies, they are often poorly integrated with care services. Better integration could enhance service delivery and outcomes for people in need. This could be achieved through policy change and the development of new care services. The piloting of new solutions in the community and integrated care programmes as provided by Health Innovation Hub Ireland can assist in connecting innovation with the healthcare system.

Innovative Design and Development Processes
All stakeholders should be involved in the design and development of Fall Detection Technology service solutions to ensure that these services meet the requirements of the people at risk of falling, their care network as well as the healthcare service providers. Many technologies are developed based on end user requirements but without the involvement of the end user. There is a need for a Universal Design approach and user testing of technology solutions with all stakeholders in order to build in Principles of Universal Design. This could be achieved through research and innovation projects developing and demonstrating suitable methodologies for design of technologies and engagement with lifetime communities. Innovative tendering processes such as the Small Business Innovation Research (SBIR) programmes have also provided evidence of successful development and piloting processes.

Investment in Universal Design

Social innovation which builds in a Universal Design approach from the outset has the capacity to reach significantly wider markets than an approach which disregards human diversity and results in outputs suited to a narrower range of abilities (CEUD, 2019). Alongside this, Governments need to adopt a more inclusive approach with Universal Design practices embedded in policies and our institutions in order to advance design of smart technologies to fully meet the needs of people of all ages and abilities. This can be quickly adopted through existing Age-Friendly strategies and programmes which are in place in every local authority across the country.

7. Conclusion

Falls are a highly significant risk factor to the health and wellbeing of older people and people with disabilities. The management of people at risk of falling can reduce both the economic and social impact of the consequences of falls. Technology can play an important role in the response to incidents of falls.

As part of this study an extensive stakeholder engagement process was conducted to identify the impact and design state of Fall Detection Technologies as well as their impact on lifetime communities. The focus of the engagement was on existing, commercially available Fall Detection Technology in Ireland. It was found that these Fall Detection Technologies can reduce the risk of falling or mitigate the harm caused by long lies by raising alerts. They can also help reduce the emotional consequences of falls by providing reassurances to both people at risk and their caregivers. Fall Detection Technologies can have a positive effect on lifestyle by allowing people at risk of falling to live independently.

The study considered the Universal Design of these Fall Detection Technologies. It was found that the available technology was generally simple and intuitive to use. However, there was some uncertainty about whether it worked in certain settings or if a false alarm could be cancelled. Cost was found to be an issue in accessing Fall Detection Technologies. However, where certain technologies were supported, such as the Senior Alert Scheme, access was much more equitable. Comfort and perceived stigma of vulnerability of wearable devices was found to problematic for some. Inflexibility of use of some technologies was found. For example, the requirement to press a button or pull a cord to raise an alert is not possible if faller is unconscious. Some people at risk of falling forget or are unwilling to wear the fall detection device rendering it useless. The limited battery life of devices with automatic fall detection capabilities was also found to be an issue.

It is clear that an accurate picture of the gaps and design challenges can help to provide a foundation from which to develop more successful integrated solutions. Universal Design processes can advance the design of smart technologies to meet the needs of people of all ages and abilities. From this, key interventions and methods to improve fall detection products and services can be determined and implemented. The design of Fall Detection Technologies should however, not only focus on the usability, but also the wider context including their suitability and sustainability in community settings.

Few existing Fall Detection Technologies work well or are supported outdoors. New and sophisticated Fall Detection Technologies offer great promise. However, many are at a low maturity level and have not gone much beyond the research laboratory. Advances in consumer electronics such as smart watches have great potential. The rate of development of smart technology however has also led to a fragmentation in the area with many manufacturers not making it easy to use devices from one ecosystem in another.

The social impact of Fall Detection Technologies on a lifetime community can be very significant. People at risk of falling are supported to live independently and be active in their community. However there is also a social responsibility required for Fall Detection Technologies to work effectively. To provide adequate support to people at risk of falling, Fall Detection Technologies need to be integrated into both informal and formal care networks. These care networks include family and friends volunteering their support as well as professional care staff and call monitoring services. The robustness, reliability and sustainability of these network is critical to the success of any fall detection service.

The provision of fall detection services also makes economic sense. The cost and benefit analysis of a fall detection service has shown that there is a significant economic benefit to provision of such a service in a lifetime community (O'Dwyer, Murphy, 2018). The provision of fall detection services can offer considerable benefits to a lifetime community and be provided with little impact on the physical environment of that community.

Smart home technology is having a fundamental effect on how we live in our homes and in the community. It can enhance entertainment, make homes more secure and energy efficient. It can also assist us with many daily life tasks. This can be especially useful for older people and people with disabilities to help them with many daily tasks and also to make sure they are safe in their own homes. Fall Detection Technologies are part of a broader set of assistive technologies that can be an integral part of a smart home. Homes equipped with these technologies encourage independence and also allow older people and those with disabilities to remain living at home for longer rather than having to rely on residential care settings.

Extending the use of Fall Detection Technologies to the community can benefit people at risk to move outside the home and be more active in their community. The technological review shows the technological components already exist or are being developed to achieve this. Together with suitable care networks fall detection services can play a significant part of the realisation of a **smart lifetime community**, a lifetime community supported by smart technologies.

A vision for Fall Detection Technologies within the context of smart lifetime communities might look like as follows:

> Tom is 75 and is starting to get infirm. He lives on his own. Tom's home is a smart home. At all times, Tom's home recognises where he is in the home. It knows what he is doing,

whether he is in bed, in the kitchen, if he is cooking or watching TV. The smart home system uses ambient sensors for this.

Tom talks to his home through a voice recognition system and his home can respond. When Tom's home detects that Tom has forgotten to take his medicine, it reminds him. When the home detects that he has fallen, it alerts a caregiver or family member. It can even directly alert emergency services if it detects a serious health issue.

But the community that Tom lives in is a smart lifetime community and many homes as well as public and private buildings are like Tom's home. When he visits his friend Rachel, Rachel's home detects that Tom is visiting. This is based on Tom's and Rachel's home exchanging information, in a privacy preserving manner, which allows Rachel's home to recognise Tom. Tom is recognised by his style of walking, voice and other personal characteristics. This reassures Tom that he is as safe in Rachel's house as he is in his own.

When Tom is out and about, his smart watch keeps an eye on him, while technology in the home ensures his home is secure when he is out. If his smartwatch detects a fall or other health issues, it communicates emergencies to caregivers, family members or emergency services. If Tom doesn't have his smartwatch on when he is leaving his home, the home reminds him to wear it. Tom liked this feature so much he asked his smart home to remind him of lots of other things too; such as appointments, birthdays, bin days and even when he needs to do his exercises. Therefore, taking a holistic view of applying smart technologies through a Universal Design approach has the potential to create these smart lifetime communities.

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9. Appendices

Appendix 1 – Review Strand

This appendix contains

Appendix 1a) Research Search Terms

Appendix 1b) Fall Detection Suppliers and Retailers in Ireland

Appendix 1a: Research Search Terms

Design Methods and Principles

- Universal Design
- Universal Design Principles
- Universal Design Projects
- Universal Design Case Studies
- Universal Design Interfaces
- User-Centred Design
- User-Centered Design
- Inclusive Design
- Design for All
- Design for One

Smart Home Technologies

- Smart Home
- Smart Home Technology
- Smart Home and Assisted Living
- Smart Home for the Elderly
- Smart Home and Internet of Things
- Assisted Living Technologies
- Smart Home and Universal Design

- Review of Smart Home

Falls and Fall Detection

- Risk of Falls
- Falls of Elderly People
- Fall Detection Technology
- Fall Detection Devices
- Wearable Fall Detection
- Ambient Fall Detection
- Automatic Fall Detection
- Radar based Fall Detection
- Vision based Fall Detection
- Wi-Fi Based Fall Detection
- Solutions for Fall Detection
- Review of Fall Detection

Lifetime Community

- Lifetime Communities
- Communities for All Ages
- Age Friendly Communities
- Lifetime Community and Health
- Lifetime Community and Smart Technology

Appendix 1b: Fall Detection Suppliers and Retailers in Ireland

Selected suppliers and retailers of Fall Detection Technologies in Ireland;

- Alert-it (Alert-it, 2018)
- Assist Ireland (Assist Ireland, 2018)
- Chubb United Technologies (Chubb United Technologies, 2018)
- Doro Care (Doro Care, 2018)
- HomeCare Technologies (HomeCare Technologies, 2018)
- Homesafe (Homesafe, 2018)
- Independent Living Ireland (Independent Living Ireland, 2018b)
- TASK Security Systems (TASK Security Systems, 2018)
- Telecare.ie (Telecare.ie, 2018)
- Tunstall Emergency Response (Tunstall Emergency Response, 2018)
- Tynetec (Tynetec, 2018)

