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TECHNOLOGY STRATEGY FOR DEVELOPING THE ASSISTIVE ROBOTICS MARKET

by

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Author's Declaration

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Abstract

Technology Strategy for developing the assistive robotics market

Gabriel Esteban Aguiar Noury

Robotics has increased productivity in industries such as manufacturing, defence and construction but less so in healthcare where, despite the pressures from demographic changes, barriers to the adoption of assistive robotics (AR) persist. Due to the cutting-edge nature of the technology, the field requires studies that explore how it is developed and applied, effectively resulting in the development of an AR market in healthcare. Therefore, the research question for this thesis is 'What strategy can be adopted to develop the AR market?'

This thesis adopted a Collaborative Action Research methodology to explore the development of an AR market in one UK region (Cornwall), and through this experience develop a Technology Strategy for building and orchestrating the creation of AR markets in other regions. This thesis is based on interdisciplinary research that draws from fields such as business management, entrepreneurship policy, robotics development and evaluation, and health technology adoption research.

The intervention in Cornwall focussed on two key market constituents: the healthcare sector and producers (suppliers, i.e. firms and developers). The main work with the healthcare sector focused on supporting the AR adoption process. To this end, 35 events in Cornwall were used to raise awareness of AR, exploring healthcare challenges and the sector's role in co-creation activities. The main work with the producers was to identify market barriers while actively supporting them in the product development process. Here, 28 AR companies in total from the UK, Ireland, the US, France and China working at different business stages were supported as part of this activity.

Eight case studies were generated, including two completed trials of AR and two external strategic partnerships. An entrepreneurship programme that supported 58 entrepreneurs was designed, creating four robotic start-ups for the region. Finally, a lab for the evaluation of AR technologies to support companies was also established.

Through the work with the healthcare sector, this thesis identified a lack of awareness of the AR market and the critical role that the sector plays in its development process. On the supply side, this thesis explored the main market barriers, including a lack of specialized agencies at a planning level, a fragmented healthcare sector that inhibits entrepreneurship, and outdated governmental policies for technology-based innovations. Overall, the findings confirmed a complete lack of preparedness and a need for changing traditional methods that are blocking innovation.

Building upon these findings, this thesis presents a Technology Strategy for the creation of AR markets. The strategy offers practical recommendations on how regions can build and benefit from AR development. Through co-creation and open innovation principles, the strategy establishes key market actors and the multilateral nature of relationships between them. It also details a complete entrepreneurship programme to create companies for the region and business platforms to start the AR market. For the healthcare sector, it describes a complete AR knowledge awareness programme to guide the engagement with the sector. For the producers, it presents best practices and a new model for the development of AR technologies.

This is the first study of its kind to offer a sector-specific Technology Strategy for the emerging AR market, aiming to improve the consolidation of this sector. The strategy could be used in regions that share characteristics with Cornwall, but its applicability to other regions is also worth exploring.

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Chapter 1

Introduction

This chapter outlines the motivation, objectives, limitations, and contributions to the research. Then it describes the structure of the thesis.

1.1 Motivation

Robotics has a profound influence in industries such as manufacturing, defence, security, and construction (IFR, 2016). It has increased the productivity of companies and nations, satisfying new consumer demands and challenges, driving economic growth (Bahrin et al., 2016). However, the healthcare sector has a tradition of inhibiting tech innovation adoption; the innovation process is long, incremental and path-dependent, strongly influenced by medical practice and developments in different sectors, technologies and scientific disciplines (e.g.: Schreiweis et al., 2019; Sun and Medaglia, 2019; Ross et al., 2016; Alkhaldi et al., 2014; Garud et al., 2013).

The healthcare sector is under unprecedented pressure with the increase of the ageing population, the rise of individuals with one or more long-term health conditions, and the shortages of qualified nurses and residential care workers (All-Party Parliamentary Group on Global Health, 2016; EURobotics, 2014; ONU, 2015). For example, more than

9 million people in the EU need help to get out of bed (EUrobotics, 2017). It is clear that a new wave of innovations is needed if we want to provide people with an affordable and efficient healthcare system (European Commission, 2012).

Assistive robotics (AR) is an emerging field being developed to try to provide support to patients and carers, in helping to address these challenges (Butter et al., 2008; Dahl and Boulos, 2014; IFR, 2016). The main aim of AR technologies is to empower people to live independently managing their own conditions (EUrobotics, 2017). However, while we have seen many research and development (R&D) projects, for example, those funded by EU programmes (e.g., H2020, 2016), relatively few reached the market with new products or services (Kose and Sakata, 2019; IFR, 2016). As a result, the question that then arose was 'How we can support the development of the AR market?'.

The 2014-2020 Strategic Research Agenda for Robotics in Europe highlights the need for research into improving the consolidation of the robotics market in Europe (EURobotics, 2014). The report also highlights the need for a programme to bring robotics into the healthcare system. It acknowledges the role that robots play in other industries, contributing to significant economic and societal challenges and stresses the importance of developing robotics to address the health and social care challenges as well, which is to develop an AR market in Europe.

In 2001, the Japan Robot Association published its report on Technology Strategy for Creating a "Robot Society" in the 21st Century (JARA, 2001). Authorities were concerned about the absence of a national technology policy and marketing scheme for the domestic robotics market, a lack of entrepreneurship spirit, bias towards traditional manufacturing industries, and a decline in education level in engineers. Therefore, to address these concerns and foster innovation and economic growth, the association developed a strategy to frame and enable a more dynamic market through different actions and policy recommendations.

Through a collaborative approach between government, private, and academic sectors, Japan was able to establish a business environment that promotes robotics and autonomous systems (RAS) research and innovation, while supporting adoption in different industries. As a result, Japan is not only the world's leading manufacturer and exporter of robots but also a leading robot adopter. With 297,200 industrial robots at work in 2017, Japan had the second-highest installed base of industrial robots in 2017 (IFR, 2018).

However, Japan's Technology Strategy was shaped by its situation, society and challenges back in the 20th century. Besides, it did not focus on assistive robotics but on robotics in general (e.g.: industrial robots, drones, entertainment robots). If we want to address the barriers for the AR market in Europe, we have to understand its situation: the market barriers and challenges for the healthcare and producers (EURobotics, 2014). Learning from interventions, understanding the AR development process through a market perspective, from conception to adoption, is a means of furthering this understanding (EURobotics, 2014). This thesis thus contributed to the development of the AR market in Europe by proposing a Technology Strategy that builds upon our market actors' needs and challenges.

Literature is abundant now on entrepreneurial and innovation ecosystems that share principles and objectives in the creation of clusters to boost, incubate, and support innovations (i.e.: Feld, 2012; Frank, 2017; Garching, 2014; Kenney and Patton, 2005; Malmberg and Maskell, 2002; Markmann, 2012; Mulas et al., 2015; Neck et al., 2004;

Oh et al., 2016; Spigel, 2017). However, these studies do not consider the emerging AR innovation process and challenges.

We can also find projects that have supported the development of a consumer market for different technologies. For instance, the 3-year Consumer Models for Assisted Living project funded by Innovate UK that worked with electronic assisted living technologies for people aged 50 to 70 (COMODAL, 2014), or the EU funded SmartLine project that worked mainly with Internet of things (IoT) solutions (SmartLine, 2017). These studies have contributed to the body of knowledge and market formation for their respective technologies, clearly showing the impact of research focused on a specific technology and its market.

The AR field is different from any other technology and even different from other robotics markets (*Chapter 3*). The field, drawing on the nascent human-robot interaction research area, has different market drivers, development process and applications, and legal and financial constraints. Therefore, it demands studies that address these elements to accelerate the AR market development and traction (Butter et al., 2008). The field also involves important consideration around ethics and care (*Chapter 3*), such as ubiquitous surveillance, patient autonomy, non-human therapy, deception or AI bias (e.g.: Belk, 2020; Fiske et al., 2019; Portacolone et al., 2020). Besides, as evidenced in Chapter 3, the AR market is just starting worldwide. This is a fragmented market, with a number of small players pushing new solutions into the healthcare sector, and limited evidence of R&D projects that move into new products (*Chapter 3*).

All of these show the need for an effective strategy to bring AR technologies into the healthcare sector in Europe (EURobotics, 2014).

This thesis was framed and conducted with the support of the eHealth Productivity and Innovation in Cornwall and the Isles of Scilly (EPIC) project (EPIC, 2017). EPIC was a three-year-long project that started in May 2017, partially funded by the European Regional Development Fund (ERDF). EPIC aimed to develop the eHealth sector in Cornwall and the Isles of Scilly (UK), improving the economy and the health and wellbeing of people in the region.

1.2 Objective

The overall aim of this thesis was to develop a Technology Strategy for building and orchestrating the creation of regional AR markets. The AR Technology Strategy is an overall plan that outlines objectives, principles and actions relating to the development of the AR market. This strategy will support public and private economic and healthcare development organisations, as well as universities and research centres, seeking to develop the AR market while supporting and empowering regions to address their healthcare challenges. The strategy developed could be used in regions that share this thesis baseline (*Chapter 3*).

Contributing to this overall aim, the objectives of this thesis were:

- To start an AR market in Cornwall, under the context of the EPIC project, and explore the current landscape, actions and strategies for the creation of the market.
- To identify processes, drivers and barriers that influence the development and adoption of AR technologies by supporting AR companies at different business stages.

- To examine health and social care professionals, patients, and carers' perception towards the technology and healthcare challenges for AR.
- To explore co-operative and competitive interactions among market stakeholders to capture value from AR development, defining models of cooperation and cross-sector engagement between universities, healthcare organizations and companies.

1.3 Contribution

The thesis provides a framework for the development of the assistive robotics market. This thesis contributes to the research and development of robotics technologies and healthcare innovation and adoption research.

- The thesis addresses two of the five critical high-level research priorities established in the 2014-2020 Strategic Research Agenda for Robotics in Europe (EURobotics, 2014); *"To provide systems able to contribute to the major economic and societal challenges"*, and how to *"build strong links between academia and industry and to exploit those links to their full potential".*

  It does so by providing a Technology Strategy that outlines a programme with objectives, principles and actions for the socio-economic development of regions through the development of the AR market (*Chapter 6* and *Chapter 7*). Robotics empowers regions to address their healthcare and societal challenges (Butter et al., 2008; EURobotics, 2014), while the development of an innovative market contributes to the region's economy (van Praag and Versloot, 2008). In addition, the AR Technology Strategy built upon the collaboration of academia and industry (*Chapter 6*), detailing principles and actions for both to profit from this cooperation.

- The thesis addresses several *key targets* from the 2014-2020 Strategic Research Agenda for Robotics in Europe (EURobotics, 2014) including creating *"an environment in which SMEs can flourish"*, *"The establishment of cross-sector engagement to strengthen and promote the uptake of robotics technology"*, and *"That policymakers understand the importance of Robotics and its potential impact"*.

  It does so by developing an ecosystem that supports AR entrepreneurship in Cornwall, and through this experience, presents a Technology Strategy for other regions to achieve this result (*Chapter 3*). This was achieved by working with the healthcare, producer and the academic sectors, supporting the uptake of AR (*Chapter 4* and *Chapter 5*). Therefore, the AR Technology Strategy details how to establish and work across sectors to support AR development and adoption (*Chapter 6*). For policymakers, the thesis also highlights the importance of European-focused standardisation activities and AR product certification (*Chapter 6*).
- From an academic perspective, this thesis contributes to the field of translational research. For this end, the thesis details principles and actions to increase the likelihood of Universities' spin-off and cross-sector strategies for research to achieve impact while working in the healthcare sector (*Chapter 6*).
- For the field of robotics, this is the first thesis of its kind that works on AR deployment and adoption methods through a market transformation perspective, instead of focusing on soft elements of innovations (*Chapter 5*). Through this, the thesis not only focuses on technology and societal acceptance,

but it embodies the key tenets of the AR innovation phenomenon such as companies, complementarities, technological interdependencies, distinct roles played by market actors, and the multilateral nature of relationships between them. (*Chapter 5*). This is something that traditional robotics research has overlooked (EURobotics, 2014).

- For the private sector, this thesis provides a list of recommendations and good practices to reduce the development time of their AR technologies, and private partnerships opportunities to grow the market (*Chapter 7*).
- For healthcare organisations (HCO), this thesis raises awareness of the central role these organisations play in the development of technologies and how to collaborate in co-creation activities (*Chapter 6*).

The AR Technology Strategy proposed will be openly available for public and private economic and healthcare development organisations that want to address challenges in their healthcare system and their economy through the development of this market.

1.4 Limitations

This thesis built upon the creation of an emerging AR market in Cornwall. The development of a minimum viable product (MVP) takes around five to ten years for AR technologies (*Chapter 3*). Since this thesis focused only on the first three years of the market development, it only addressed the conception, design and evaluation of AR prototypes by new start-ups; in this sense, it is still an emerging market.

Due to the current state of the worldwide robotics market (*Chapter 3*), this thesis did not work on exploring the trading elements. First, we need to focus on creating and supporting the consolidation of the AR market (EURobotics, 2014).

Besides, due to the time frame of the thesis, the lack of studies in the field (i.e., supporting the development of regional AR markets), and the development time of the technology and market, this thesis does not include an evaluation of the proposed AR Technology Strategy in another region. The strategy builds upon the lessons learned from a 3-year intervention in Cornwall building an AR market (*Chapter 4* and *Chapter 5*). Through this pragmatic approach, it defines a set of best practices for others to start the AR market in their regions (*Chapter 6* and *Chapter 7*). This strategy includes principles as co-creation, open innovation and business platforms (*Chapter 6*), which aim to support the sustainability of the intervention, and therefore, the market. However, further studies are needed to fully evaluate the transferability and sustainability of the proposed strategy (*Chapter 8*).

1.5 Outline of the thesis

This thesis comprises of seven chapters organised in the study workflow. Figure 1 shows how the chapters are connected and the objectives of each chapter.

Following the introductory chapter, Chapter 2 presents the methodology used through the thesis, collaborative action research (CAR), and the approach taken in each of the CAR cycles. Then Chapter 3 describes the system dynamics of the AR market and Cornwall, analysing the current situation of the region before the intervention. This allowed the thesis to define the initial context of the region and where the proposed AR Technology Strategy could be transferable.

Chapter 4 and Chapter 5 describe the CAR cycles deployed with the healthcare sector and producers (firms and developers). Both chapters explain the activities carried on in the region, the interventions’ results, and a discussion of the findings.

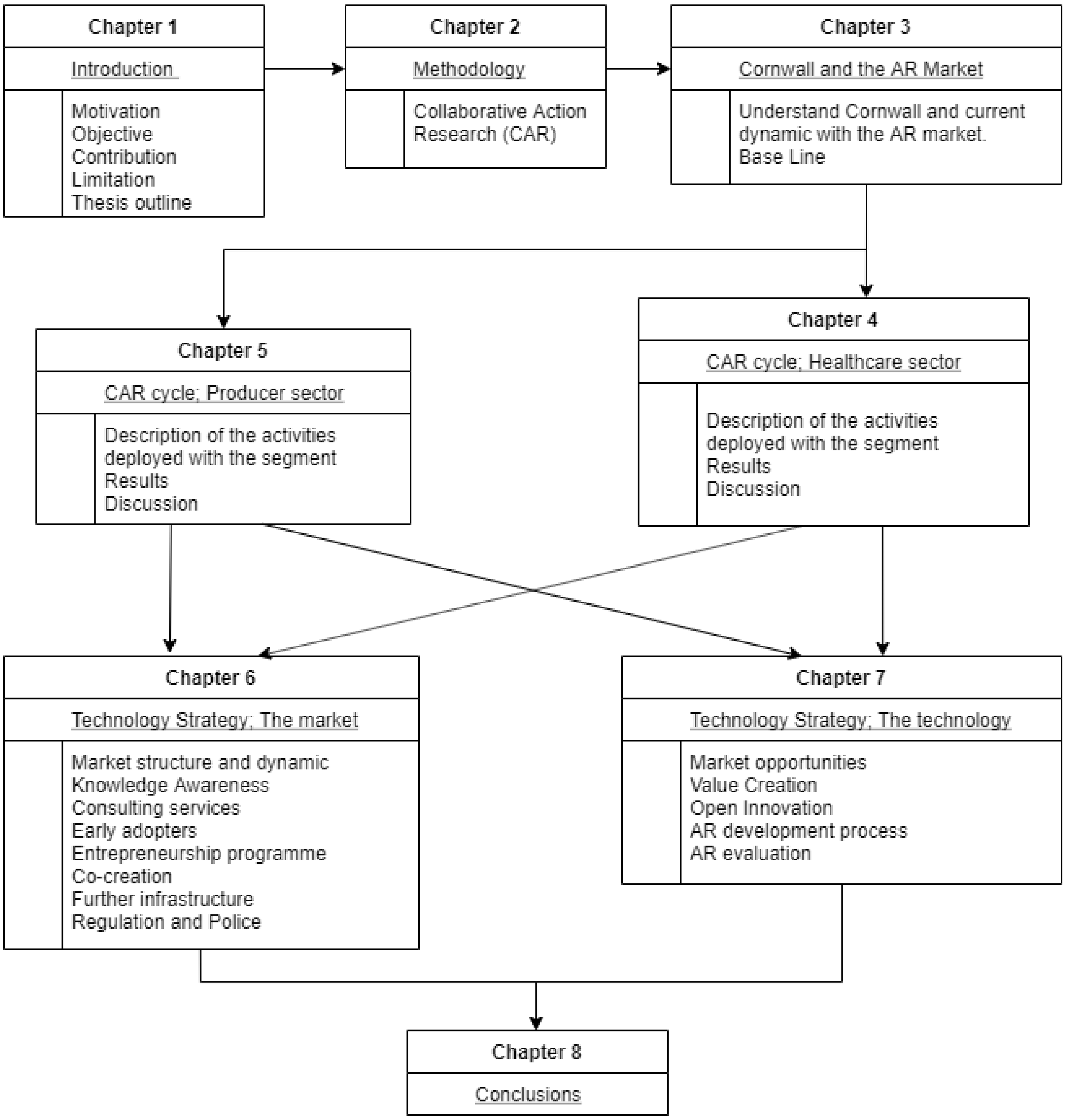

Figure 1; Thesis structure.