Appendix 2 – Anonymised Details of Participants

Participant ID	Category	Anonymised Details	Total
A01, A02, A07, A10, A12, A14, A19, A20, A29	Person at risk of falling	Older or disabled person with limited mobility at risk of falling	9
A03, A04, A05, A06, A08, A09, A13, A15 - A18, A21 - A28	Person at risk of falling	Older abled bodied person at risk of falling	19
B01- B24	Informal Carer	Informal Carer of an older or disabled person at risk of falling	24
C01, C02	Formal Carer	Nursing Assistant in Hospital Setting	2
C03, C06	Formal Carer	Nursing Home Carer	2
C04, C05, C07, C09	Formal Carer	Home Help Carer	4
C08, C14	Formal Carer	Day Care Centre Carer	2
C11, C12, C13	Formal Carer	Carer at Home for Disabled	3
D01, D03, D19, D20	Falls Risk Professional	Nurse (Public Health / Clinical Specialist / Integrated Falls Services)	4
D02, D05, D07, D08, D09	Falls Risk Professional	Occupational Therapist	5
D04, D06	Falls Risk Professional	Physiotherapist	2
D10, D11, D14, D15, D16	Falls Risk Professional	Care Home for Disabled Risk Assessor	5
D17	Falls Risk Professional	Doctor	1
E01 - E05	Retailer	Retailer of Fall Detection Technologies	5
F01 - F03	Researcher	Researcher of Assisted Technology	3
F04	Researcher	Fall Detection Researcher	1

F05	Researcher	Older Person Healthcare Researcher	1
G01	Designer / Innovator	Technology Designer	1
G06	Designer / Innovator	Town Planner	1
G07. G08	Designer / Innovator	Web Service Designer	2
G02, G03, G04	Designer / Innovator	Healthcare Innovation Specialist	3
G05	Designer / Innovator	Technology Innovation Specialist	1
H01, H02, H04, H13, H14, H16	Lifetime Community	Community Group Worker in Age Advocacy	6
H03, H06, H15	Lifetime Community	Community Group Worker in Active Ageing	3
H05, H07, H09, H10, H12, H19, H20, H22	Lifetime Community	Community Group Worker in Age Friendly Programme	8
H08, H21	Lifetime Community	Community Support Worker	2
H11, H17, H18	Lifetime Community	Community Development Worker	3
J01 - J03, J06, J07, J09	Local Authority	Age Friendly Programme Staff	6
J04, J05, J08	Local Authority	Business Development Staff	3

Appendix 3 – Interview Protocols

This appendix contains

Appendix 3a: Informed Consent Form

Informed Consent Form for:	Nimbus Research Centre, Cork Institute of Technology

Name of Researcher:	
Name of Principal Investigator:	**Jane O'Flynn**
Department / Unit:	**Nimbus Research Centre, Cork Institute of Technology**
Contact Details:	tel: 021 4326758 email: jane.oflynn@cit.ie
Title of Research:	**Investigation of the Universal Design of Fall Detection Technologies in the Smart Home and their Impact on Lifetime Communities**

Section 1: Information

Purpose of the Research

The Nimbus Research Centre in Cork Institute of Technology and Independent Living Ireland a company based in Athenry, County Galway are carrying out a study on the usage and design of the Fall Detection Technology in Ireland today.

This study is being carried out thanks to funding from the National Disability Authority of Ireland.

What the Research will involve?

We are looking for your help in our study.

We would like to ask you a number of questions related to your awareness of the risks related to falls and your experience of technology.

Also if you have a device that detects falls or can create an alert if you fall, we would like to see how you use this device.

Participant Selection

We want to interview people from the following groups;

- people who are at risk of falling or have concerns about falling
- people who provide informal care to people at risk of falling (such as family members, neighbours)
- people who provide professional care in a home environment to people at risk of falling (such as home helps, nursing and sheltered housing staff)
- people who carry out fall risk assessments
- people who retail fall detection technologies
- people who develop and carry out research in fall detection technologies.

Voluntary Participation

This is entirely voluntary.

You may

- withdraw from the study at any time during the course of this interview

- refuse to answer any or all questions

- withdraw from the study at any time in the future by contacting the Principal Investigator Jane O'Flynn (contact details are provided below)

Confidentiality

Any data we gather during this interview will be confidential and anonymised.

The anonymised data will be stored securely and will only be accessible to the project team and will not be used for any purpose other than this study.

Duration

This interview will take about half an hour.

Procedure(s)

We would like you to tell us

- about incidents of falling, either from your own experience or from someone you know

- the effect a fall has on your own lifestyle or that of someone close to you

- your concerns about falling and what if anything you have done or plan to do to alleviate these concerns

- your knowledge or experience of technology that can help if someone falls

- your opinion of what else technology could do to help

Proposed use of Result

We plan to publish a report at the end of this study and to present our findings at suitable conference(s). The report may be published by the National Disability Authority of Ireland.

Possible Risk or Disadvantages to Participation

We don't anticipate any risk or disadvantage to you caused by participating in this study. However, if you feel at any time that the questions cause you any upset, please let us know and we can stop the interview.

Benefits of this Research

The consequences of falling, the risk of falling and the fear of falling can impact on how people live and interact in our community. However, there are a number of technologies available that help when people fall.

This study into fall detection technologies will allow us to gather evidence about

- how useful these technologies are?
- are they well designed?
- are they affordable?
- how they are integrated into the home and community?
- what else should technologies do to help?

The report may also influence

- the design of fall detection devices
- research into new fall detection technologies
- public policy and recommendations for the provision of fall detection technologies.

Reviewers of the Research

This research

- is supervised by Prof. Dirk Pesch and Dr. Jim Harrison of CIT
- is approved by the Research Ethics Committee in CIT
- will be reviewed by the National Disability Authority of Ireland

Future Queries/Contact

Name:	Jane O'Flynn
Phone:	021 4335096 / 021 4326758
Email:	jane.oflynn@cit.ie

Section 2: Consent Form

I/We…………………………………………………. agree to participate in research study on

Investigation of the Universal Design of Fall Detection Technologies in the Smart Home and their Impact on Lifetime Communities.

I/We have read the information provided on this research study, or it has been read and explained to me/us.

I/We have had the opportunity to ask questions and as such understand the purpose and nature of the research study.

I/We consent voluntarily or give consent for others under our guardianship to be a participant in this research study and understand my/our/their rights to withdraw.

Signed………………………………………………

Date……………/……………/……………...

Signed………………………………………………

Date……………/……………/……………...

Do wish to be informed of the outcome of this research?

Yes, my contact details are

……………………………………………

No

Appendix 3b: Interview Protocol for a Person at Risk of Falling
Notes for interviewer

Methodology
The methodology being employed here stems from a phenomenological standpoint. The aim is to collect data that focuses on each participants' experience as an individual at risk of falling. Semi-structured interviews, either via face-to-face or phone calls, will be used to achieve this. The facilitator will interview each participant, while a second facilitator notes their responses. The language used in the interviews follows Universal Design principles, i.e. it is simple and accessible to everyone.

Data Collection
Qualitative and quantitative data will be collected through audio recording and note-taking. Key participant information and responses will be noted by the interviewer during the interview.

Data Analysis
Audio and notes taken during the interviews will be coded for key phrases. Qualitative findings will be based on these key phrases, especially around participant experience. Quantitative findings will also be formed from this coding activity, e.g. number of falls reported, number of hospitalizations from reported falls, etc.

Interview Procedure
The participant should be interviewed at a place convenient to them – preferably their own home. They should be thanked for their time, and given a short and clear overview of what the interview is about, what it is for and what the outcomes of the project will be. The interview will be asked if they are happy for the interview to be recorded. They should be given an estimated duration for the interview length of 30-40 minutes. The interviewer should spend some time ensuring the interviewee is comfortable and ready to talk before commencing the interview. The first question should be used as a 'warm-up' to get the participant accustomed to the interview process, and to ensure they are comfortable with talking to the interviewer.

Observation Procedure
The observation procedure will follow the survey tool developed by as part of the *Universal Design and Technology for Older People: A Survey Tool for Assessing Technology Design for Older People* project (Hermann S. et al. 2012).

Interview and Observation Protocol – People at risk of falls

Interview Logistics

Location: Participant's home / resources centre / interviewer office

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical day to me?

Do you have someone coming to you to help you out during the day?

Can you tell me about your involvement with your local community?

Question 2: Can you tell me about your experience with falling?

How many falls would you say you have had over the past 10 years?

Have you or someone close to you ever experienced a fall in the past ten years?

Did your fall affect your lifestyle?

Do you ever feel worried about falling?

Question 3: Have you ever owned any fall detection devices such as, an alarm bracelet or pendant?