Through the knowledge developed in these three chapters, Chapter 6 and Chapter 7 provide the AR Technology Strategy. Chapter 6 focuses on the market; the structure and dynamic of the AR market, the main initial activities, the AR entrepreneurship programme, a co-creation framework, and policy recommendations for creating an emerging AR market.

In the same way, Chapter 7 provides practical recommendations for the developers. It focuses on the market offer, development and design recommendations for AR technologies, open innovation principles and actions, and the evaluation process of the technology. Moreover, Chapter 7 presents a new model for AR development and the design of the Robot Home for AR evaluations. Finally, Chapter 8 draws the conclusions of the thesis and providing suggestions for further work.

Chapter 2

Methodology

This thesis aimed to make real change, the development of an assistive robotics (AR) market in one region, and from that derive a Technology Strategy for others to build the AR market. This is not a conventional robotics thesis; it could not have been undertaken in a lab or a simulation. It required working with multiple stakeholders whose interests are different and who cannot be forced to collaborate (Sagor, 1993). My role was as participant-observer; I was both agent of change working with relevant stakeholders and observer (Whyte and Cole, 2012). Even more, this thesis is based on interdisciplinary research that draws from fields such as business management, entrepreneurship policy, robotics development and evaluation, and health technology adoption research.

Therefore, following the rationale behind action research (Brydon-Miller et al., 2003), I needed to identify the situation of the region, Cornwall, concerning the AR market before any intervention. For this, I had to engage with the region's setting, with the reality that healthcare and AR producers were experiencing. Only then I would be able to define the main challenges and a plan to foster AR innovation in Cornwall. This plan will change according to the results observed from the intervention (Brydon-Miller et al., 2003).

The methodology needed to support the fundamental goal of conducting research with the active participation of people in a region, to deploy an intervention that will engage with the world and study the effects of the same.

Therefore, the collaborative action research (CAR) methodology was used since it provided a framework for researchers to observe, plan, intervene and reflect on the intervention made in a specific context (Sagor, 1993). CAR is an iterative process comprised of repeated cycles. Each cycle has four core activities; planning, acting, observing and reflecting (Sagor, 1993). The iteration between cycles let researchers identify the barriers, enablers and benefits of the intervention made, and address them in another cycle (*Figure 2*).

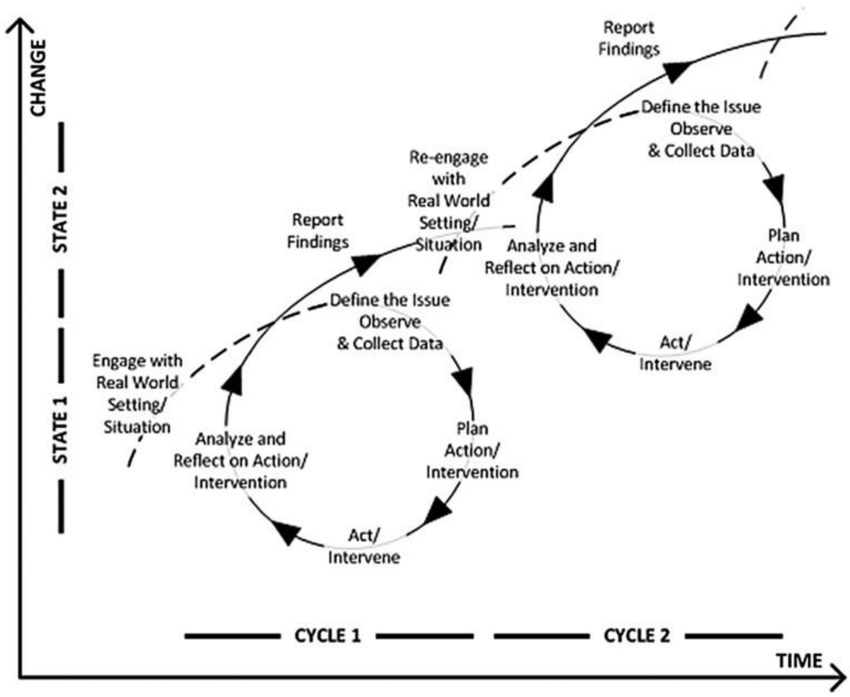

Figure 2; Collaborative action research cycle.

In addition, CAR allows building meaningful relationships through which the researcher could investigate and understand the decision-making process (Bryant, 1995). Since the thesis aimed to build an AR market in the region that will support both, consumers and producers, there was a collaborative nature of the approach that engenders an interest of participation in terms of both the collection and interpretation of data from the research participants (Aspland et al., 1996). This represents stakeholders cooperating to develop a field of mutual interest through cycles of action, experience and reflection (Sagor, 1993), in order to develop insight into this particular phenomena; developing the AR market.

Even more, the CAR methodology lets us work with the environment and respond to the effects of our interventions (Sagor, 1993). Therefore, it has been used in previous research exploring regional development (e.g.: (Brydon-Miller et al., 2003; Fisher and Jackson, 1999; Hunsberger et al., 2017; Kowanko et al., 2009; Ozcevik et al., 2010; Selin, 1994)). These studies explored topics from improving people's wellbeing to building capacities in deprived regions, topics that align with the aim of the thesis (*Chapter 1*).

There are alternatives to CAR that also focus on engagement with stakeholders or systems. For instance, Engaged Scholarship (Korte, 2009) or Soft Systems Methodology (Checkland, 1989). However, they were found unfit for this thesis. For instance, Soft Systems focus on the appreciation of a problem situation among a group of stakeholders rather than solving a pre-defined problem (Checkland and Poulter, 2010). Its main aim is to define an organization or system problem rather than solving it (Checkland and Poulter, 2010). This thesis needed to solve a problem that is already known (as explained in *Chapter 1* and *Chapter 3*), to develop a strategy for building and orchestrating the creation of the AR market. The same applies to Engaged Scholarship models that collect different perspectives and competencies to co-produce information about a complex problem (Korte, 2009). They do not offer a suitable framework for solving a system-problem (McKelvey, 2006).

To make a comprehensive study of the region before the intervention, and to define the first engagement activities for both CAR cycles, this thesis began by analysing Cornwall and the AR market by applying the first steps of the *Technology Innovation System* (TIS). Chapter 3 presents an overview of this method and the respective findings. This first analysis took place between July and October 2017. The data was collected via desk research before the first engagement with the region as defined by the CAR cycle (*Figure 2*).

From a macro level, the fundamental elements of any market are the customers and the producers; without them, there is simply no market (Spigel, 2017). In the AR market, they are the healthcare sector and the producer sector (firms and developers) (Dahl and Boulos, 2014). This is explored later in Chapter 3, section *3.3. Structural components*.

CAR allows the thesis to take different approaches with each of the two stakeholder group while still being able to reflect on the findings from the other (Sagor, 1993). Through this, the thesis framed the intervention with two different approaches, also supporting the interdisciplinary nature of the thesis. In the CAR cycles with the healthcare sector, a *Technology Innovation Adoption* approach was taken, while with the producer sector, an *Innovation through Barriers Identification* approach was adopted. Through these approaches, I gave further structure to the intervention. Both approaches and all the activities carried out in the cycles are described in Chapter 4 and Chapter 5 respectively.

Finally, to simplify the overall representation of all the interventions undertaken in the region and to structure the thesis sequentially and coherently, the thesis will not refer to each cycle (e.g.: “CAR cycle 3 with the producer sector” or “CAR cycle 4 with the healthcare sector”). Instead, the thesis will describe and refer to the CAR cycles as one main CAR cycle; one for the healthcare sector and one for the producer sector. Figure 3 and Figure 4 show the main CAR cycles with both sectors.

In summary, this thesis adopted a *Collaborative Action Research* (CAR) method since this provided a framework for the intervention and participation of the main AR stakeholders (Sagor, 1993). Before the intervention, I applied the *Technology Innovation System* (TIS) method to understand the region and its dynamic with the AR market (Bergek et al., 2008 - *Chapter 3*). In the CAR cycle with the healthcare sector, a *Technology Innovation Adoption* approach was taken (Robert et al., 2009 - *Chapter 4*), while with the producers, an *Innovation through Barriers Identification* focus was adopted (Hadjimanolis, 2003 - *Chapter 5*). Through this experience, I developed a Technology Strategy for building the AR market (*Chapter 6* and *Chapter 7*).

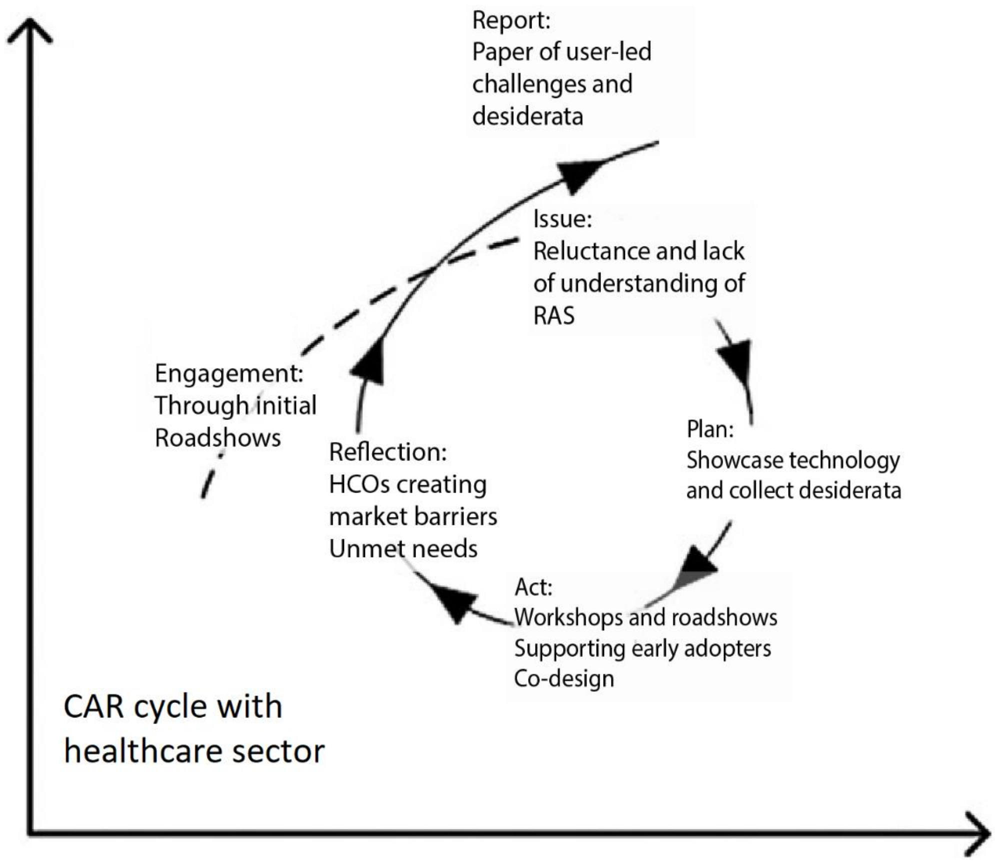

Figure 3; Main collaborative action research cycle implemented with the healthcare sector.

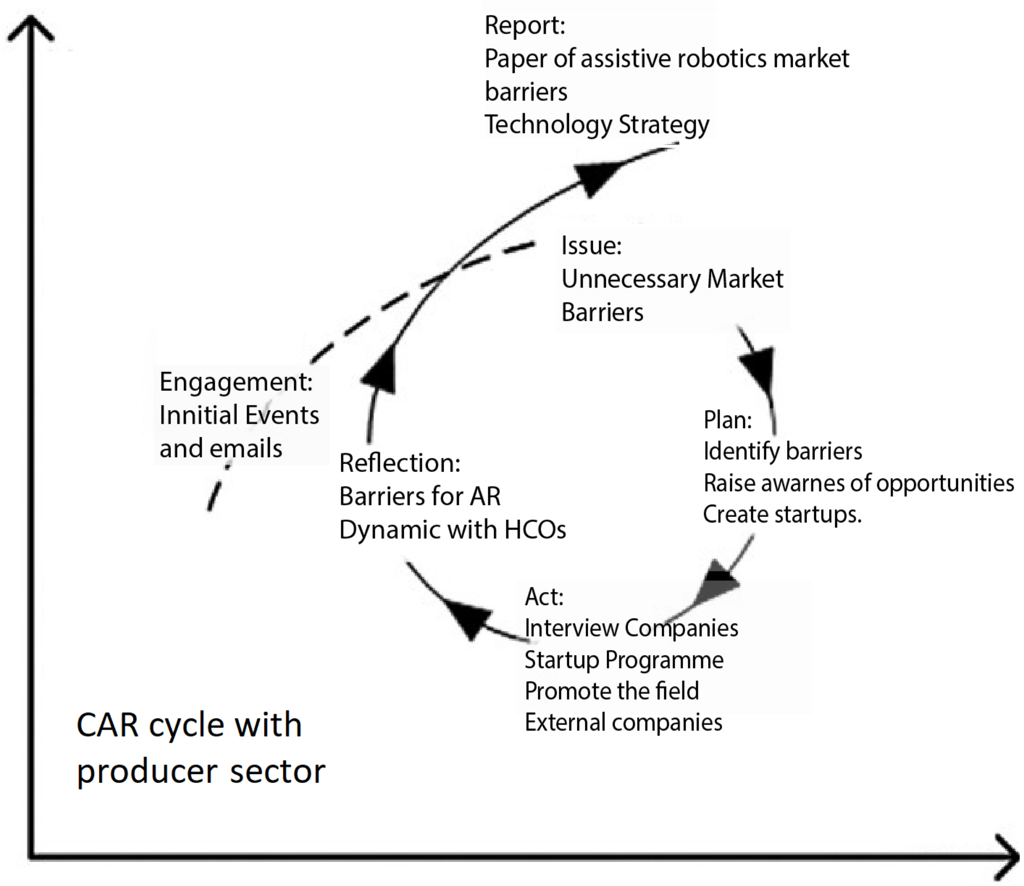

Figure 4; Main collaborative action research cycle implemented with the AR producer sector.

Chapter 3

Cornwall and the assistive robotics market

Before the intervention, it was essential to understand the region and the current landscape for the AR market to define the first activities for each CAR cycle (*Chapter 2*). This became a baseline that allowed the thesis to define the minimum requirements that the proposed AR Technology Strategy needs to be deployed in another region.

In this chapter, I followed the *Technology Innovation System* (TIS) method to characterise the AR market and dynamic with Cornwall before the intervention. The chapter studies the stakeholders, market dynamics and development opportunities for the AR industry in Cornwall.

This analysis allowed the thesis to:

- Identify and build upon the region’s strengths,
- Discover AR opportunities and work upon eliminating or minimising threats.
- Establish a baseline for the thesis.
- Define the context upon which other regions could adopt the AR Technology Strategy.

The chapter concludes by presenting a SWOT analysis of the AR market in the Cornwall region. This provides the reader with a concise summary of the state of this market including the potential for its further development.

3.1 Technology innovation system

Technological innovation system (TIS) research studies the actors, networks and institutions contributing to the overall function of developing, diffusing and utilising new technologies (Bergek et al., 2008). By doing so, TIS provides a framework for understanding system dynamics and innovation barriers.

Various researchers and policy experts have undertaken empirical studies of innovation systems (Klein Woolthuis et al., 2005). By studying the actors and networks, they understand the system or market dynamic and its performance. This informs national authorities and international organisations or agencies in their effort to drive socio-economic growth in regions (Bergek et al., 2008).

Bergek et al. developed a scheme of analysis as an effort to extract practical guides from previous studies (Bergek et al., 2008). This scheme provides researchers with a tool to identify policy issues and goals to foster innovation. What makes Bergek et al. scheme attractive to this thesis is their technology innovation system approach (TIS); a socio-technical system that focuses on the development, diffusion and use of a particular technology.

By taking a TIS approach, you are not solely considering the technology, but all the different components that influence the innovation process. This includes infrastructure, institutions, interactions and capabilities, plus the technology (Bergek et al., 2008). This framework is a functional approach to analyse the components and dynamics with a process focus, which have an impact in the development, diffusion and adoption of new technologies.

The framework consists of six steps, as seen in Figure 5. However, this thesis used the TIS framework only to understand the region and the AR market before the intervention. Therefore, only the exploratory steps were used:

- The first step is to define the TIS focus; knowledge field or a product. In this case, the field is the AR market.
- After, I identified the components of the system; actors, networks and institutions of the AR market.
- Finally, I studied the functions of the market as seen in Figure 5.