Why and how did you get it?

Have you ever had to use it?

Question 4: If you have the device with you, could you give me a short demonstration of how you might use your device?

(They will be asked to display the device to the interviewer, and indicate how they would use it. Interviewer should use the survey tool to collect data on the device functionality and usability. Questions should be answered with either Y or N, with comments added as necessary.)

How does it work?

What happens when the button is pressed?

How did you learn to use it?

Do you find it easy to use?

Question 5: Is there anything you don't like about the device?

Would it be good if it worked both outside the home and in the town?

Would it be good if it an alert was sent automatically so you wouldn't need to press the button?

Would it be good if it sent your location?

Do you think any of these changes would be worth paying more for?

Question 6: Is there any reason why you might not use your device after you have fallen?

Would you ever consider getting rid of your device?

How do you know when is the time to use your device?

Have you ever felt worried that you might annoy or bother someone by using your device?

Question 7: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3c: Interview Protocol for an Informal Carer

Interview Logistics

Location: Participant's home / care centre / interviewer office

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe a typical day spent caring to me?

> *Do you call to help out during the day?*
>
> *What kind of tasks do you generally help out with?*

Question 2: Can you tell me about your relative's experience with falling?

> *How many falls would you say your relative has had over the past 10 years?*
>
> *Did their fall affect their lifestyle?*
>
> *Do they ever feel worried about falling?*

Question 3: Have they ever owned any fall detection devices such as, alarm bracelet or pendant?

> *Why and how did they get it?*
>
> *Have they ever had to use it?*

Question 4: Is there anything you don't like about the device?

> *Would it be good if it worked both outside the home and in the town?*
>
> *Would it be good if it an alert was sent automatically so they wouldn't need to press the button?*
>
> *Would it be good if it sent their location?*
>
> *Do you think any of these changes would be worth paying more for?*

Question 5: Is there any reason why your relative might not use their device after they have fallen?

> *Have they ever considered getting rid of the device?*

Do you think they know when the right time to use the device is?

Do you think they have ever felt worried that they might annoy or bother someone by using their device?

Question 6: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3d: Interview Protocol for a Formal Carer

Interview Logistics

Location: Care home / care centre / office

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical [working] day to me?

What are the main tasks you undertake?

Question 2: Can you tell me about your patients' experience with falling?

Has a patient in your care experienced a fall in the past ten years?

Did their fall affect their lifestyle?

Do your patients often feel worried about falling?

Thinking of the average patient, how many falls would you say they have per year?

Question 3: Have they ever owned any fall detection devices such as, an alarm bracelet, pendant and/or other technologies that detect falls?

Why and how did they get it?

Have they ever had to use it?

Question 4: Could you tell me about how the device/s work?

What happens when the button is pressed?

How did your patients learn to use it?

Do they find it easy to use?

How do carers respond when a device detects a fall?

Question 5: Is there anything you don't like about the device?

Would it be good if it worked both outside the home and in the town?

Would it be good if it an alert was sent automatically so you wouldn't need to press the button?

Would it be good if it sent their location?

Do you think any of these changes would be worth paying more for?

Question 6: Is there any reason why a patient might not use their device after they have fallen?

Have your patients ever consider getting rid of their device?

How do they know when is the time to use their device? (i.e. a real emergency)

Do you think they are ever worried that they might annoy or bother someone by using their device?

Question 7: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3e: Interview Protocol for a Healthcare Professional

Interview Logistics

Location: Care home / care centre / office

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical working day to me?

> *What are the main types of tasks you complete?*
>
> *How frequently do you conduct fall risk assessments?*

Question 2: Can you describe how you might conduct a fall risk assessment?

> *Is there a standardised method?*
>
> *Is the same method used across Ireland?*
>
> *Do you find it to be effective?*
>
> *Is there anything about it you might change?*
>
> *Do you provide your patients with an assessment of their risk of falling outside the home?*

Question 3: What are some of the main indicators that a person is at a higher risk of falling inside (and outside) the home?

> *Are there any common traits or behaviours that people at high risk display?*
>
> *What are the most common dangers to patient safety inside and outside their home?*

Question 4: What, in your opinion, are some of the best ways to prevent falls in the home for people at risk?

> *Is there any general advice you give to all your patients?*

Question 5: Have you ever recommended to your patients that they get any fall detection technolgogy such, as a fall detection or alarm device?

> *Why/ why not?*

What types of devices to you usually recommend?

Question 6: How do you think fall detection devices might be improved?

Would it be good if it worked both outside the home and in the town?

Would it be good if it an alert was sent automatically so the wearer wouldn't need to press the button?

Would it be good if it sent the wearer's location?

Do you think any of these changes would be worth paying more for?

Question 7: Are there any changes that we as a community could adopt to make life easier for people at risk of falling?

What would you change about your role, if you could?

Do you think you could be better supported in any way?

Question 8: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3f: Interview Protocol for a Retailer

Interview Logistics

Location: Care centre / office / retail outlet / phone

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical working day to me?

> *What are the main types of tasks you complete?*
>
> *How frequently do you advise on fall detection technologies?*

Question 2: Can you describe who your typical customer is?

> *Is it the person at risk, their carer, healthcare professional, care home privder, or other?*
>
> *How do they find you?*
>
> *Do they get any financial support to pay for this technology?*

Question 3: What fall technologies solutions do you sell?

> *What is the range of products you sell?*
>
> *What types of devices do you usually recommend?*
>
> *What is typically installed in a private home, nursing home, shelter accommodation?*

Question 4: What works well and not so well with the current fall detection technologies?

> *What problems occur due to design or installation of the technology?*
>
> *What problem occur due to user behaviour?*

Question 5: What do think should happen fall detection technologies to develop in the future?

> *What is required technically?*

What is required to support end users?

Question 6: How do you think fall detection devices might be improved?

Would it be good if it worked both outside the home and in the town?

Would it be good if it an alert was sent automatically so the wearer wouldn't need to press the button?

Would it be good if it sent the wearer's location?

Do you think any of these changes would be worth paying more for?

Question 7: Are there any changes that we as a community could adopt to make life easier for people at risk of falling?

What would you change about your role, if you could?

Do you think you could be better supported in any way?

Question 8: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3g: Interview Protocol for a Researcher
Interview Logistics

Location: Office / research centre / phone

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical working day to me?

> *What are the main types of tasks you complete?*
>
> *How actively are you involved in the research of fall detection technology?*

Question 2: Can you describe the research landscape for fall detection technology?

> *What areas are currently being investigated by the research community?*
>
> *What are the trends in this research?*

Question 3: Can you describe the research you do into fall detection technology?

> *What is the focus of your research?*
>
> *What technology are you developing?*

Question 4: What works well and not so well with fall detection technologies?

> *What problems occur with the technology?*
>
> *What problems occur due to user behaviour?*

Question 5: What do think should happen fall detection technologies to develop in the future?

> *What is required technically?*
>
> *What is required to support end users?*

Question 6: How do you think fall detection devices might be improved?

> *Would it be good if it worked both outside the home and in the town?*

Would it be good if it an alert was sent automatically so the wearer wouldn't need to press the button?

Would it be good if it sent the wearer's location?

Do you think any of these changes would be worth paying more for?

Question 7: Are there any changes that we as a community could adopt to make life easier for people at risk of falling?

What would you change about your role, if you could?

Do you think you could be better supported in any way?

Question 8: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 3h: Interview Protocol for a Designer
Interview Logistics

Location: Office / phone

Duration: 30-40 minutes

Facilitator/s: Jane O'Flynn, Kieran Delaney, Sarah Hayes, Michelle O'Keeffe (Nimbus Research Centre, CIT) and Patrick Mulvihill, Kathy Waldron (Independent Living Ireland) project investigators

Interview Questions

Question 1: Can you describe your typical working day to me?

> *What are the main types of tasks you complete?*
>
> *How actively are you involved in the design of (fall detection) technological devices or solutions?*

Question 2: Can you describe how (fall detection) technological devices or solutions are typically designed?

> *What design processes / methods are typically used?*
>
> *What are the trends in design practices?*
>
> *Is the end user typically involved in the design process?*

Question 3: Can you describe the work you do in the design of (fall detection) technological devices or solutions?

> *What devices or solutions do you design?*
>
> *How do you create your designs?*
>
> *What are the steps you undertake?*

Question 4: What works well and not so well with the design of (fall detection) technologies?

> *What problems occur with how they are designed?*
>
> *What problems occur due to lack of end-user engagement?*

Question 5: What do think should happen with the design of (fall detection) technologies to develop in the future?

> *What is required?*
>
> *Which stakeholders should be involved in the design?*

Question 6: How do you think fall detection devices might be improved?

Would it be good if it worked both outside the home and in the town?