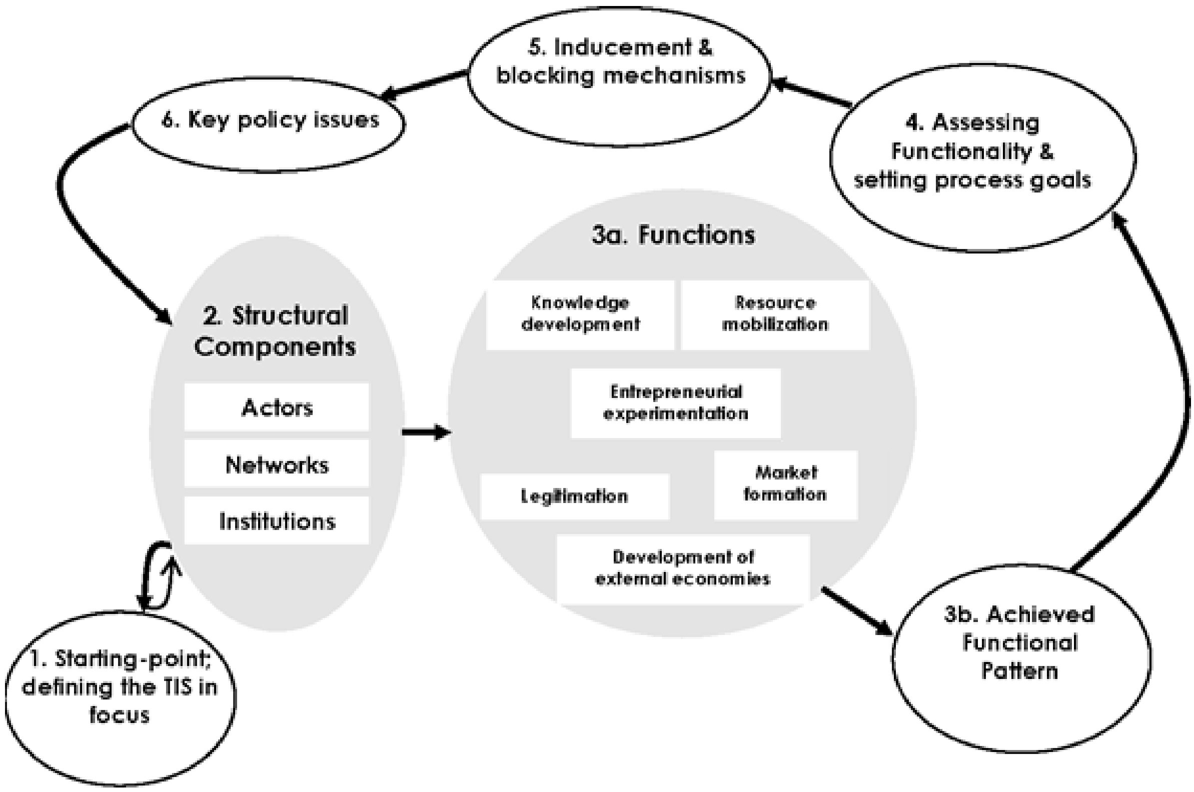

Figure 5; Technology innovation system framework. Source; (Bergek et al., 2008)

Finally, Technology Readiness Levels (TRLs) represent a useful tool to estimate the maturity of technologies, including AR. TRL is a known measurement system that through its scale from 1 to 9, allows different organizations taking decisions concerning the development and transitioning of technology (Héder, 2017). Figure 6 shows the different levels of the scale. This thesis uses this intuitive method to help the reader understand the maturity of the market, the companies engaged (*Chapter 5*), and some AR projects presented throughout the chapters.

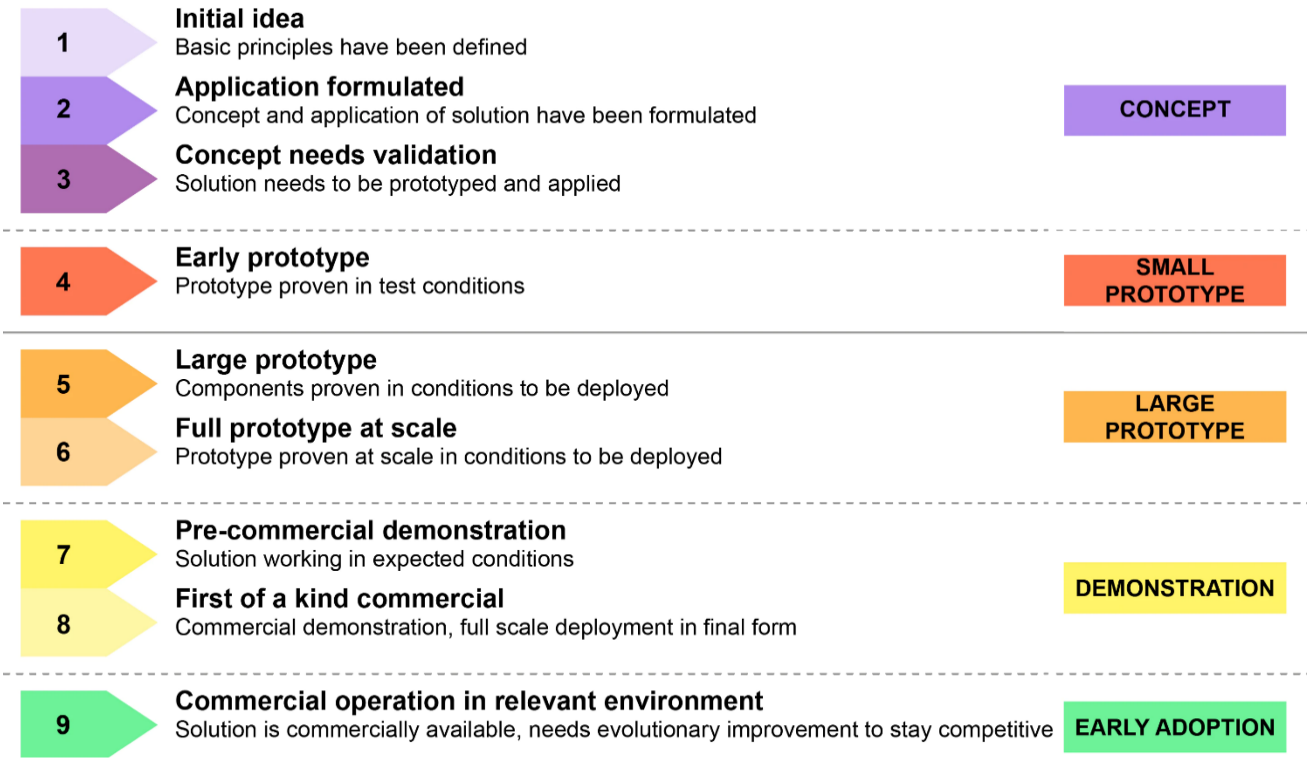

Figure 6: Technology Readiness Levels. Source (IEA, 2020)

3.2 The assistive robotics market

Following the definition of the EUrobotics and the Partnership for Robotics in Europe SPARC, assistive robots are robotic and autonomous systems (RAS) whit the primary role of providing assistive help to carers or directly to patients, in hospital, specialist care facility or domestic healthcare settings (EUrobotics, 2017; SPARC, 2014). Robots that could be operated by health professionals or staff, but also interact directly with their service user(Dahl and Boulos, 2014). This sector excludes clinical robots (i.e.: surgical robots (Ballantyne and Moll, 2003)), robots for clinical diagnosis (Anantham et al., 2007) or training purposes (Taehan Sanbuinkwa Hakhoe. et al., 2008).

AR has a range of applications in healthcare. It features robots that organise, remind, and deliver medications (e.g., Pillo, 2019). There are robotic arms for wheelchairs to support users reaching and manipulating objects (e.g., KINOVA, 2018). We also have AR for assisting a person with their personal care (e.g., Armada et al., 2014), robotic shower systems to assist frail users (e.g., I-SUPPORT, 2018), and more activities of daily living as brushing your teeth, eating or putting clothes (e.g.: I-DRESS, 2018; OBI, 2018). Exoskeletons are used in the rehabilitation process of patients with severe muscular dystrophies or as walking aids (Enrico, 2017), while robotic assistant platforms are used to set alarms (e.g., JIBO, 2017), provide real-time information through web services (e.g., BlueFrog Robotics, 2017), and to encourage healthy lifestyles activities or behaviour change therapies (Lehmann et al., 2013), for instance, promoting exercise (e.g., ACANTO, 2017).

It also includes lifting and displacing aids, from helping nurses transfer patients from beds to wheelchairs, or modular robots helping seniors move around their homes using traditional rail system of hoists (e.g., CHIRON, 2016). It also comprises robots for the transportation of goods within healthcare organisations or people in need (Bloss, 2011), and communication purposes (Tsui et al., 2011).

Socially assistive robots are also part of this sector, offering patient aid improving social, emotional, or cognitive functioning, tackling problems such as anxiety (Feil-Seifer and Mataric, 2011). AR could be used to address loneliness and social isolation. For example, the most well know AR robot; Paro the seal (PARO Robots, 2014). Several studies since 2000 have systematically shown that Paro reduces loneliness among older people (Robinson et al., 2013), and is capable of improving the mood and anxiety of seniors (Moyle et al., 2013).

Moreover, telepresence robots promote social interaction (Kristoffersson et al., 2013), while supporting remote diagnosis and monitoring of patients. For instance, the French company Cuttii is offering a monthly paid service for seniors to acquire their telepresence robot and access different learning sessions in real-time with different people through the robot video call system (Cutii, 2017).

This covers just a fraction of the various applications for which assistive robots are being developed in universities and research labs (Wang et al., 2006). The scope of AR is rich and varied, with the potential to change the way we have been treating a range of impairments and conditions (Dahl and Boulos, 2014). Figure 7 shows some visual example of AR robots. Table 1 provides more examples of AR projects in health and social care.

Figure 7; Assistive robots available in the market. 1 Care-O-bot; domestic robot assistant, 2 Cutii; telepresence robot for older people, 3 Leka; a therapeutic robot for children with developmental disorders, 4 Obi; robotic feeding device, 5 AV1; robotic avatar for children with long term conditions.

Table 1; Examples of assistive robots in health and social care.

Robot	Description	Benefits	TRL
JACO 3 Fingers (KINOVA, 2018)	Robotic arm that can be installed in electric wheelchairs	Support activities of daily living (i.e., drinking from glasses, opening doors, picking up objects, scratching itchy parts of head and body)	9
ASIBOT (Armada et al., 2014)	Robotic arm that can operate in bathrooms	Support with self-care (i.e., shaving, brushing their teeth, cutting their hair, putting make-up.)	4
JUVA (CHIRON, 2016)	Modular robot which moves around houses using the standard rail system of hoists	Support transferring people (i.e., stand up from bed, move around the home)	5
I-SUPPORT (I-SUPPORT, 2018)	Robotic shower system to assist frail persons	Support with self-care	5
I-Dress (I-DRESS, 2018)	Robotic system that will provide active support for dressing	Assistance with Dressing	4
Obi (OBI, 2018)	Robotic arm that supports feeding	Support activities of daily living	9
CyberLegs++ (Enrico, 2017)	Robotic cognitive orthoprosthesis for lower limbs	Support rehabilitation therapy	9
Cyberdyne (Anatomical Concepts, 2017)	Upper and lower limb exoskeletons	Support patient mobility	9
Paro (PARO Robots, U.S., 2014)	Robotic seal to reduced loneliness	Reduce loneliness and social isolation	9
Leka (Leka, 2014)	Robotic smart toy for children with autistic spectrum disorders	Support social skill therapies	8
Cutii (Cutii, 2017)	Telepresence robot for old people	Reduce loneliness and social isolation (i.e., online courses)	9
LUCAS (Physio-Control Inc., 2017)	Chest compression system for cardiac arrest	Support emergency respond	9

According to the Global Healthcare Assistive Robot Market report made by Global Market Insight, in 2017, the size of the global AR market (surveillance and security, humanoid robots, rehabilitation/exoskeletons, socially assistive) was over USD 359.1 million, with a 19.3% compound annual growth rate estimation from 2018 to 2024 (GMI, 2017). The biggest segment of the market is exoskeleton medical devices for people with different physical impairments (e.g.: spinal cord injury), mainly used in clinical rehabilitation (MarketsandMarkets, 2019). This segment is driven by an increase in the number of people suffering from strokes and spinal cord injuries (GMI, 2017). Additionally, insurance companies are supporting the adoption of this segment by framing policies for the coverage of exoskeleton medical devices, mainly to stand out in the insurance market(MarketsandMarkets, 2019). But exoskeletons mainly deal with physical interaction, leaving social applications (i.e.: social assistive robots) and applications with high autonomy outside the trading market. The exoskeleton segment is also lacking traction outside healthcare facilities (i.e.: robots used in patients' houses, supporting daily living) (MarketsandMarkets, 2019).

To exemplify this point, let us take a look at the companies leading the AR market. Several AR market studies (e.g.: DataIntelligence, 2020; ResearchandMarkets, 2019; MordorIntelligence, 2019; MarketsandMarkets, 2019) have identified the companies in Table 2 as the leading firms in the sector. They are all currently trading (TRL – 9), but from the 15 companies, eight are companies developing exoskeletons for clinical use. Besides, from the remaining eight, Fraunhofer Society and Softbank are multinational conglomerate organizations that hold many technologies, energy, and financial companies (SoftBank Robotics, 2020; Fraunhofer, 2020), while Ubtech main revenue comes from educational robots and toys (Ubtech, 2020). As seen in Table 2, the revenue gap between these companies is visible. However, Kinova, Intuition Robotics and Blue Frog Robotics are good examples of what small start-ups can eventually achieve for the AR field (KINOVA, 2018; Intuition Robotics, 2020; BlueFrog Robotics, 2017).

The market is highly fragmented (MordorIntelligence, 2019), where many innovative AR applications (*Table 1*) are being driven by some small players located mostly in the most significant technology clusters in the world (Butter et al., 2008). As a result, we can conclude that the AR market is in a nascent state, worldwide, and there are few solutions available for the public (EUrobotics, 2017; Dahl and Boulos, 2014; Wang et al., 2006).

Table 2: Leading AR companies in the market. All the companies are currently trading (TRL - 9).

Company	Country (ISO)	Technology	Application	Main Product on Market	Estimate Revenue (M)	Founded
Fraunhofer Society	DE	Social assistive robot	Social care	Care-O-bot	$ ~3,000	1949
Ubtech Robotics	CN	Humanoid	Social care	Aimbot	$ 510	2012
SoftBank Robotics	JP	Humanoid	Social care	Pepper/NAO	$ 121	1981
Hocoma	CH	Exoskeleton	Rehabilitation	Lokomat	$ 21.4	1996
Kinova	CA	Robotic arm	Support activities of daily living	JACO	$ 15	2006
Cyberdyne	JP	Exoskeleton	Rehabilitation	HAL	$ 12.1	2004
Ekso Bionics	USA	Exoskeleton	Rehabilitation	EksoNR	$ 10.8	2005
Intuition Robotics	USA	Social assistive robot	Social care	ElliQ	$ 10	2015
Fourier Intelligence	CN	Exoskeleton	Rehabilitation	HandyRehab	$ 8	2015
ReWalk Robotics	USA	Exoskeleton	Rehabilitation	ReWalk Personal 6.0	$ 6.54	2001
F&P Robotics AG	CH	Robotic arm	Support activities of daily living	Lio	$ 6	2014
Motorika	USA	Exoskeleton	Rehabilitation	Optimal-G Pro	$ 4.5	2004
Barrett Technology	USA	Exoskeleton	Rehabilitation	Burt	$ 4	1990
Blue Frog Robotics	FR	Social assistive robot	Social care	Buddy	$ 3	2014
Rex Bionics	NZ	Exoskeleton	Rehabilitation	Rex	$ 0.17	2007

The AR market is fundamentally different from the ‘mHealth’ or any digital tech market. While both have the software element, the AR market also requires hardware design and production. Digital technologies work in already established platforms such as phones or computers. AR firms need to develop their platforms. This simply increases the ventures’ challenge, development time, investment and risk. To develop a minimal viable product (MVP), most start-ups have to develop, on average, three to four prototypes as explored in Chapter 5. They need access to fast prototyping equipment and off the shelf devices as microcontrollers, servos, and different sensors. All of this increases exponentially the investment needed to develop AR devices compared to apps (Thompson, 2019). From the engagement with the producer sector described in Chapter 5, it was perceived by the companies interviewed and supported that governments, regulatory agencies and funding organisations have been treating AR development as app development, and this only inhibits innovation.

Furthermore, AR is also different from any robotics and autonomous system. For instance, manufacturing or agricultural robots focus on the design of the mechatronic structure. Aerial, marine and transportation robots work on autonomous navigation and object detection. In contrast, the AR field builds upon the nascent human-robot interaction field (Dahl and Boulos, 2014); robots that interact physically with their user, continuously and autonomously monitoring their condition, while supporting them in different wellbeing activities. Different structural systems abilities and technologies are needed, different design processes and testing methodologies as well (Loh, 2018). Besides, robots can have an impact on the mental health of their users (Zubrycki and Granosik, 2016). Robots have been recently used as valuable therapeutic devices in numerous studies, especially with seniors with cognitive decline and children with developmental needs (Zubrycki and Granosik, 2016).