Would it be good if it an alert was sent automatically so the wearer wouldn't need to press the button?

Would it be good if it sent the wearer's location?

Do you think any of these changes would be worth paying more for?

Question 7: Are there any changes that we as a community could adopt to make life easier for people at risk of falling?

What would you change about your role, if you could?

Do you think you could be better supported in any way?

Question 8: Is there anything else you would like to add that we haven't spoken about already?

Conclusion

The interviewer should ask if the interviewee has any questions for them. Finally, the interviewer should thank the participant again for their time, and mention the helpfulness of their contribution to the project. They should be offered the opportunity to hear about the outcomes of the research when it is completed via email or post.

Appendix 4 – Research Ethics Approval

CIT CORK INSTITUTE OF TECHNOLOGY
INSTITIÚID TEICNEOLAÍOCHTA CHORCAÍ

Office of the Registrar & Vice President for Academic Affairs
Oifig an Chláraitheora & Leas-Uachtaráin do Ghnóthaí Acadúla
Dr Áine Ní Shé, *BEd, MA, PhD, LRSM, LTCL*

Ms Jane O'Flynn
Nimbus Research Centre

3rd January 2018

Dear Ms O'Flynn,

On the advice of the Research Ethics Committee (REC), on the basis of documentation submitted, the Institute grants you permission to undertake the study entitled ***"Investigation of the Universal Design of Fall Detection Technologies in the Smart Home and their Impact on Lifetime Communities"***.

Concern was raised by the REC in connection with Consent for Vulnerable groups. This has now been addressed by the project proposers via revised submissions.

Furthermore, the REC request that the research team revert back to the REC for review if any changes to the proposed study, its implementation, or to the use of data as outlined are considered in the future.

We wish you well in your research efforts.

Yours sincerely,

Áine Ní Shé

Dr Áine Ní Shé
Registrar & Vice President for Academic Affairs (Acting)

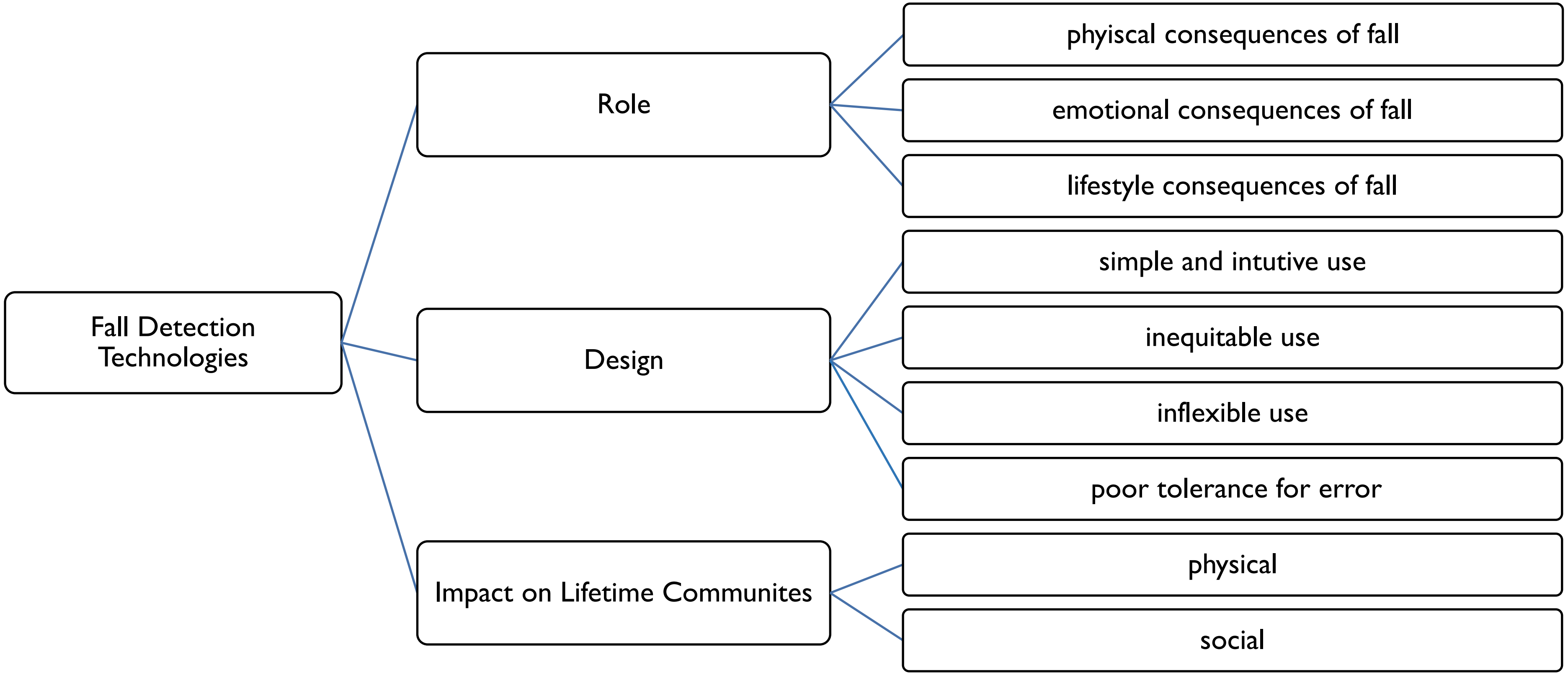
Bishopstown, Cork, Ireland. **Tel:** +353 21 433 5389 **Fax:** +353 21 433 5016 **Email:** registrar@cit.ie **Web:** www.cit.ie