In addition, several studies have identified and discussed central ethical and social issues for AR (e.g.: Stahl and Coeckelbergh, 2016; Guan, 2019; Van Wynsberghe, 2016; Frennert and Östlund, 2014). For instance, the implications of robots replacing healthcare staff and its consequences for the workforce (Riek and Howard, 2014). In the same way, the implications brought by the de-humanisation of care, and how this could affect patients (Sharkey and Sharkey, 2011). Issues such as robots’ autonomy, role and task, moral, deception and trust, arise from the development of AR solutions. For example, if robots are used in therapies for children with schizophrenia, what tasks can and should be delegated to robots? Should the robot be supervised? And how much should it do without direct human supervision? Can the robot reflect on the ethical quality of what it does? And if so, is it responsible for its actions? If not, is this deception (i.e.: not real social-emotional involvement) justifiable? These are just some of the questions and challenges studied in the field of human-robot interactions. Certainly, these questions and challenges change according to the AR application.

As a result, all of the mentioned intrinsic qualities of the technology produce different market barriers and development challenges for AR firms and developers in this emerging industry.

From the engagement with the AR companies from this thesis (*Chapter 5*), I have identified several barriers for the AR market. Here I mention two that start explaining the current lack of traction of the market: evidence and evaluation, and key research challenges.

On one hand, there is limited evidence of AR projects that convert into new products and services for the public (Kose and Sakata, 2019; IFR, 2016). There is also an absence of regulatory paths for the technology that include safety verification procedures and critical appraisal tools (EUrobotics, 2017). All of these contribute to the lack of market penetration. As a result, there is no appreciable evidence of AR cost-effectiveness (EUrobotics, 2017). This affects principally the funding and adoption of the technology, which contributes to the market failure (*Chapter 5*).

On the other hand, the fundamental technology is not yet mature enough. Chapter 7 presents some of the challenges and key research areas of the technology that we need to address first to accelerate AR production and adoption (e.g.: long-term autonomy and awareness, social intelligence, communication). Therefore, as in any other high-tech field, innovations will not reach the user unless we bridge these gaps. Chapter 7 proposes value creations opportunities to solve some of these challenges, for instance, downsizing the product offer, which has been a way to address the lack of technology readiness (Sheaffer et al., 2009).

3.3 Structural components of the assistive robotics market

Following the UK-RAS white paper on robotics in social care (UK-RAS, 2017), the main stakeholders of the AR market are presented in Figure 8 (next page). The AR market has two main actors; the producer sector (firms and developers) and the healthcare sector. Then we have the research and innovation institutions (e.g.: research centres, universities). Another player in the AR market is the government, including local authorities, due to its bond with the healthcare sector and innovation development. Finally, we have regulatory agencies in charge of the certification and adoption of technology for the healthcare sector.

Healthcare sector, government and regulation organisations have a defined dynamic (SBRI Healthcare, 2018). The only stakeholder which is new to the current structure is the AR producer sector. A sector that is slowly emerging, aiming to address the new healthcare challenges that we are facing.

Healthcare systems around the world share one major characteristic: hierarchy and fragmentation (Mieczkowska et al., 2004). Take, for instance, the UK National Health Service (NHS). Commonly seen as one entity, it is, in fact, a group of many individual organisations; NHS England, NHS Scotland, NHS Wales, and the affiliated Health and

Social Care in Northern Ireland, Public Health England, 211 Clinical Commissioning Groups (CCGs), 168 hospital or acute trusts, around 11,000 general practice (GP), and thousands of community providers (SBRI Healthcare, 2018). Each often includes clinicians, financial managers, commissioners and Information Technology (IT) managers.

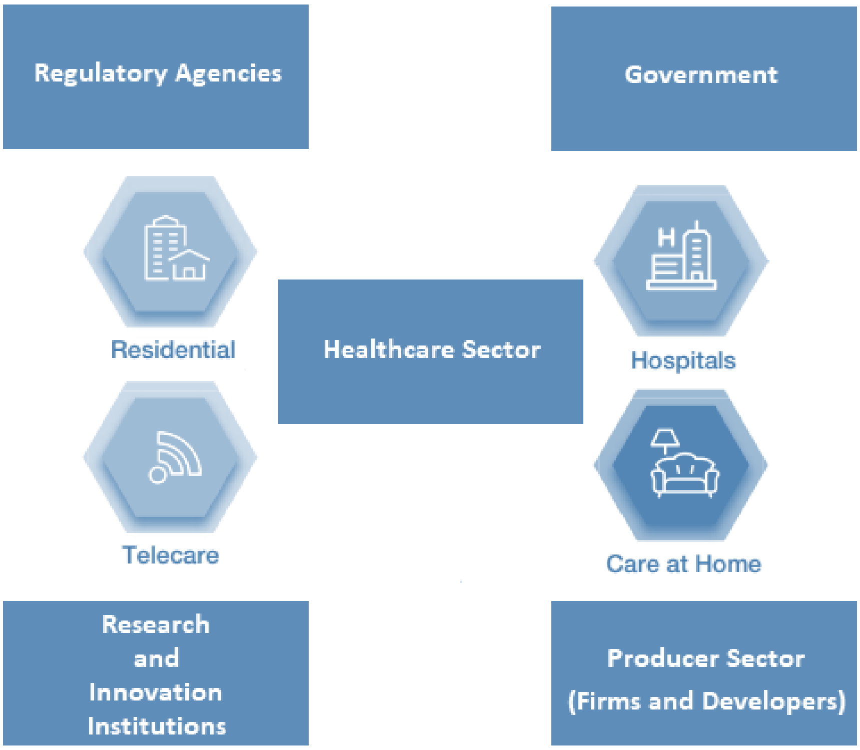

Figure 8; The assistive robotics market stakeholders. Source; (UK-RAS, 2017)

This thesis does not address the healthcare system as NHS focus, but instead, it takes a universal approach; the healthcare sector as an individual organisation (*Chapter 4*). This approach aims to develop an AR Technology Strategy that could be implemented outside the UK. This approach follows other studies of technology adoption, which typically take this perspective of an individual organisation (i.e.: Llewellyn et al., 2014).

For this thesis, the **healthcare sector** will include public and private health and care providers (e.g.: hospital, clinics, nursing homes, residential care, charities) and the patient; the user of the technology. The **producer sector** includes the start-ups and SMEs that are leading the development of this sector. It also refers to the systems integrators, manufacturers or suppliers.

3.4 System functions of the assistive robotics market

The functions from the TIS method allowed me to understand the dynamics of the described AR market in Cornwall. I have used the functions to establish the current state of the AR market in the region.

- *Knowledge development* refers to the current knowledge of the AR market, and it can be measured by a range of indicators such as publications, learning curves, or the number of patents.
- *Market formation* analyses market development and market drivers. This includes market phase, purchasing processes, demand, institutional stimuli for market formation.
- *Entrepreneurial experimentation* allows the mapping of the number and variety of ventures taking place and understands the reasons behind successful projects.
- *Legitimation* focus on social acceptance and compliance with relevant institutions.
- *Resource mobilization* comprises factors such as funding opportunities, seed and venture capital, or human resources/talent.
- *Development of positive externalities* focuses on resources from outside the TIS, as external firms, political power or specialised intermediates. These resources contribute to the growth of the market.

3.4.1 Knowledge development and diffusion

AR is an emerging field (IFR, 2016). Due to its infancy, the type of knowledge development is limited to the scientific/technical field while the source comes from the work of research and innovation institutions working in R&D of various technological challenges (EURobotics, 2014). Most of the AR literature available focuses on the technology development and evaluation (e.g.: (Ayusawa et al., 2016; Piezzo and Suzuki, 2017; Winkle et al., 2018; Wu et al., 2016)). This represents the first line of the development process. For instance, (Yusif et al., 2016), (Greco et al., 2009), or (BenMessaoud et al., 2011) studied user needs, acceptability and usability of innovations in technology with end-users. We also have papers that describe the development and evaluation of new R&D prototypes (e.g.: Kachouie et al., 2014; Kristoffersson et al., 2013). Overall, this represents the overview of the knowledge available and its diffusion.

However, most of the research is far from being ready for adoption or even evaluated in rigorous studies (SPARC, 2014). Take, for instance, AR for supporting people living with dementia, an application that demands to have AR technologies with a good level of autonomy and market readiness. From a literature review conducted by Dawson et al. on randomized controlled trials or clinical controlled trials of technologies, in general, to support people with dementia to live at home, the study identified 131 publications since 2002 (Dawson et al., 2015). None of these studies evaluated robotic technologies. The same was found by Liang et al. reviewing interventions for older adults with Alzheimer disease or mild cognitive impairment (Liang et al., 2018), and by He et al. exploring cognitive interventions for mild cognitive impairment and dementia (He et al., 2019).

Conversely, entrepreneurs and healthcare organizations (HCOs) can only access the knowledge developed by research and innovation institutions, knowledge that is available through papers and academic conferences due to the limited interaction of academia (Tomlinson, 2002). That is why we see most of the AR companies coming from spin-offs from universities (EURobotics, 2014). For Cornwall, this knowledge could be sourced through centres of excellence such as Falmouth University, University of Exeter, and the University of Plymouth (Amion Consulting, 2015).

3.4.2 Market formation

3.4.2.1 Market development

In July 2017, Cornwall did not have any AR companies. This was evidenced after an extensive search at the UK Company House. The only robotic companies in the region, Engineered Arts Ltd and Cyberstein Robots Ltd, were registered as "artistic creation" and "performing arts" respectively. Both companies developed robots in Cornwall; Robothespian and Titan, but their only use was for entertainment.

On the other side, there were not product suppliers that work with any AR solution in the market. This could be led by the mentioned lack of AR companies trading on the market, not only in the region but also in the world. However, even animatronic toys as the Hasbro dog and cat were not supplied by any regional business in 2017 (*Chapter 5*). This absence of entrants to the market influenced the perception of its legitimacy (Carroll, 1997) demonstrating the need to start developing the producer segment in the region.

This was the same trend for the rest of the UK. As mentioned in section 3.2, the AR market is an emerging sector, with few companies in known tech clusters. In 2017, some

AR start-ups could be found in London, e.g.: No Isolation (TRL: 9, No Isolation, 2020); Emotech (TRL: 6, Emotech, 2020); Bot and Us (TRL: 5, Bot and Us); Consequential Robotics[1], (TRL: 8, Consequential Robotics, 2020); Moley Robotics, (TRL: 6; Moley, 2020). There could have been other AR start-up in the country, but due to the described low density of the market and low visibility of the tech, they were not found or engaged during our work with the producer sector (*Chapter 5*). This also showed the overall TRL of the market, where companies are mainly working in early R&D stages (TRLs from 1 to 5). Furthermore, as explained in the next sub-sections, the innovation landscape and infrastructure of Cornwall is different from the UK, with clear implications for the development of the field in this region.

3.4.2.1.1 The eHealth sector

I moved then to analyse the eHealth sector to explore the status of other markets working as close as possible with the AR field in Cornwall. Since the eHealth sector also focuses on innovative solutions for the healthcare sector, mostly on digital technologies (Eng, 2002), it is the closest market to the AR sector.

The 2015 Cornwall and Isles of Scilly Research, Development and Innovation: Evidence Base report, using the Standard Industrial Classification codes for *Hospital Activities* and *Other Human Health Activities*[2]; concluded that the eHealth sector in Cornwall should be classified as a nascent or emergent market (Amion Consulting, 2015). There was a relatively immature local value chain, but with significant growth potential.

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[1] While the company is a spin-out of the University of Sheffield, the company is registered in London in the UK Company House.
[2] Codes 86101 and 86900 respectively.

In 2017, Cornwall had a "*limited to partial*" existence of eHealth resources and near trend growth potential. There was no specific formal business cluster or network for eHealth in Cornwall, and the supply chains were currently limited (Amion Consulting, 2015; Institute of Public Care, 2015; Sewell et al., 2015). Even more, software engineering and programming were distinguished as a significant skills gap in Cornwall (Sewell et al., 2015). Figure 9 shows the low density of digital tech specialisation in Cornwall in 2017.

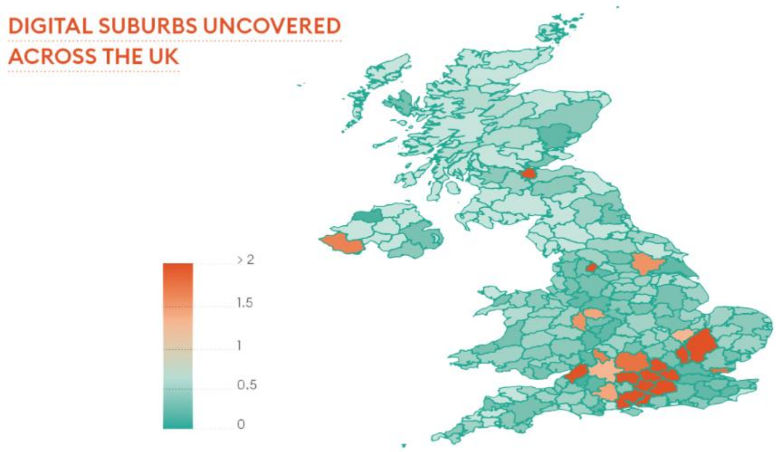


Figure 9; Digital tech density in Travel to Work Areas across the UK. Source; (Bash, 2016)

Still, the 770 information and communication business in Cornwall (Office for National Statistics, 2017) benefited from the highly developed Cornwall IT infrastructure through extensive superfast broadband coverage (Sewell et al., 2015) and took advantage of the Big Data and data sharing opportunities available (Cornwall Trade and Investment, 2017). Furthermore, Cornwall already had national projects and initiatives in the eHealth sector (e.g.: Cornwall Innovation, 2017; Cornwall Trade and Investment, 2017; ECEHH, 2017; NIHR, 2017; Royal Cornwall Hospitals NHS Trust, 2017; SBRI Healthcare, 2018).

3.4.2.2 Market Drivers

The main market drivers for the creation of an AR market in Cornwall were demographic, and healthcare challenges faced by the region. They brought several opportunities to the creation of AR businesses due to naturally clustering market users.

3.4.2.2.1 Population Overview

Cornwall has an ageing population well above the national average by 18% that keeps increasing (Public Health England, 2017). Of the 553,687 people living in Cornwall in 2016, around 20% were under 18, 56% aged 16-64, and 24% aged 65 or over (*Figure 10*) (Office for National Statistics, 2012). The ageing group will continue to grow by 2020, whit an increase of 18% of the population aged over 25 (*Figure 11*) (Institute of Public Care, 2015).

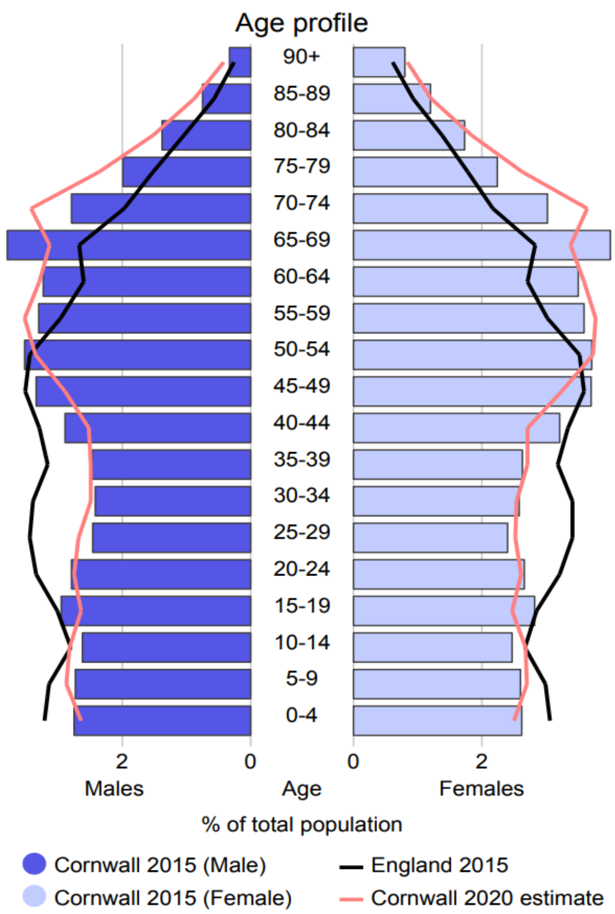


Figure 10; Age profile of Cornwall. Source; (Public Health England, 2017)

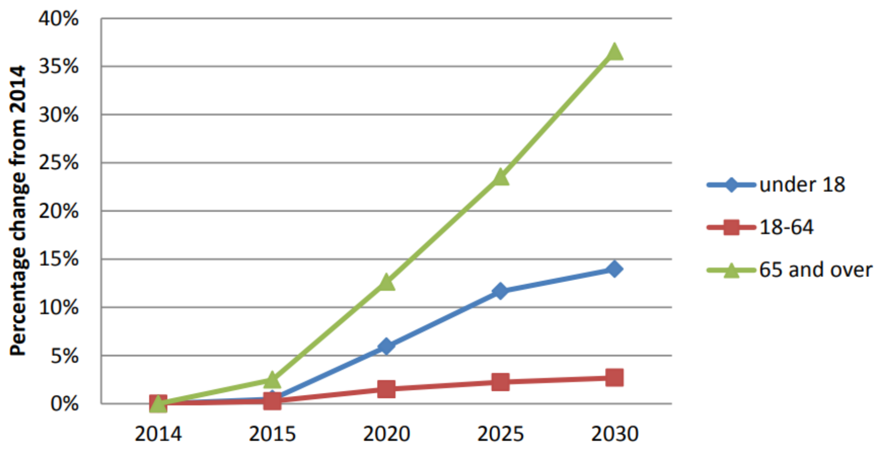


Figure 11; Population projections for Cornwall. All people, from 2014 to 2030. Source; (Institute of Public Care, 2015)

It is also important to mention that the dependency ratio of Cornwall, the relation between dependants and the working population, was of 73.4% by 2015, 13% higher than the average in England (Public Health England, 2017). All of this clearly showed that Cornwall was and still is facing the challenges brought by the increase of the senior population more than most counties of the UK, challenges that will intensify with the years to come. However, this also promotes the region as an ideal location for companies working in the 'silver sector' (Amion Consulting, 2015).

According to the Office for National Statistics, Cornwall's population density is one of the lowest in England at 1.5 persons per hectare (Office for National Statistics, 2012). Compared to the rest of Europe (*Figure 12*), Cornwall is considered a thinly populated area, where more than 50% of its population lives in rural grid cells; less than 300 inhabitants per Km^2 (Eurostat, 2015). As seen in Figure 12, Cornwall shares this characteristic with most of the EU. Together with the senior population, it is a factor to consider for the scalability of the AR Technology Strategy.

3.4.2.2.2 Health Overview

In 2017, According to the Cornwall Health Profile 2017 published by the Public Health England agency, the local priorities in Cornwall were "*reducing smoking, physical* *inactivity, unhealthy diets, excess alcohol, and lack of social connections*" (Public Health England, 2017).

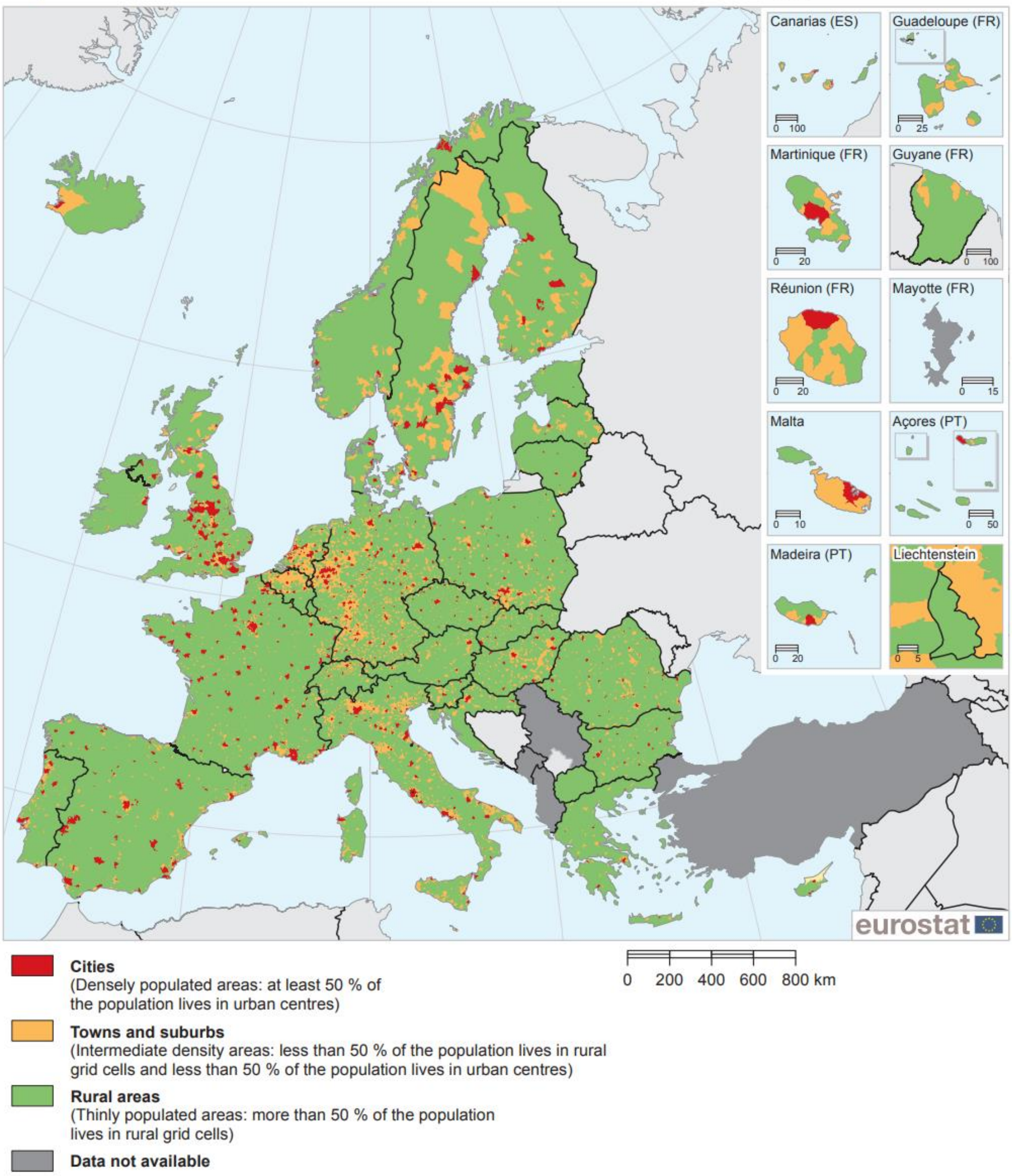


Figure 12; EU Degree of urbanisation. Source; (EUROSTAT, 2015)

With a male life expectancy of 79.6 years and a female of 83.4 years, the majority of deaths in Cornwall were due to "cardiovascular diseases, cancer, mental illness, lung diseases and musculoskeletal problems" (Public Health England, 2017). Deprivation and inequality were also some significant concerns. In the most deprived areas life expectancy was 6.6 and 5.1 years lower among men and women respectively than in the least deprived areas (Public Health England, 2017).

According to the 2012 Census, 11.9% of the population provided unpaid care to a family member, neighbour or friend (UK Office for National Statistics, 2013). The 2012 census also reported that one in ten residents declared that long-term health problems or impairment "*limited a lot*" their day-to-day activities (Cornwall Council, 2015).

Due to Cornwall's older population increasing well above the national average (Cornwall Council, 2015; Public Health England, 2017), there is a local imperative to find cost-effective solutions for this segment. The share of individuals with dementia will grow, from around 9,000 by 2015 to about 15,000 by 2030 (Institute of Public Care, 2015).

Finally, Cornwall has the Royal Cornwall Hospital Trust, formed by three hospitals; Royal Cornwall Hospital, in Truro, St Michael's Hospital, in Hayle, and West Cornwall Hospital, in Penzance (*Figure 13*). According to the 2011 Cornwall Infrastructure Delivery Plan, across these three hospitals, there were about 750 beds and around 5,200 staff. In the same delivery plan, they identified an increase of outpatient attendance by 15%, and the number of day surgery procedures by 17%, from 2007 to 2011 (Infrastructure Delivery Plan Secretariat, 2011).

Cornwall had more than 350 registered care providers, of which 66% were care homes, and the rest gave domiciliary care (Institute of Public Care, 2015). There were 73 general practices in Cornwall (Cornwall Council, 2017).

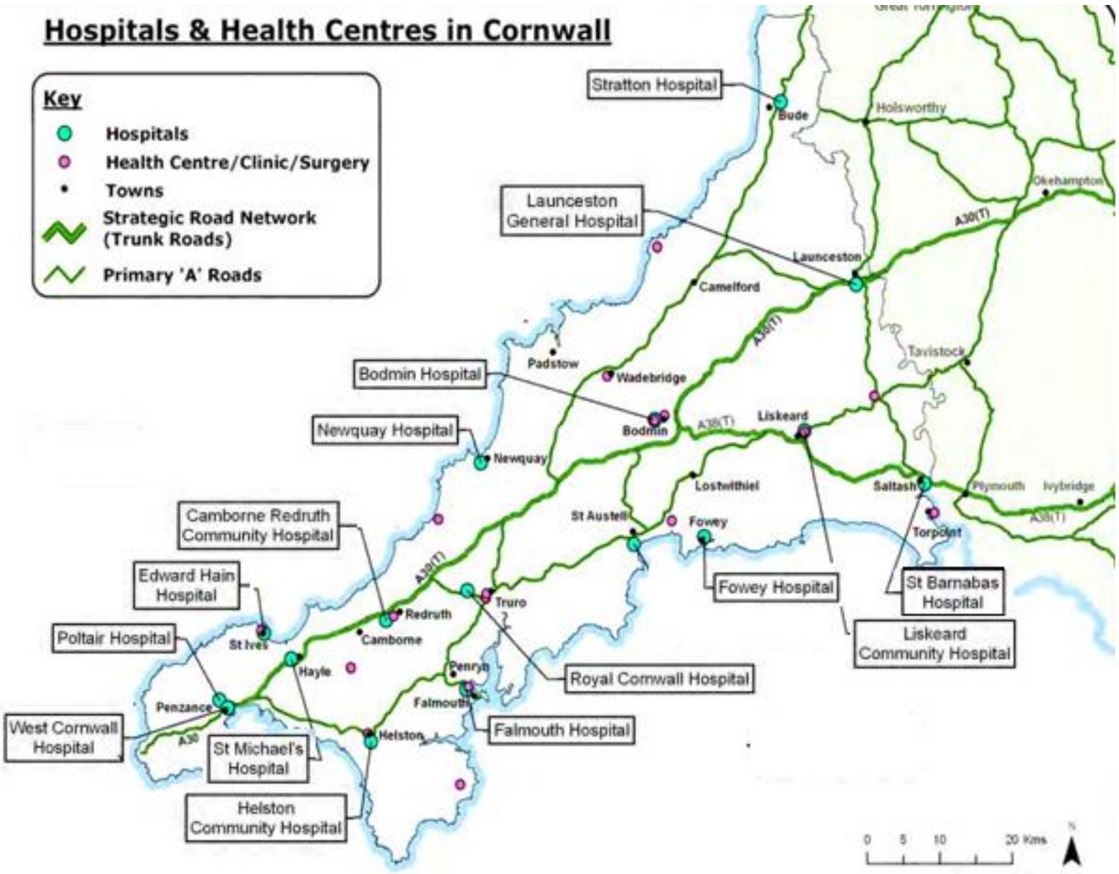


Figure 13; Hospitals and health centres in Cornwall. Source; (Infrastructure Delivery Plan Secretariat, 2011)

3.4.3 Entrepreneurial experimentation

In general terms, in 2017, entrepreneurship in Cornwall (understood as new venture creation) did not seem like an attractive career option, and the number of technology start-ups was so low it could not be measured (Bash, 2016). Figure 14 shows the growth stage of technology companies in the UK. The region was lacking mainly in methods and incentives for attracting and retaining talent (Bash, 2016). This translated into a skill gap to support the mainstreaming of new technologies for health and social care (Neck et al., 2004).

However, through my entrepreneurial programme (*Chapter 5*), I noticed an overall high-motivated spirit from potential entrepreneurs. Graduates and undergraduates students that are willing to engage in high innovation ventures, from AR to wearables, to augmented reality and AI applications. Future entrepreneurs with a marked desired of starting new businesses and confident in their technical skills. This represented the human talent of the market that needed to be supported to start delivering inventions for the healthcare sector (Feld, 2012).

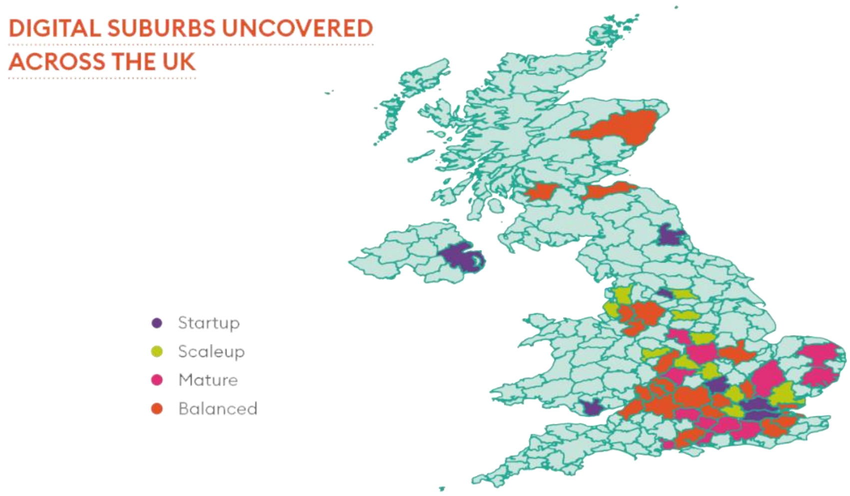


Figure 14; Growth stage distribution of companies in Travel to Work Areas across the UK. Source; (Bash, 2016)

During the mentioned programme, I also experienced a lack of business knowledge and understanding of the healthcare sector from potential entrepreneurs. In addition, most of them ignored the opportunities in this sector (*Chapter 5*).

Entrepreneurship and innovation have become the ultimate intangible asset of companies and governments worldwide (OECD, 2010). It is considered a strategic asset to improve competitiveness (Spinosa et al., 2015). If successful, innovations can improve our standard of living while empowering the economy (OECD, 2010). They contribute to employment and productivity of nations (van Praag and Versloot, 2008). Supporting entrepreneurs and innovation will profoundly affect Cornwall's economy, which is similar to other less developed regions in Europe (*Figure 15*).

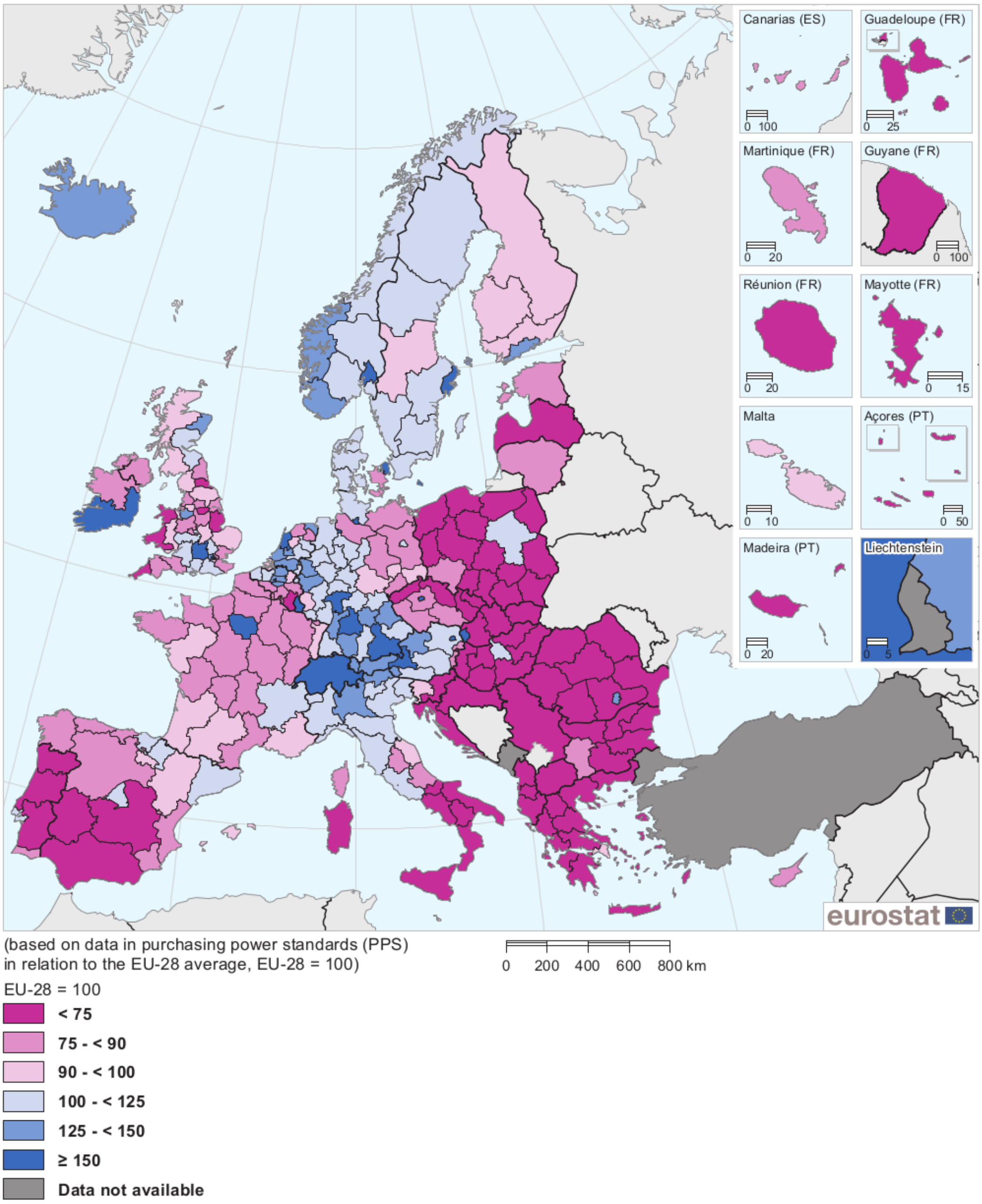


Figure 15; Gross domestic product per inhabitant, 2016. Source; (Eurostat, 2018)

3.4.4 Legitimation

Legitimation refers to social acceptance and compliance with the relevant institution (Bergek et al., 2008). The attitudes and beliefs of the healthcare sector are reviewed in Chapter 4. As an overview, Cornwall’s healthcare sector prior to the intervention was not aware of the AR market, its opportunities and the role they played in the co-creation process of potential solutions (*Chapter 4*). In addition, this lack of awareness was followed with distrust towards AR technologies due to current pop culture and media references (e.g., “AI world control”).