Appendix 5 – Thematic Analysis Maps

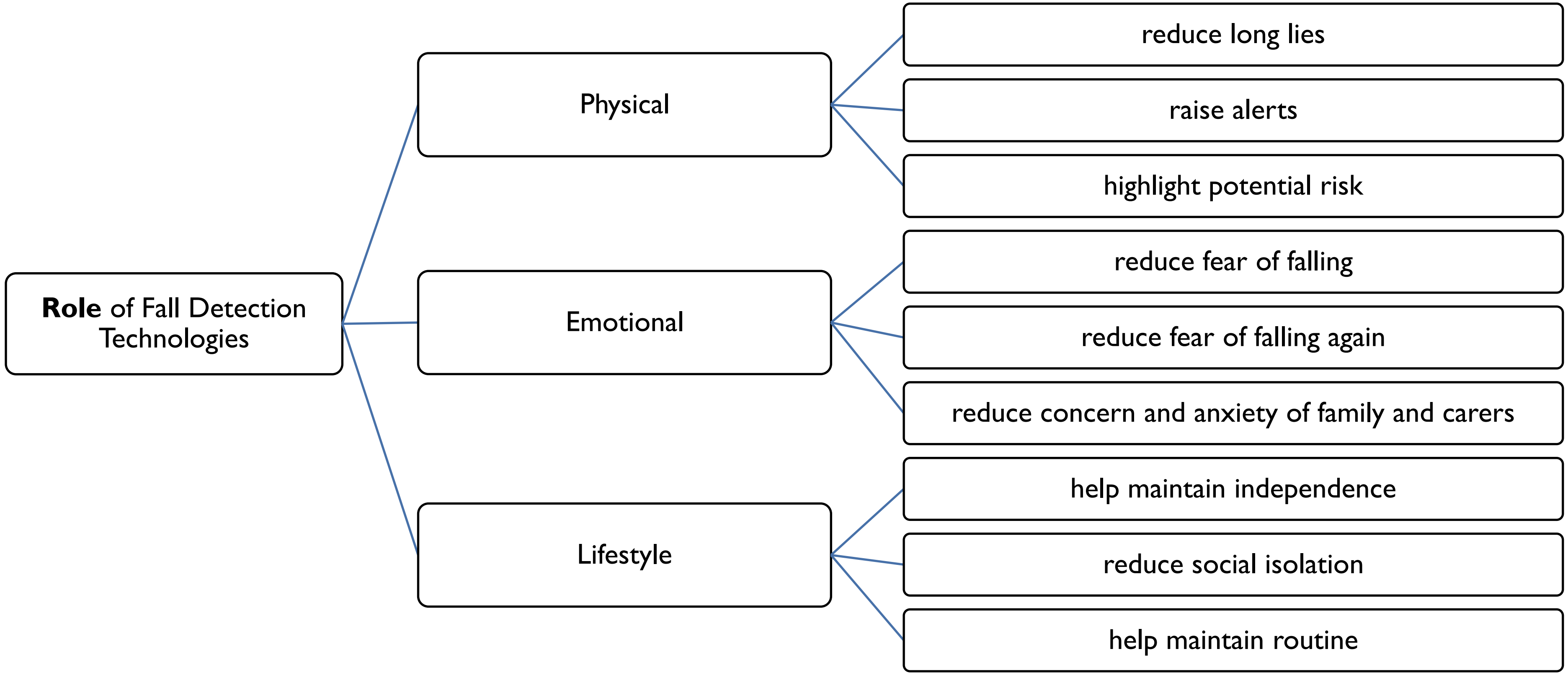
This appendix contains

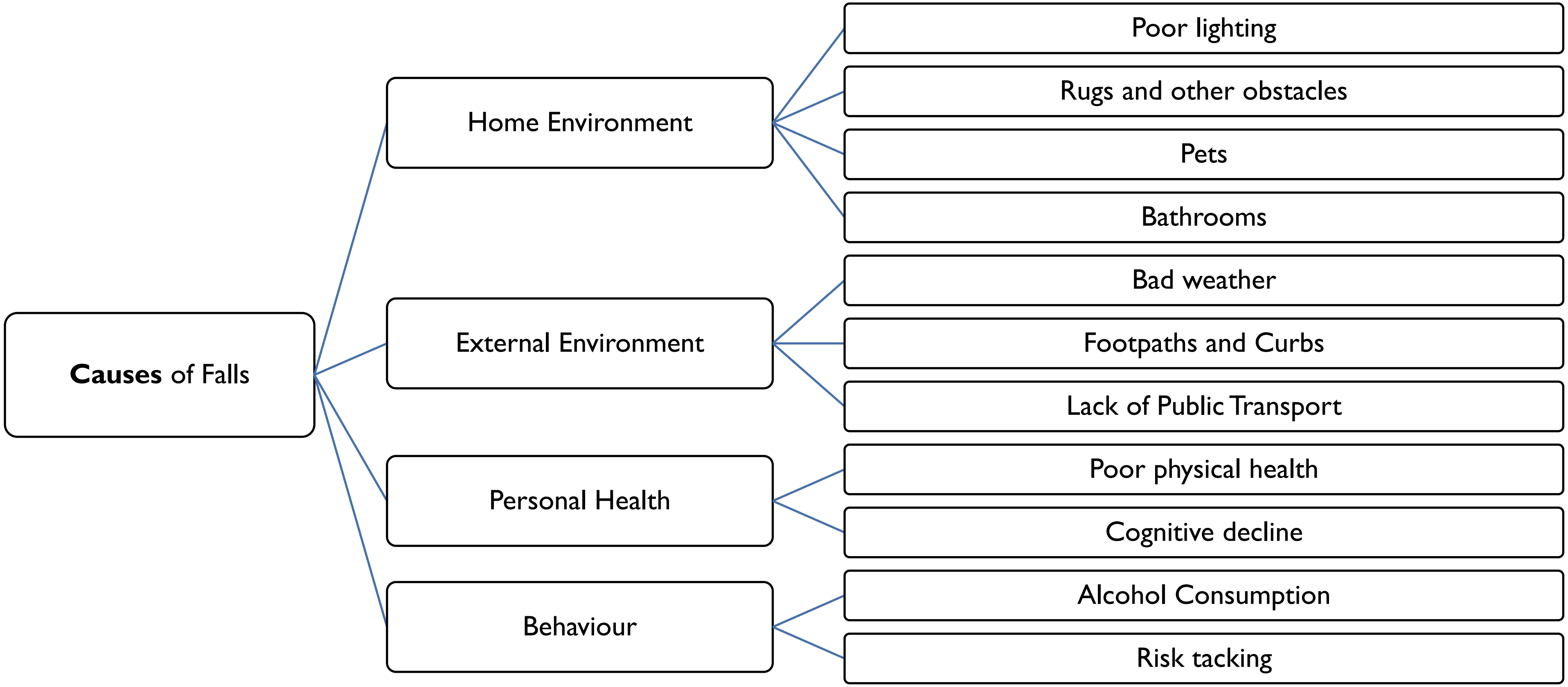
Appendix 5a)	Investigation into Fall Detection Technologies
Appendix 5b)	The Role of Fall Detection Technologies
Appendix 5c)	The Design of Fall Detection Technologies
Appendix 5d)	The Impact of Fall Detection Technologies on Lifetime Communities

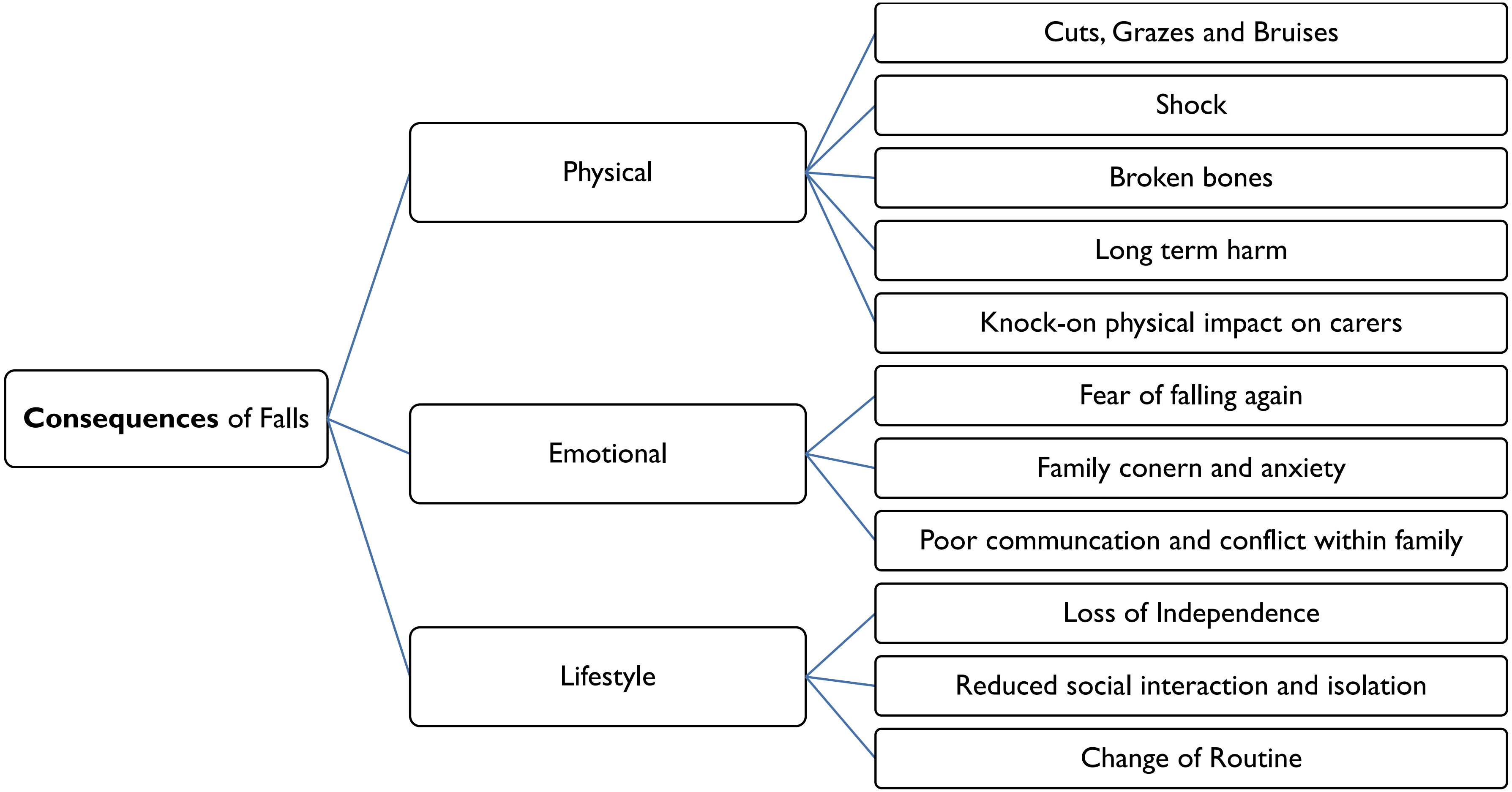
Appendix 5a: Investigation into Fall Detection Technologies



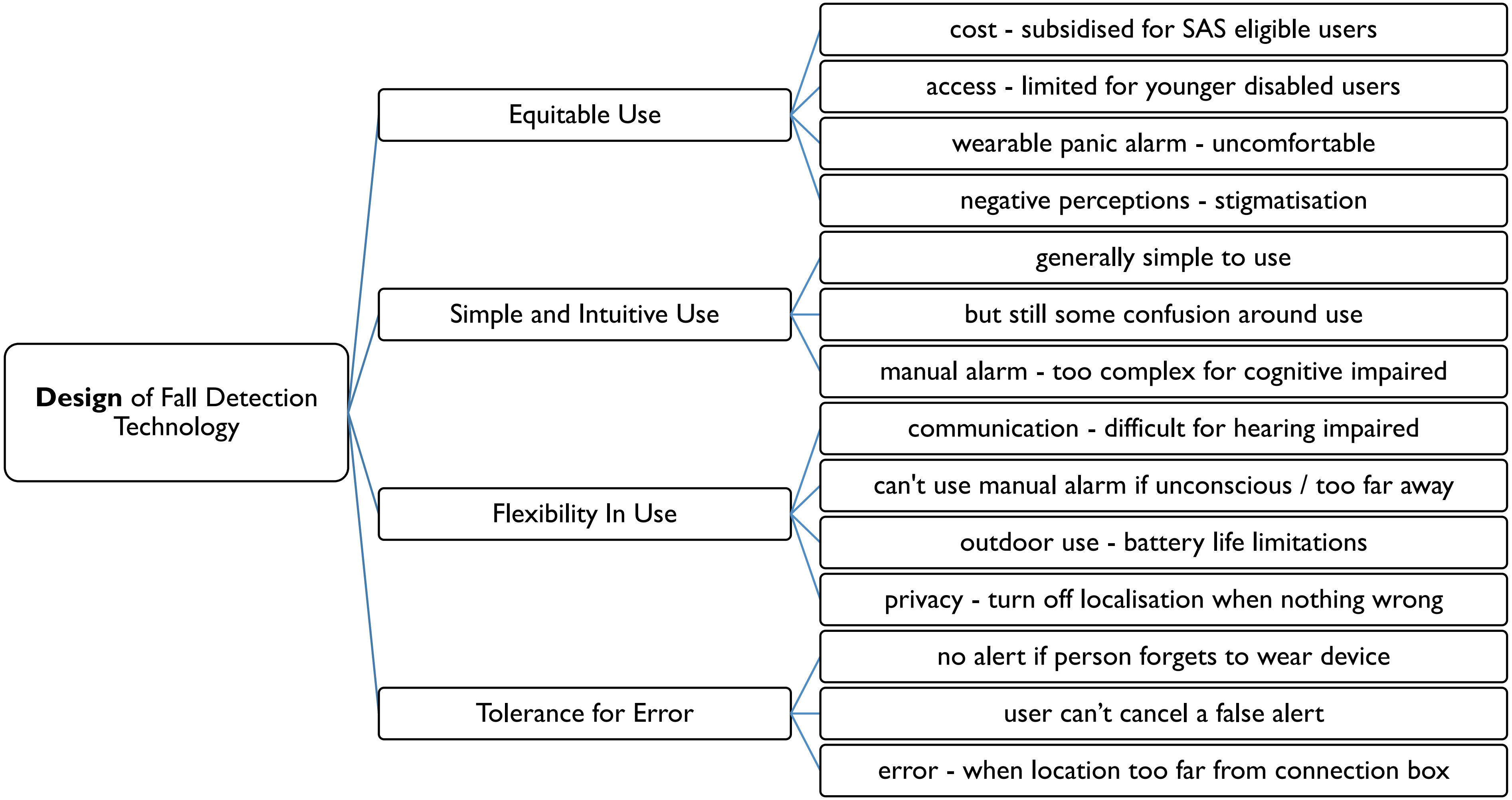
Appendix 5b: The Role of Fall Detection Technologies

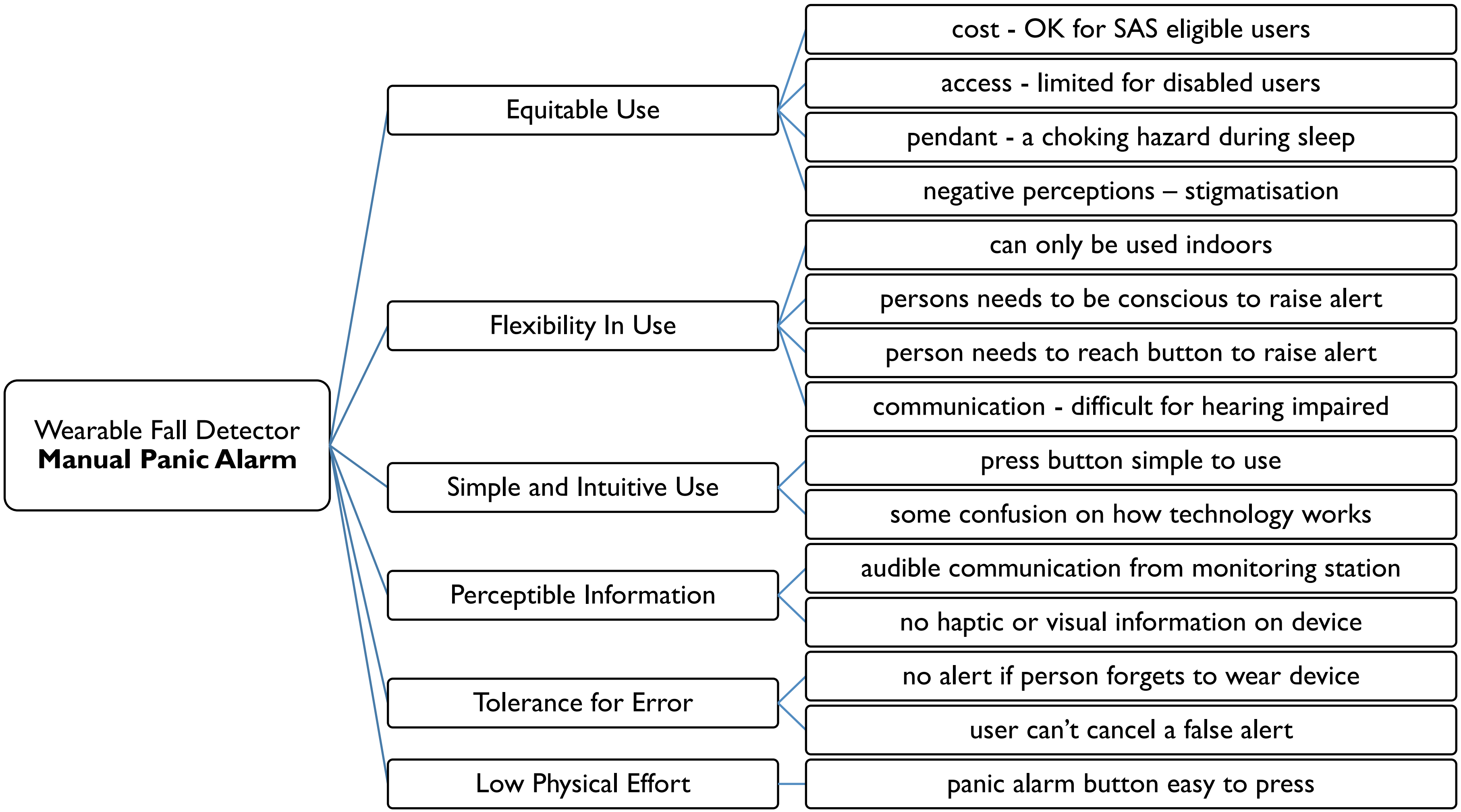



Causes of Falls
Home Environment
External Environment
Personal Health
Behaviour
Poor lighting
Rugs and other obstacles
Pets
Bathrooms
Bad weather
Footpaths and Curbs
Lack of Public Transport
Poor physical health
Cognitive decline
Alcohol Consumption
Risk tacking