In terms of the alignment between the AR market and current legislation, there is a substantive issue; there is no regulation for the AR sector (*Chapter 6*). There was no regulation when I started the work, and there is still no regulation while writing this thesis. Regulation that is needed for the design and development following standards and good design practices, for the critical evaluation of the health outcomes of AR prototypes and the certification of AR products. Ultimately, there is a need for regulation that will support the adoption of AR technologies.

This thesis makes an emphasis on this issue, explains the implications throughout the next chapters and shows how unprepared the healthcare system is towards any high-tech venture. This is still a challenge that inhibits the market to achieve its potential and is the obligation of the robotics community to raise awareness of this issue[3].

3.4.5 Resource mobilization

In 2017, Cornwall had different sources of grant funding for innovation projects, mainly through ERDF schemes such as EPIC, Acceleration through Innovation, SmartLine, Agritech, to name a few. These funding targeted SMEs. However, while grants are an attractive option, they do not offer the same benefits as venture capital (VC) or investment sustainability (Sun et al., 2018). Therefore, while there were options for AR; there was not a current sustainable source of capital.

[3] The 29 of January of 2019, I raised this issue in the Ageing Fit conference in the context of my presentation of *“Looking ahead to Silver care market access strategy and regulatory constraints”*. The conference was held in Nice, France, and it hosted more than 500 participants, including EU commissioners and policy experts.

Even more, investment for AR in the UK was low concerning the scale and importance of the described care and health challenges (Wirtz et al., 2018). It was evident that most of the robotics R&D activities came from EU funded projects via the Horizon 2020 scheme mostly targeting research-intensive centres outside Cornwall. These programmes focussed on technical development and had poor market penetration (Veugelers et al., 2015).

From a national context, InnovateUK, a non-departmental public body part of the United Kingdom Research and Innovation organisation, has been financing the development of robotics projects (InnovateUK, 2015). For example, in July 2016, InnovateUK opened its funding competition for robotics and autonomous systems applications (GOV UK, 2016). The competition required applicants to involve at least one SME. The investment was up to £5 million, and the aim was to stimulate new public-private partnerships across robotics and autonomous systems.

Neither the 11 projects funded under £100k, nor the 12 projects funded over £100k target the healthcare sector as their main project application/beneficiary. Besides, perhaps unsurprisingly, from the 23 robotic projects, none were led by an SME from Cornwall (GOV UK, 2018, see *Annexe K* for a summary of the projects).

However, funding programmes for start-ups start to rise, for a sector that is technological and capital intensive (Bahrin et al., 2016). As the Robotics in Healthcare Final Report outlines; *"Funding from governmental institutions is needed to create a grown market"* (Butter et al., 2008).

In terms of human resources, there is a support infrastructure for innovation, research and development in health tech in Cornwall, which is well defined (Amion Consulting, 2015). This can be evidenced by the universities in the region, and organisations such as Royal Cornwall Hospital Trust, and valuable networks beyond Cornwall such as NHS Innovations South West, the National Institute for Health Research Collaboration for Leadership in Applied Health Research and Care, and the South West Academic Health Science Network.

3.4.6 Development of positive externalities

We have established that the AR market is an emerging market. Therefore, there were no established external resources for the development of this sector. In 2017, there were no specialised intermediates that supported the development of AR in the UK.

While the UK-RAS network raised awareness about the opportunities of this sector (UK-RAS, 2017), as a scientific network, it could not develop and implement the AR market in the UK. On the other hand, organisations such as the Academic Health Science Network or the National Institute for Health and Care Excellence were prioritising the development of the digital sector (Winter, 2016). For instance, if you visited the National Institute for Health and Care Excellence website in 2017, a UK organisation in charge of evaluating the quality and advice about services for health, public health and social care, you were unable to find any recommendation regarding AR technologies.

In 2017, there were no initiatives or ongoing governmental programmes to nurture the formation and development of the AR market. In 2014, InnovateUK announced a Robotics and Autonomous Systems Strategy for robotics in general, i.e. not sector-specific (Clark, 2015). The Engineering and Physical Sciences Research Council, through their Healthcare Technologies Grand Challenge, identified robotics in health and social care as a critical area for development and investment (EPSRC, 2017). However, nothing concrete was proposed.

Finally, while in major tech clusters around the world, we saw a few new AR firms (SPARC, 2014), they did not have any influence on other regions. In 2017, most of the AR start-ups were trying to establish themselves in their region. Section 3.2 has already mentioned some of the reasons behind this lack of market traction. Chapter 5, which focused on the work with the producer sector, explores and describes the current market barriers.

Finally, while research in the UK around AR is state-of-the-art, leading robotic platforms for the sector can be found in Japan and the US (Butter et al., 2008; EURobotics, 2014). For instance, big multinationals such as SoftBank Robotics have been encouraging entrepreneurs to develop applications for their NAO and Pepper robots (SoftBank Robotics, 2017). This also included applications in the healthcare sector. For example, the Spanish company Yasyt with their Pepper app for geriatric centres, or the UK company Emotion Robotics with their Nao app to assist children with autism to improve communication (SoftBank Robotics, 2017). However, no promotion was undertaken in Cornwall from this or other big tech companies.

3.5 Conclusion

The AR market is an emerging market worldwide, where a number of small players located mostly in the most significant technology clusters in the world are pushing new solutions into the healthcare sector. There is limited evidence of R&D projects that move into new products and services for the public. The knowledge development is limited to the scientific/technical field. However, whit the primary role of providing assistive help to carers or directly to patients, in hospital, specialist care facility or domestic healthcare settings, the global AR market (surveillance and security, humanoid robots, rehabilitation, socially assistive) has an 18.9% compound annual growth rate estimation for the 2016 to 2024 period.

The AR market is fundamentally different from any other sector. For instance, AR builds upon the nascent human-robot interaction field (Dahl and Boulos, 2014); robots that interact physically with their user, continuously and autonomously monitoring their condition, while supporting them in different wellbeing activities. These are robots that could have an impact on the mental health of users, impact that is subject to the level of autonomy of the technology (Zubrycki and Granosik, 2016). Furthermore, the AR market also requires hardware design and production, increasing the ventures' challenge, development time, investment and risk. As a result, the AR market has different market barriers for firms and developers.

However, following our engagement with the producer sector (*Chapter 5*), it was evidenced that governments, regulatory agencies and funding organisations have been treating AR development as app development, hampering innovation. As a consequence, the market today requires a clear certification path, evaluation procedures and critical appraisal tools.

The findings from the TIS analysis were conclusive: due to the state of AR worldwide, I did not expect that a region such as Cornwall had any presence of the market (firms or products). Even more, Cornwall's current entrepreneurship landscape and low digital tech density were adverse for the AR field. Entrepreneurship in Cornwall did not seem like an attractive career option and the number of technology start-ups was so low it could not be measured (Bash, 2016). Overall, the region was lacking mainly in methods and incentives for attracting and retaining talent (Bash, 2016).

However, as described in this chapter, due to Cornwall's population profile and healthcare challenges, characterized mainly by the growth of the senior population, the region had positive drivers for entrepreneurship. In addition, the region had EU funding opportunities to support the development of new businesses.

Other regions might have the same characteristics. For instance, due to the global landscape of the sector, we do not have AR clusters in most regions. Consequentially there has also been an absence of mechanisms to support innovation development in the field. In the same way, Cornwall's demographic population, healthcare challenges, and overall gross domestic product are still similar to most underdeveloped regions in the EU as exhibited in this chapter. Therefore, these regions could also benefit from the development of an AR market, to foster innovation while addressing healthcare challenges and empowering their local economy.

The findings from the TIS analysis allowed this thesis to build a Strength, Weakness, Opportunities and Threats (SWOT) profile for the AR market in Cornwall (*Table 3*). The purpose of the SWOT profile is to create a baseline for public and private economic and healthcare development organisations, as well as universities and research centres, which want to start the AR market in their regions through the AR Technology Strategy presented in the thesis. The implications that the SWOT elements have over the AR market have been discussed throughout this chapter.

Table 3; Strengths, weaknesses, opportunities and threats analysis of Cornwall before the intervention.

Strengths	**Weaknesses**
• Positive UK policy towards entrepreneurship • A cluster of customers and potential customers (lead users) • Initial national and EU policy drivers for robotics • Active participation of charities and voluntary sector organisations. • Knowledge and research infrastructure (universities and research centres) • Awareness of the health/institutional challenges among HCOs and government • Funding opportunities that could be used for AR ventures	• No AR firms in the region (examples for entrepreneurship) • Missing tech cluster (low digital tech density) • Lack of AR awareness from the healthcare sector • Government prioritising the healthcare digital sector • Absence of innovation infrastructure (e.g.: prototyping labs) • Constrained mindfulness among businesses of the market opportunity • No current strategy and regulation for the AR market • Gaps in skills availability from producers • Lack of talent retention policy and initiatives in the region • No distribution channels for AR • No perception of the region as an innovative region
Opportunities	**Threats**
• Public pressure to improve healthcare service delivery • IoT, big data and AI developments and opportunities • Achieve early adoptions by implementing available technologies in the global market (e.g.: telemedicine) • Develop a testbed for AR applications • Attract external AR firms by promoting potential consumers • Opportunities from the global spread of digital tech (e.g.: internet, mobiles) • Start collaboration programs between market stakeholders; pilots pathway for academia to accelerate technology adoption and play a central role in the market	• Data governance and lack of regulation for AI • Significant investment requirements for AR development • Need for technology manufacturers and suppliers for the development of AR components and prototyping equipment • Long development process for AR • Financial and managerial pressures for companies • Healthcare fragmentation inhibits AR projection to other users/organisations/regions • Absence of subsidising schemes for HCOs to adopt AR • Uncertainty with current product regulation policies

The AR Technology Strategy proposed builds upon the weakness and threats of the region and the market barriers identified from the engagement with AR companies presented in Chapter 5. If a region counts with any added value (strengths and opportunities), the AR Technology Strategy could also be used since it will benefit from these positive characteristics. Hence, any region with any other resource to the overall innovation infrastructure could also implement the AR Technology Strategy of this thesis. However, if the region does not count with the strengths detailed, mainly a policy that supports the creation of businesses, it is imperative to focus on these deficiencies first.

The UK's current regulatory framework towards start-ups and business ranked the country 8th out of 190 in the ease of doing business index (Kolb, 2018). Depending on their regulations, other countries could (more likely) rank below. This will impact on the applicability of the AR Technology Strategy since, to start this market, the strategy relies on entrepreneurship (*Chapter 6*). If a country imposes barriers to the creation of companies (e.g.: long waiting times for company registration, registration fees, taxation without incomes) these will ultimately impact entrepreneurship and inhibit any emerging market in general (Thurik, 2009). Then, alternatives should be explored to address this national productivity issue first.

In addition, funding is another challenge. Even though the AR Technology Strategy presented does not rely upon financial investment, it is absolutely clear that without seed funding opportunities ventures will not be able to take off. As evidenced in this chapter, the UK offers funding opportunities to SMEs to develop their business through R&D activities that, even though sometimes do not target the AR sector in particular, could be used to support these ventures.

While the EU countries also have access to funding opportunities such as Horizon 2020 or ERDF funding, it could be the case that the producer sector will not count with the same local funding opportunities. Thus, alternatives have been presented in the thesis to support regions and AR start-ups to overcome this threat (*Chapter 6* and *Chapter 7*). Ultimately, by building regions that support innovation, funding will follow (Mulas et al., 2015).

Finally, the recommendations given for the conceptualization, development and evaluation of AR presented in Chapter 7 can be followed by companies disregarding their region. These guidelines were built from the engagement with companies working in different countries and on the technology requirements.

Chapter 4

CAR cycle: Healthcare sector

For this cycle, I adopted a *Technology Innovation Adoption* approach. This method studies the process that takes place when organisations implement new technologies. By doing so, it provides adoption frameworks applicable to different domains that spread innovation at pace and scale.

I engaged with Cornwall's healthcare sector through:

- eight workshops,
- 35 knowledge awareness events,
- four co-creation and evaluation activities.

This first cycle studied and intervened during the first stage of the AR adoption process. The aims were to:

- Identify the current state of AR with our healthcare sector.
- Raise awareness of AR and its benefits.
- Change negative attitudes and beliefs towards AR.
- Understand users' needs and challenges for AR.
- Explore collaboration opportunities/mechanisms.

4.1 Background

There is an extensive body of research in technology implementation and adoption in the healthcare sector. For instance, Ross et al conducted a systematic review of systematic reviews of the factors that influence the implementation of eHealth (Ross et al., 2016). Forty-four systematic reviews were identified, from 2009 to 2014, with a broad range of technologies. Factors such as development, purchasing and installation cost have been reported as the main implementation factors by several studies (e.g.: Zhang and Shahriar, 2020; Christodoulakis et al. 2017; Police et al, 2011; Botsis and Hartvigsen 2008). In addition, technology adaptability and interoperability is still a major barrier to the implementation of eHealth solutions (e.g.: Goldstein et al, 2014; Alvarado et al, 2017). However, healthcare stakeholders' access to knowledge and information has been seen as the backbone enabler for the implementation of systems across all eHealth domains (Ross et al., 2016). For example, education was reported to increase staff acceptance and usability (e.g.: Inversen and Ching-to, 2020; Tsai et al., 2019; Oluoch et al, 2012). For Cornwall, as explained in this chapter, education represented the main objective of the intervention with the sector.

This vast body of knowledge comes from models that study how users come to accept and use a technology based on different factors such as technology attributes, contextual factors, effort expectancy, social influence and more. A plethora of theoretical models have been proposed (Dwivedi et al., 2019), some dating from 1977 (Fishbein and Ajzen, 1977). Take, for instance, the Theory of Reasoned Action (Ajzen, 1991), the Technology Acceptance Model (Davis, 1986) or the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003). These are models that analyse user intentions to use a technology and their usage behaviour. Through them, researchers have studied the perception of individuals to mobile services, online social support, e-learning programs, and other different technologies, and have presented the different barriers and challenges for the adoption of the technologies. Even more, recent models have emerged describing technology acceptance by specific target user (e.g.: the senior technology acceptance model; Chen and Chan, 2014).

Beuscher et al. used the Unified Theory of Acceptance and Use of Technology model for capturing older adults' likelihood to use social assistive robots (Beuscher et al., 2017). The study found that overall the evaluated robot was well accepted, with research participants positive rating the robot's understanding, voice, hearing, engagement and appearance. Lee et al. used the technology acceptance model to study 79 older adults acceptance to a soft service robot in the home environment, finding positives indicators around perceived ease of use and perceived usefulness (Lee et al., 2020). These are some examples of knowledge development and diffusion in the field described in Chapter 3. While these studies have supported the development of better AR platforms and the understanding of barriers to adoption in different scenarios, they do not provide a framework to support the creation of the AR market.

It is also worth mentioning the work carried by the 3-year Consumer Models for Assisted Living project funded by Innovate UK (COMODAL, 2014). This project aimed to support the development of a consumer market for electronic assisted living technologies for younger older people (people aged 50-70). The COMODAL study showed the need to focus on the technologies and the markets created for those technologies. Understanding this will support the further development and adoption of technology solutions for healthcare. COMODAL contributed to the field by providing a deeper understanding of their target consumer needs, a complete business model for their target companies, and the identification of the consumer journey in their target market, from finding a product to its purchase (COMODAL, 2014).

Besides, some studies have described how to accelerate technology adoption in the NHS. Take, for instance, the SBRI Healthcare and their annual reviews for bringing new technologies to the NHS (SBRI Healthcare, 2018). The reports comprise a series of case studies around different technologies and their path in the NHS adoption process. Nevertheless, these studies only describe the process and share relevant recommendations for product developers and relevant healthcare stakeholders. They do not study how innovative markets for the healthcare sector could be created and supported.

As explained in Chapter 2 and Chapter 3, this CAR cycle aims to understand where Cornwall's healthcare sector is in the AR adoption process and intervene to support the process towards building an AR market in the region. Robert et al. claim there are two general methods of studying innovation adoption and assimilation of technology: the stage and the process approach (Robert et al., 2009). The stage approach treats innovation as an asset that moves through several standard and sequenced stages, ending in the innovation used in an organisation. The size or features of the organisation constitute the adoption variables and will define the adoption rate. Conversely, the process approach sees innovation adoption as an iterative, complex and multi-directional process. Traditionally, healthcare adoption research has predominately taken the first approach since it allows researchers to analyse adoption in a sequence of ordered stages for an already complex organisation (Robert et al., 2009). Therefore, this CAR cycle has also implemented the stage approach.

Authors have defined distinct phases for the stage approach (e.g.: (Hage and Aiken, 1967; Klein and Sorra, 1996; Zaltman, Duncan and Holbek, 1973)). From a general perspective, Frambach and Schillewaert distinguished three main stages: initiation, adoption decisions and implementation (Frambach and Schillewaert, 2002). Robert et al., building on previous experience from mentioned studies, also establish three stages: knowledge awareness, evaluation choice and adoption (Robert et al., 2009). The CAR cycle follows the model of Robert et al. for its consideration of previous research (*Table 4*).