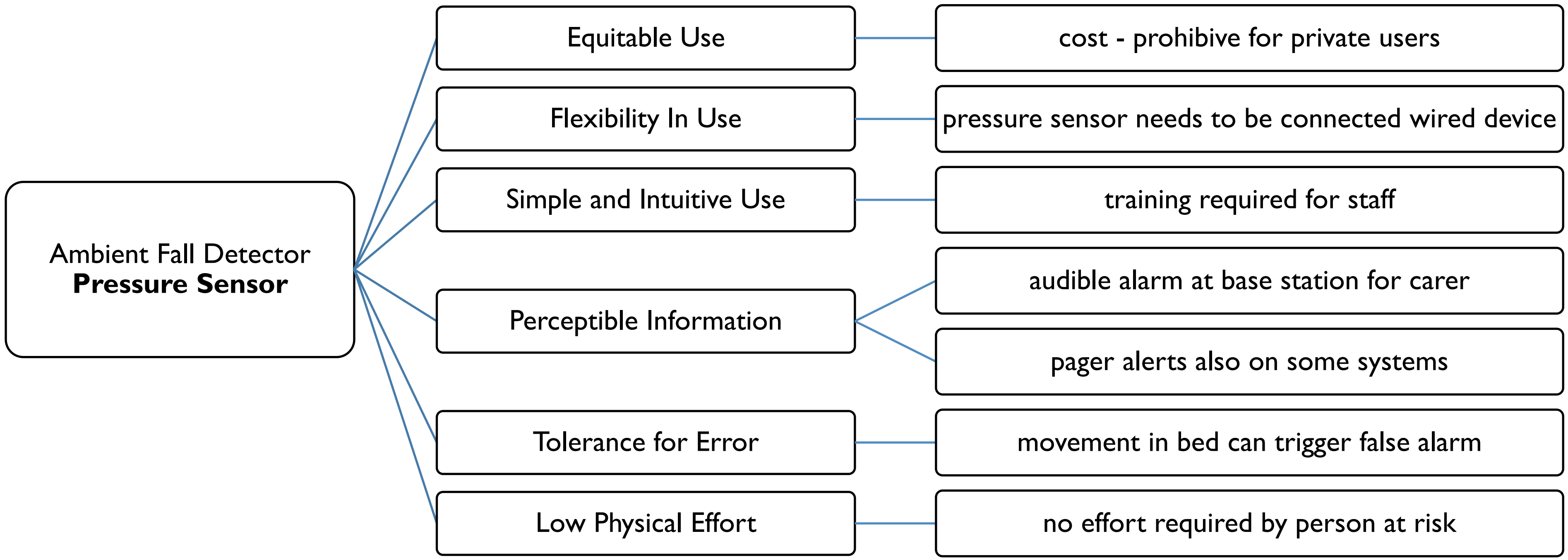

Consequences of Falls
Physical
Emotional
Lifestyle
Cuts, Grazes and Bruises
Shock
Broken bones
Long term harm
Knock-on physical impact on carers
Fear of falling again
Family conern and anxiety
Poor communcation and conflict within family
Loss of Independence
Reduced social interaction and isolation
Change of Routine

Appendix 5c: The Design of Fall Detection Technologies

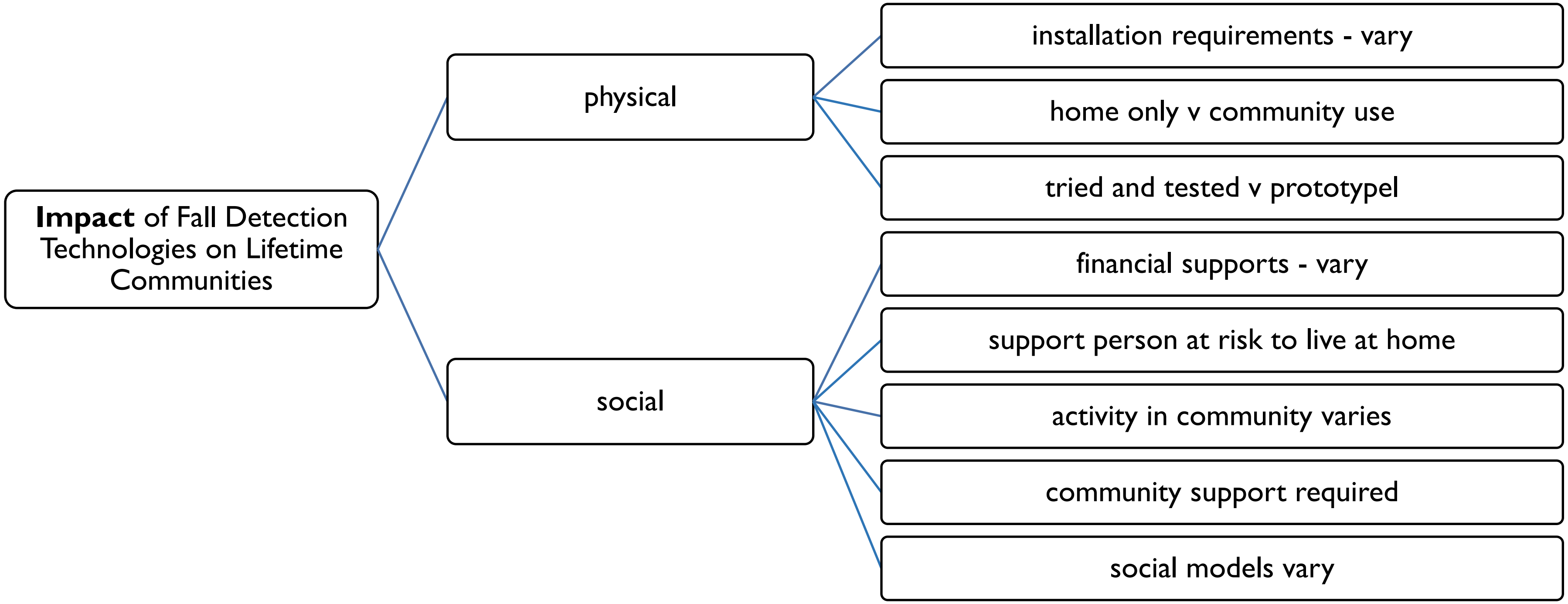


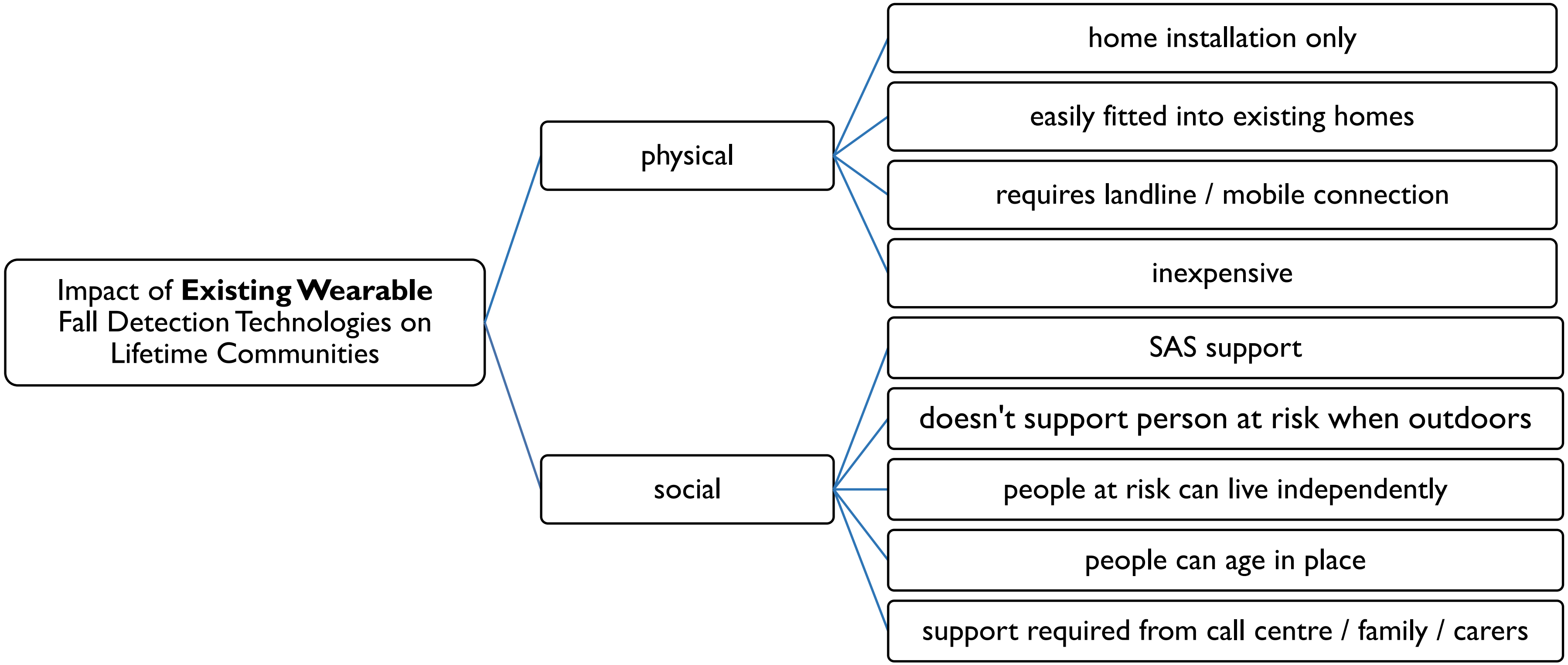


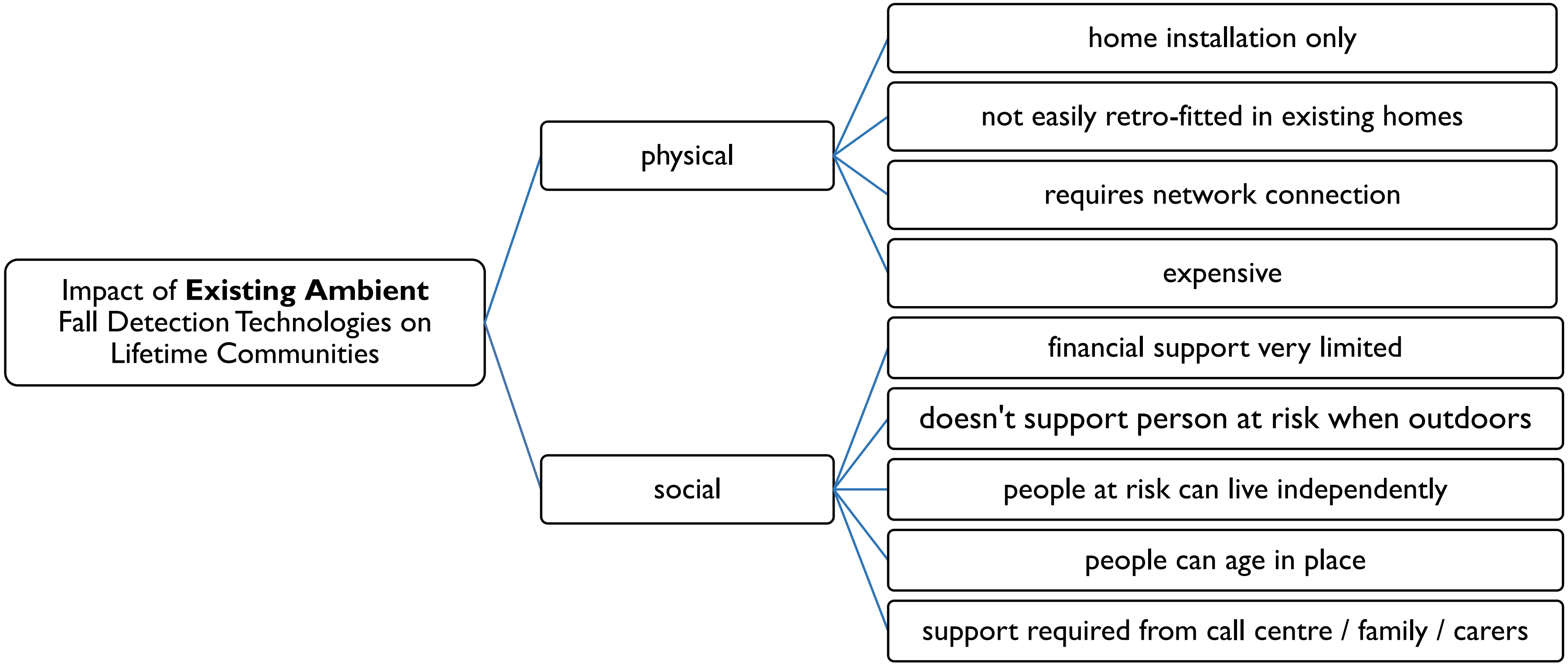
Wearable Fall Detector
Manual Panic Alarm
Equitable Use
Flexibility In Use
Simple and Intuitive Use
Perceptible Information
Tolerance for Error
Low Physical Effort
cost - OK for SAS eligible users
access - limited for disabled users
pendant - a choking hazard during sleep
negative perceptions – stigmatisation
can only be used indoors
persons needs to be conscious to raise alert
person needs to reach button to raise alert
communication - difficult for hearing impaired
press button simple to use
some confusion on how technology works
audible communication from monitoring station
no haptic or visual information on device
no alert if person forgets to wear device
user can’t cancel a false alert
panic alarm button easy to press

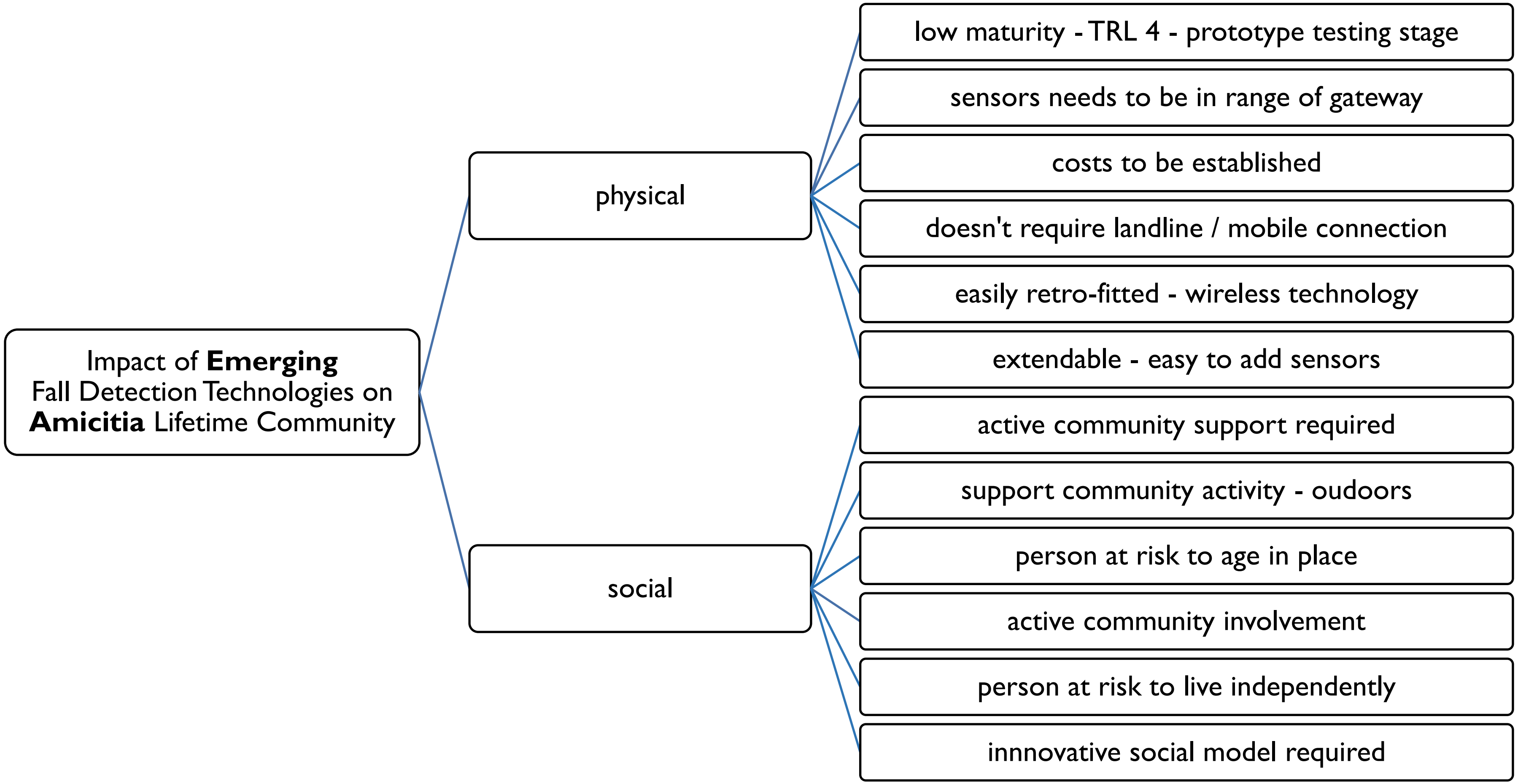

Ambient Fall Detector
Pressure Sensor
Equitable Use
cost - prohibive for private users
Flexibility In Use
pressure sensor needs to be connected wired device
Simple and Intuitive Use
training required for staff
Perceptible Information
audible alarm at base station for carer
pager alerts also on some systems
Tolerance for Error
movement in bed can trigger false alarm
Low Physical Effort
no effort required by person at risk

Appendix 5d: The Impact of Fall Detection Technologies on Lifetime Communities




Impact of **Existing Wearable** Fall Detection Technologies on Lifetime Communities
physical
home installation only
easily fitted into existing homes
requires landline / mobile connection
inexpensive
social
SAS support
doesn't support person at risk when outdoors
people at risk can live independently
people can age in place
support required from call centre / family / carers


Impact of **Existing Ambient** Fall Detection Technologies on Lifetime Communities
physical
home installation only
not easily retro-fitted in existing homes
requires network connection
expensive
social
financial support very limited
doesn't support person at risk when outdoors
people at risk can live independently
people can age in place
support required from call centre / family / carers


Impact of **Emerging** Fall Detection Technologies on **Amicitia** Lifetime Community
physical
social
low maturity - TRL 4 - prototype testing stage
sensors needs to be in range of gateway
costs to be established
doesn't require landline / mobile connection
easily retro-fitted - wireless technology
extendable - easy to add sensors
active community support required
support community activity - oudoors
person at risk to age in place
active community involvement
person at risk to live independently
innnovative social model required