Table 4; Robert et al. model for innovation adoption. Source; (Robert et al., 2009)

Decision-making stage		Characteristic	Rationale	Eventual adoption
Knowledge Awareness	1. Apprehension: individuals learn of the innovation's existence 2. Consideration: individuals consider the innovation's suitability for their organisation 3. Discussion: individuals engage in conversations concerning adoption	Submission of a formal, written request for the allocation of capital funds to purchase given technology Informal information gathering, evaluation and choice among individual participants (primarily physicians)	Clinical	A good fit between technology and interests/abilities of physicians High observability of impact on patient care
Evaluation-Choice	4 Acquisition proposal: it is formally proposed to purchase the equipment that embodies the innovation 5. Medical-fiscal evaluation: medical and financial costs and benefits are weighed up 6. Political-strategic evaluation: political and strategic costs and benefits are weighed up	Programmed organisational decision-making Bureaucratic decision-making	Fiscal; political	Low capital budgetary complexity Decentralised capital budgeting Less rigorous financial analysis Less pluralistic forums (i.e. a less political process) Long CEO tenure, high CEO educational level and high CEO support Younger medical staff Higher specialisation in medical staff
Adoption	7. Trial: the equipment is purchased but still under trial evaluation 8. Acceptance: the equipment becomes well accepted and frequently used 9. Expansion: the equipment is expanded or upgraded	Equipment actual arrival in the organisation	Strategic	Larger hospitals Urban hospitals Serving a higher socio-demographic population

Besides the number of stages, the characteristics of the technology play an important role. Characteristics as trialability (i.e., complexity, scale and cost), compatibility (i.e., consistency with existing values, experience and needs of potential adopters), and observability (i.e., product visible to consumers) will influence the take on of the technology (Robert et al., 2009).

As explained in Chapter 3, the AR market is still in its infancy, with few companies offering products or services to the final user. Today, there are relatively few examples of AR in use, making it difficult for many to observe first hand, and there have been few trials of its use. This places AR in the first stages of the adoption process, namely knowledge-awareness.

In addition, one of the main barriers in implementing health innovations in other domains is the lack of knowledge and understanding of the benefits of the technology by health professionals (Ross et al., 2016). Developers need to invest time and money training and educating prospective buyers about their products (Quilter-Pinner and Muir, 2015); fragmenting market trading and discouraging entrepreneurs. Plus, an additional barrier, is winning access to service user input in the design and development of technology from the industry (Goldstein et al., 2014).

Overall, due to the nature of the technology being studied, the current global AR market and the traditional barriers for the adoption of new technologies in the healthcare sector, our work with this sector should be on the knowledge awareness stage. The initial interaction with Cornwall's healthcare sector will confirm this hypothesis.

4.2 Main challenge

The first engagement with the healthcare sector was through six events in Cornwall; two residential homes, two surgeries, and two events with patient participation groups and outpatient departments. The goals of these events were to evaluate the level of awareness of AR and the opportunities they could bring to the healthcare sector. This first engagement lasted one month, from the 21/07/2017 to the 01/08/2017.

Participants were recruited and the events organised by EPIC (Jones et al., 2019). Health and social care professionals were identified and approached from a varied range of health and social care disciplines, including residential and domiciliary care, general practice, doctors and nurses, pharmacists, mental health specialists. Service users were recruited through online advertisements, newspaper articles and advertisements, support groups and public engagement events in some locations.

During these events, I presented several use-case scenarios to explain the applications of AR according to the audience (e.g.: technologies to support ageing independently, visual impairments, monitoring, video consultation), following the health overview of the region presented in Chapter 3. These scenarios were short descriptions of how some AR devices will carry out a specified task, using pictures and videos of the technology[4]. This approach has been taken by previous studies as (Lehmann et al., 2013; Zubrycki and Granosik, 2016; Martin-Ortiz et al., 2017) that also explored participants' awareness and views regarding robots. Through exploratory discussions, framed as semi-structured interviews, I asked participants if they were aware of AR solutions, and explored their views regarding the use of AR. Through this initial interaction, I discovered that, overall,

[4] An example of videos used: https://youtu.be/LBmH2anivOk

they were not aware of AR, and from initial visual observations, that they had overall sceptical initial attitudes towards AR. None of the participants had ever seen, interacted with or acquired an AR technology. Additionally, none of the care homes, assisted living housing, day centres, surgeries, hospitals or practices that I visited during the first year of the intervention had an AR device. Some of them could not understand the benefits and saw the technology as a threat to their daily work. Despite this negative impression, the public generally seemed open to listen and to consider the potential of AR technologies once shown what AR could offer. Furthermore, all of these findings were also evidenced in the eight workshops conducted in the region and detailed in the section below.

These initial findings followed our analysis from Chapter 3; there was a lack of knowledge and understanding of the benefits of AR by the healthcare sector. This lack of knowledge and information acts as a barrier to implementing innovations (Frambach and Schillewaert, 2002). They had never interacted with AR and pop culture movies have shaped their understanding and subsequent fears regarding robots. These negative attitudes and beliefs have been reported as barriers to health tech across all domains (Alkhaldi et al., 2014; BenMessaoud et al., 2011; Ross et al., 2016; Glende et al., 2016; Pino et al., 2015).

4.3 Plan and intervention

Following our initial intervention (section above) and TIS analysis presented in Chapter 3, it was evident that the AR sector in Cornwall was in the first stage of the Robert et al.’s innovation adoption model: knowledge awareness (Robert et al., 2009). In this first stage, the individuals are still learning, considering the value of and engaging in further conversation surrounding the adoption of the technology. Besides, as explained by Robert et al., our main research subjects are in the clinical sector or healthcare sector. This includes healthcare workforce (e.g.: physician, nurse, community health worker) and patients (including families).

Previous research on eHealth adoption has shown that education increases staff acceptance of health innovations (Ross et al., 2016). While access to appropriate training has been a facilitator for technology adoptions (Alkhaldi et al., 2014), practitioners' positive attitude towards health tech improved acceptance and implementation rate (Ross et al., 2016). Therefore, our main research subjects needed to be made aware as well as being educated about the current technology available in the market, of the new trends in innovation and the new procedures been driven by AR.

To achieve this, EPIC decided to conduct events to raise awareness of AR and generate positive attitudes towards the technology. The design of our knowledge awareness events was shaped following previous research on eHealth implementation (Alkhaldi et al., 2014; Groenewegen and de Langen, 2012; Hagan Hennessy et al., 2018; Winter, 2016). As a result, the knowledge awareness events needed to:

- Show participants the benefits of AR.
- Explore the usefulness of AR for the healthcare workforce (patient care, clinical outcomes and quality of medical practice).
- Increase interest and motivation to use AR.
- Reduce negative perception of AR disruption in the delivery of care.
- Reduce distrust in AR's autonomy, liability concerns, privacy and security.

In the same way, the robotics literature has shown us that allowing people to interact with AR increases user acceptance (e.g.: Glende et al., 2016; Gerling et al., 2016; Broadbent et al., 2009; Greco et al., 2009). Therefore, EPIC acquired four types of AR technologies: a) Pepper, a humanoid robot; b) Padbot, a telepresence robot; and c) Miro and d) Paro; two different types of therapeutic robots (*Figure 16*).

Figure 16; Robots used during the events. (From left) Human-like, Pepper; Animal-like, Paro, and Miro; Machine-like, Padbot.

Pepper and Paro are commonly taken as leading examples of social assistive robotics in several studies (Moyle et al., 2013; Nunez et al., 2015; Piezzo and Suzuki, 2017; Shibata et al., 2009). Miro, instead, is being evaluated for its potential as a robot home companion and its applications in robot-assisted therapy (Collins et al., 2015). Finally, we used Padbot, an example of a telepresence robot already available in the market, to explore in more depth how AR could address social isolation issues.

Roadshows have been an important tool to identify and address the public's and healthcare professionals' need for greater awareness (e.g.: Ahmed et al., 2020; Mathews et al., 2007; Parveen et al., 2017). These mentioned studies have adopted roadshows to raise awareness of different topics, from lymphedema to antimicrobial resistance. While their roadshows' materials, time, location and structure changed according to the topic, resources and audience, all of these studies reported positive results for discovering existing knowledge and understanding on a certain topic and improved participants' knowledge enhancement and retention.

Therefore, EPIC also decided to conduct roadshows in different areas across Cornwall to reach a wider audience. This roadshows promoted AR and eHealth technologies (Jones et al, 2019). The roadshows were adapted and delivered according to the partner organizations and audience involved (e.g.: iSight Cornwall, people with blind and visual impaired; Disability Cornwall, people with a long term health condition or disability; Crossroad, care home). They usually took place in large rooms where we had enough space for the robots, and where the participants were allowed to interact with the technology. During these events, we presented several use-case scenarios to explain the applications of AR according to the audience (e.g.: technologies to support ageing independently, visual impairments, speech therapy), and following the health overview presented in Chapter 3. Participants were not only health professionals or carers, but also included patients, their families and patient group representatives.

These roadshows lasted around three to four hours. They required a preparatory work, where I developed several apps for Pepper. These included simple dialogues, programmes of autonomous user greeting and a catalogue of the different assistive robots in the sector. The aim was to develop enough content for the robot to work autonomously in these events and interact freely with the participants without continued support. In addition, I also developed some practical case examples. For instance, an aerobic program for Pepper where the robot led an exercise class in front of care home residents (*video*[5]).

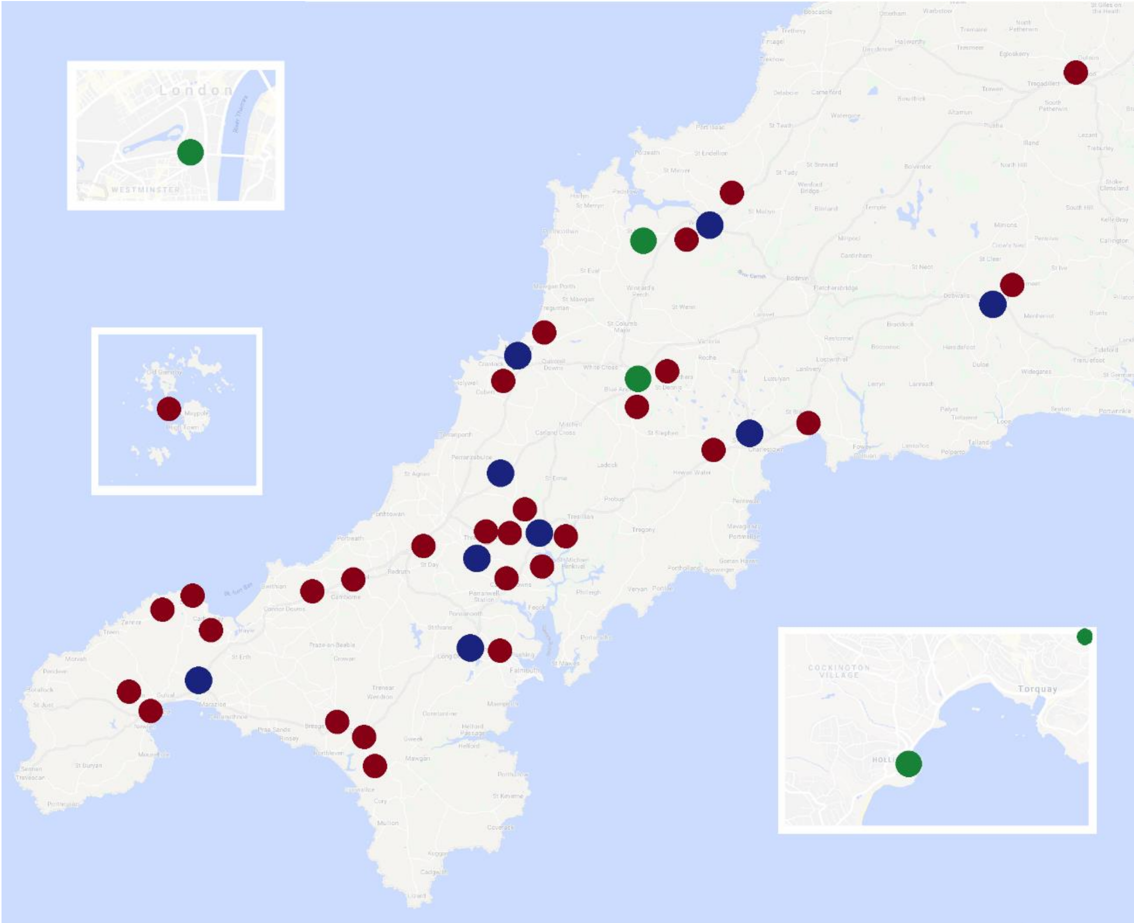
It required groundwork to discuss the participants' concerns regarding AR solutions. These concerns centred around the barriers to technology adoption, the challenges they considered robots should be solving, and where and how robots can be used cost-effectively (Riek and Howard, 2014).

Finally, during these events, I also explained the leading role that health professionals play in co-creation activities. Their role in the development process, providing entrepreneurs and start-ups their knowledge and experience to design useful, user-centred AR products (Bradwell et al., 2020). These events allowed us to encourage the healthcare sector to become more active players during the innovation process (*Figure 17*).

I was part of 35 engagement events from July 2017 to December 2019, by going to care homes, community and support centres, health conferences, disability day services, HCO conferences, among others (*Figure 18*).

[5] Link; https://twitter.com/Reflectionsw/status/959440683990962176

Figure 17; Roadshows pictures. On the right up; me and Pepper in one of our roadshows interacting with a participant with visual impairment. On the right down; in Cornwall Disability Day. On the left up; in a care home. On the left down; in a surgery.



Healthcare Engagement

EPIC Roadshow - Crossroads House Care Home
EPIC Roadshow - Liskeard Eventide Home Ltd
EPIC Roadshow - Kehelland Trust
EPIC Roadshow - Isles of Scilly
EPIC Roadshow - Isight - The Old Cattle Market
EPIC Roadshow - Oak Tree Surgery Outpatient Event Knowledge Spa
EPIC Roadshow - The Stennack Surgery
EPIC Roadshow - West Cornwall Community Rehab - Health & Community Hospital
EPIC Roadshow - Community Rayners Active Plus
EPIC Roadshow - Culdrose Community Centre
EPIC Roadshow - Spectrum's Pearl Centre
EPIC Roadshow - Active Plus Stennack Surgery
EPIC Roadshow - Isight- Alexander Hall
EPIC Roadshow - Launceston
EPIC Roadshow - Reflections
EPIC Roadshow - Coastline Housing – Redruth
EPIC Roadshow - Memory Cafe St Just
EPIC Roadshow - CRCC Event – Bodmin
EPIC Roadshow - Technology Enabled Care – Torbay
EPIC Strategic Advisory Forum Meeting – The Alverton Hotel
International Disability Day Cornwall Fire & Rescue Service HQ x 2
Kernow Health Nursing Conference – Newquay
Mental Health day - Royal Cornwall Hospital – Treliske
Proud to Care Festival – Truro
Therapeutic Robots - The Old Manor House
Therapeutic Robots - St Mary's Haven Residential Care Home
Therapeutic Robots Trevose Harbour House
Therapeutic Robots Eventide
Therapeutic Robots - Trewartha House

Others

Safeguarding Adults Board Conference – speaker - Wadebridge
Digital Technologies and Care Homes: Improving care through innovation – speaker - Bodmin
Outstanding Care Awards Devon and Cornwall 2018 - Torquay
University of Plymouth Health Research Showcase – London
ICE Innovative Care exhibition – West Point Exeter

Workshops

Workshop - The Health & Wellbeing Innovation Centre
Workshop - Tremough Innovation Centre
Workshop - Cornwall College
Workshop - Tennis Cornwall LTA
Workshop - Ludgvan Community Centre
Workshop - Liskeard Town Council
Workshop - Crossroads House
Workshop - The Exchange

Figure 18; Activities carried out during the knowledge-awareness stage with the healthcare sector.

From all these interactions, we built a network of healthcare professionals for SMEs and start-ups to access and overcome the barriers described by the producer sector (*Chapter 5*).

Additionally to the roadshows, in September 2017, we organised eight workshops to increase the involvement of recruited individuals, including discussion and identification of challenges that could be addressed by technology. The challenges identified are described in the next section, and can also be found in the paper from this study in Annexe B. Participants were recruited, and the workshops organized, by EPIC. These workshops had a technology showcase (described above) and up to five focus per workshop. In total, 223 participants with various backgrounds contributed to this study (*Annexe B*). This included participants from domiciliary care, residential care, general practice, hospital doctors and nurses, pharmacists, mental health specialists, and health-related charitable organizations.

Focus groups in which the different types of stakeholder can interact were considered the best way to explore views and identify current needs, since participants can develop their ideas together, stimulating idea generation and dialogue guided by a facilitator (Jung et al., 2017). Each group had 4 to 10 people and were facilitated by a team member from EPIC with a colleague keeping notes. The task set for each group was to identify areas where they thought that digital technologies, including apps and AR, might provide the basis of a 'solution'. The discussion lasted 100 min. From the focus groups, we identified 163 challenges.

For analysing the data collected, first, an open coding system was used on the 163 challenges to search for suggested solutions recorded that explicitly or implicitly referred to AR (Thomas, 2006). The result from this stage was a sub-list of 87 challenges.

Second, all 87 identified challenges were evaluated individually to validate that they represented possible robotic applications. Finally, we cluster the challenges into three main opportunities for AR described in the next section.

As the first author, I led the design and implementation of the research, the analysis of the results and the writing of the manuscript. EPIC member's contribution is detailed in Annex B – Acknowledgment. A summary of the paper's findings is presented in the section below, while its direct implications can be seen in Chapter 7 - Ideal market segments and development recommendations.

4.4 Findings

Due to these CAR cycle, more than 900 workshops and roadshows participants were introduced to AR and their benefits, in a process that took eighteen months. The primary outcome of the intervention was that health and social care professionals, patients and carers were willing to consider using AR in health and social care settings. This was seen to the extent of organisations adopting innovations such as Miners Court Care and Eventide care home acquiring a telepresence robot and animatronic pets.

Likewise, it was also evidenced that this first cycle also influenced healthcare authorities. An illustration of attitude-change towards robots can be seen in the following blog entry by Dr Lou Farbus, NHS Head of Stakeholders Engagement (EPIC blog, 2019a);

"I was more than sceptical about the good that the latest innovations in robotics could bring to a person's life. Moreover, after watching all the films where robots attempt to take over the world and the news reports about social media and smart televisions spying on us you could say that I was positively against sharing our lives with too much technology."

"[After a roadshow] *However, it was PEPPER the humanoid robot that really turned me into a TEC Super Fan […] I have spent many happy hours doing my own research on what other robots are available and what they can do… hoping against hope that one day there will be a humanoid healthcare assistant in my price range. In the meantime, I shall keep taking my robot cat* [Joy for all cat] *to work if only to encourage more innovation and bravery when we ask the people who provide our care to generate their own ideas for how we can improve health and care… the answer doesn't always have to be human."*

We have also seen an initial spirit of entrepreneurship among our health and social care sector, which started taking a more active role in the development of technology. This can be evidenced in the EPIC grants applications for the development of health innovations that have been led by this sector (Jones et al., 2019).

While it has been impossible to document all the reactions and further adoptions of innovations, there has been further evidence of how attitudes and beliefs changed thanks to this CAR cycle. For instance, after two years of interventions, we started to receive invitations from HCOs, day centres or housing associations asking us to deliver AR pilots in their facilities. We have HCOs that welcomed AR start-ups and technologies, and offered their knowledge and access to end-user to support these ventures (*Annex A - Case studies*; *Stevie*). Driven by the work done in the region, Akara LTD, a company from Dublin, was capable of running an evaluation of their humanoid robot Stevie in Reflections, a day centre for seniors in Cornwall. Reflections was part of EPIC's initial workshops, where their staff had the opportunity to interact and see how Pepper and the companion animals supported their residents. This played a role when I asked Reflections to take part in the Stevie evaluation.

Also, we have organisations such as Disability Cornwall supporting AR ventures (EPIC blog, 2019b), various care homes supporting the evaluation and development of new therapeutic animatronics pet (BBC, 2018), and day centres supporting the training programs of humanoid robots with their staff (BBC, 2019). From a sector that was at first resistant to open their doors to innovation, to new partners and collaborators in the development of new technologies, the change showed is encouraging.

As the Interim Summative Assessment Report prepared by Perspective Economics Limited evaluating EPIC performance until March 2019 (Perspective Economics, 2019) clearly states:

> *"Qualitative data gathered from in-depth interviews suggest that the Project is making progress in changing local awareness of and attitudes towards eHealth and social care products and services. "*

Furthermore, as previously mentioned, this first CAR cycle also explored the desiderata and challenges that healthcare professionals and service users have identified for AR in health and social care setting. An overview of these challenges has been presented in table 5.

Besides, the 8 workshops produced 33 focus groups with 163 main challenges overall, of which 78 were relevant to a robotic solution. They were analysed and classified into three main opportunities for AR; maintaining independence at home (36), social isolation (20), and rurality (22).

Maintaining independence at home included challenges around developing and maintaining the capabilities that empower all people to be and do what they value in their own homes. It was one of the leading robotic opportunities identified by workshops participants. Participants recognized that AR could support people with cognitive impairment resulting from dementia, traumatic brain injury or stroke who struggle to live independently. Examples of problems included people forgetting to turn off the oven after use, disorientation, mobility, dressing and undressing (*Table 5*). This also included people who lived with a chronic condition or disability, including people with learning disabilities.

Challenges around social isolation are those that emerge from the absence of contact between an individual and society. Isolation not only occurs because of geographic remoteness but also within care homes as recorded in the workshops. The new environment can be daunting for old people, leaving them feeling excluded from the outside world and alone, despite being surrounded by other residents.

Participants suggested solutions involving the use of social and therapeutic robots. Paro and Miro were discussed for their perceived ability to entertain the user. Participants mentioned that these robots not only bring reassurance and 'connection' but also could help calm people in distress, reducing agitation and anxiety in patients, and could motivate people and cheer them up.

Finally, challenges around rurality were those that arose from distance to services, in particular, specialist services, lack of access to care, and the sparse population served. The robotic solutions suggested were the use of telepresence robots that also enable GPs to move around freely, give them reliable images of the patients, and the option to physically interact with patients for a complete inspection. Some healthcare professionals through the use of drones useful to address challenges such as access to medicines (*Table 5*).

Table 5; Healthcare challenges for assistive robotics.

Maintaining independence at home	Social Isolation	Rurality
Accessing the bath	Starting and keeping	Platform for GPs video
Sitting on the toilet	conversations	call and teleoperation
Self-care assistant	Creating emotional links	Interactive symptom
Eating	with the user	checker
Assisting with white goods.	Reducing agitation and	Automatic GP schedule
Switching off/on devices	anxiety	appointment
Reaching things	Motivating users	Delivering information
Lifting heavy things	Bringing patients together	about the healthcare
Cleaning	Raising esteem of	system
Reminder of medication	caregivers	On-call health
Dressing	Developing user	monitoring systems
Waking-night support	socialisation skills	First aid response
Indoor guidance support	Entertaining patients and	Minor injuries response
Moving around	families together	Medication delivery and
Promoting healthy habits	Video calls services	administration
Health screening		
Mood and emotion		
monitoring		
Entertainment		

These findings allowed me to inform the producer sector (firms and developers) of user needs and requirements, ideal market segments and pertinent technology challenges. This is part of the AR Technology Strategy and presented in Chapter 7. In addition, the healthcare sector's engagement permitted the identification and the mapping of a network for the co-creation of AR technologies. The implications of these two points on the provider side are explained in the next chapter.

4.5 Discussion

While raising awareness was the goal of the cycle, the knowledge developed around the involvement of the healthcare sector in the development process has been the main contribution. It comes without saying that the best practice for raising awareness about any technology is to let people interact with it. Demonstrability is a crucial criterion for the diffusion of innovation (Rogers, 1995). We cannot appreciate and fully realise the potential, the scope and the nature of the innovation if we cannot physically test it and personally see the outcomes.

While accessing AR technologies might become a challenge due to availability or affordability, some alternatives have proven to be beneficial during this CAR cycle. For instance, AR companies are keen at looking for opportunities to promote and win presence in emerging markets. When presented with a good design plan for them to evaluate, collect feedback and display their tech solutions, companies are more willing to lend or provide devices for free.

This plan should include the locations and users segments that will interact with the devices and the methodology for collecting users' feedback. In terms of methodology, this thesis evidenced that companies prefer talking about User Experience and User Interface methodologies (i.e., Google HEART framework) and explore health economics and outcome research opportunities (*Chapter 7*).

Finally, regarding possible channels to promote technology, Twitter has proven to be a great ally for EPIC, not only for researchers aiming to disseminate their work but also for companies to detect new market segments.

During the discussion with the healthcare sector, AR promoters have to structure their conversation and arguments (*Chapter 6*). Even though AR has the potential to take over some tasks from the healthcare workforce, the aim of AR is not to replace staff or human contact. The dialogue should focus on freeing carers' time for them to spend it with the patient.

Moreover, from the work with the sector, it was evident that AR aims to bring people together, not to become their only point of interaction, following previous research as (van Wynsberghe, 2016). The need for automation is a direct response to the increase of the population and the need to deliver affordable but quality care.

The role of the healthcare workforce should also be considered. They know how to support patients; they understand their needs and the implications of any intervention. AR promoters should always remind the healthcare workforce of their importance in the development and delivery of innovations. Only then they could stop considering technology as a disruptor of their work and contribute to the technology adoption process. This was also evidenced by previous work such as (Alkhaldi et al., 2014).

Through our dialogue that promoted healthcare sector participation, we have achieved the openness described in the section above. An openness that is changing the innovation landscape, shaping the region and attracting external engagement from AR companies. While funding and policy initiatives have been used as the default mechanism for retaining and attracting businesses and entrepreneurship (Mulas et al., 2015), end-user involvement (i.e.: healthcare sector involvement) provides an alternative for the AR market. Through the work with the producer sector (*Chapter 5*), the most frequent barrier identified was access to users and healthcare professionals to support the co-creation process. When specialized knowledge in methods of care is needed for the development of AR, co-creation is a vital tool for product developers, and its input could overcome further barriers of adaptability and implementation (*Chapter 5*). Therefore, for the AR market, if the healthcare sector of a region is open to support new ventures, end-user involvement becomes a mechanism to support the market. Take, for instance, the external engagement of companies such as Akara, Pillo, Amy Robotics and Service Robotics (see *Annexe A - Case studies*). All of these companies were keen to engage with the region, thanks to the openness from their potential users.

Conversely, access to knowledge and lead users is a significant barrier for health tech companies in all domains and traditional models for co-creation solutions in the healthcare sector have been seen as ineffective (Alkhaldi et al., 2014). As a consequence, not induced or forced, but organic or endogenous participation by the healthcare sector in the development process becomes a strict requirement for the innovation environment. This free participation requirement was also evidenced by Nambisan and Nambisan in their study of models of consumer value co-creation in healthcare (Nambisan and Nambisan, 2009). However, its implication in the AR sector is higher. Due to the already mentioned long development time of AR products, which could take more than 5 years, and the funding difficulties (*Chapter 3* and *Chapter 5*), an altruistic spirit from the sector is vital for starting the AR market. Healthcare stakeholders have to realize their critical role in the AR development process, and understand that, eventually, AR innovations will support their work and patients. Their involvement will make this possible. Fortunately, as explored in the described intervention in Cornwall, awareness events can foster this organic participation. Establishing a clear path for the healthcare sector participation in the environment should be considered the first step. The challenge is to make it sustainable.

If the region does not accept the need for innovation, the ecosystem is destined to fail (Spigel, 2017). Cornwall's health challenges have put the region under pressure which is only likely to grow; however, the healthcare sector is not fully aware of this. They can acknowledge the difficulties and workload increase in care delivery that they have been experiencing in the last years. However, it was difficult to find health-tech champions, people keen to embrace, seek or ask for innovative changes. Most importantly, they do not perceive the importance and the role they play in the development process of new technologies. While teaching them about new technologies and the opportunities in the development process aims to change this, it does not make the process sustainable taking the roadshows approach since it requires an external organisation to continue investing time and resources on this. The region needs champions, leaders and innovators, in both segments of the market. People that will drive the change into their sector since they understand the reality that their region is facing.

Competition plays another vital role. I have seen that HCOs are more willing to open their doors to pilots and evaluations of AR if they perceived that others have done the same. HCOs invite AR companies to their facilities to run demos, aiming to promote among their service users their constant seek of new technologies and methods for improving their delivery of care. This starts the competition between similar service providers who want to be seen at the top of innovative care services.

Finally, while there were also AR needs and challenges raised by the healthcare sector, the reality is that there is limited or no producer and supplier segment (*Chapter 3*). The process of raising awareness turns into a theoretical task. The result is an explanation of a technology that is not there yet. Nevertheless, without this first exercise, producers and suppliers are likely to remain absent. These first steps, however tentative, are needed if the market for AR is to be developed. The ability to work with the two sides of this market, users and providers, allows me to react and start creating that needed producer sector. In this process, I turned from traditional robotics research, from those being assisted by robots to those that are building them. Hence, from this point on, the thesis will be focused on nurturing the producer sector.

Chapter 5

CAR cycle: Producer sector

In this cycle, I took the *Innovation through Barriers Identification* approach. This is a process that examines the reasons for inadequate innovation by studying the constraints or factors inhibiting new process and products (Hadjimanolis, 2003). Understanding the challenges facing the producer sector (firms and developers) allowed this thesis to build an AR Technology Strategy grounded on solving those barriers.

The main goal of this CAR cycle was to create new firms to start an emerging market in the region and attract external AR producers and suppliers. For this, I took a multilateral approach, working with current SMEs of the region, starting an entrepreneurship programme and exploring opportunities for supporting external AR companies.

In this cycle, I engaged with 28 robotic companies:

- Seven from the UK; one during the initial engagement (section 5.2), four start-ups from my entrepreneurial programme (*section 5.3.2*), and two already established companies (section 5.3.4).
- 12 from France (section 5.3.4).
- two from China (section 5.3.4)
- six from the US (section 5.3.4)

- one from Ireland (section 5.3.4)

During this cycle, I supported 58 potential entrepreneurs (section 5.3.2).

5.1 Background

Entrepreneurship and innovation drive substantial socioeconomic change to regions (OECD, 2010). However, how do we cultivate innovation? How can we make it sustainable? How can we channel it?

Entrepreneurship and innovation have been an important policy focus for decades, exploring how we can build effective policies to promote the growth and sustainability of entrepreneurship (Thurik, 2009). Strategic options are needed to create the right environment for innovation; regulations require adapting, research needs encouragement, consumers have to be trained and businesses supported (Kenney and Patton, 2005). Well-considered policies can profoundly influence such opportunities; well-designed actions can develop ecosystems that support the entrepreneur (Mulas et al., 2015).

However, first, we need to analyse the product development process and explore its inhibitors, so we can remove barriers and restore the natural path for innovation (Hadjimanolis, 2003). *Innovation through Barriers Identification* analyses any factor that influences negatively the innovation process (Hadjimanolis, 2003). Barriers identification is particularly useful for cutting-edge technologies and new markets (Painuly, 2001). Besides the analysis of the market functioning presented in Chapter 3, interaction with market stakeholders is the main requirement to identify barriers (Painuly, 2001).

Studies can perceive barriers in different ways (Hadjimanolis, 2003). For instance, if the study identifies barriers around the technology state-of-the-art, it takes a *research and development* perspective (Owen, 2006). Most of the literature available around AR case studies focuses only on these elements of innovations. For instance, (BenMessaoud et al., 2011; Greco et al., 2009; Yusif et al., 2016) explored the needs and perceptions of AR innovations. Others described the development of platforms and its acceptability among users (e.g.: Kanda et al., 2004; Kristoffersson et al., 2013; Shibata and Wada, 2011; Zubrycki and Granosik, 2016). Finally, numerous studies describe technology roadmaps for the development of AR and main research challenges (e.g.: Butter et al., 2008; EUrobotics, 2017).

These studies emphasise soft elements of innovation since they do not consider the development of AR as a *market-transformation* process; the implication of producing the technology from concept design to the commercialisation in a real market context (Butter et al., 2008). We need to understand that the application of robotics in healthcare is not only an issue of technology or societal acceptance. Special attention has to be paid to broader market barriers such as market failure, financial or institutional barriers, and ways to overcome those (EURobotics, 2014). Entrepreneurs and businesses find it difficult to navigate this market due to challenges that have not been studied and addressed with consequences for the market and the healthcare sector.

Therefore, to address this challenge, through this CAR cycle that focused on the development of the AR producer sector, I explored the innovation barriers from a *market-transformation* perspective. This allowed the thesis to understand the overall process, drivers and challenges that influence the emergence of a new technology (Painuly, 2001).

5.2 Main challenge

In Chapter 3, I explained that in 2017 Cornwall did not have any AR companies. There was a lack of producers, suppliers and system integrators for the AR market. Following an extensive search at the UK Company House, the only two robotic companies in the region (Engineered Arts Ltd and Cyberstein Robots Ltd) were far from working in this sector.

The 13 December 2017, EPIC director Ray Jones and I had a meeting with the CEO of one of the companies to discuss any possible involvement of the company in the healthcare sector. However, his position was clear, the region did not have the conditions required for AR companies to flourish.

In part, this was a result of the identified challenges facing Cornwall and the current global AR market (*Chapter 3*). Nevertheless, the complete absence of AR firms also evidenced the lack of awareness of the opportunities of the market. In the same way as the healthcare sector was unfamiliar with the benefits of AR (*Chapter 4*), SMEs and entrepreneurs from the region were unaware of the market opportunities. However, while there is grounded research on the health benefits of AR, there are few examples of successful AR companies (*Chapter 3*).

5.3 Plan and intervention

The main goal of this CAR cycle was evident; create new firms to start an emerging market in the region, while exploring the barriers of this intervention, and therefore barriers to entering the AR market more generally. To achieve this goal, several other factors needed to be considered and several others arose from the intervention. This chapter explains these challenges.

The CAR cycle started by raising awareness of the challenges and opportunities of AR among the digital companies of Cornwall. Then, I aimed to support innovators through an entrepreneurship programme. Finally, I explored the collaboration with external companies.

5.3.1 SMEs diversification plan

From July 2017 to June 2018, I promoted diversification activities to AR among current companies from Cornwall. By sharing the benefits of the market and offering companies opportunities to explore and develop new services and products, including the funding through the EPIC project (Jones et al., 2019) and access to lead users and healthcare organizations (HCOs), I planned to attract firms to work in AR projects.

This was achieved through several events that were attended in the region (*Figure 19*), raising awareness of the AR market opportunities for the producer sector. For instance, in March 2018, I attended the Cornwall Business Show where, through a stand EPIC had on the event, I had the opportunity to interact with more than 100 business participants.

This also included the workshops events carried out in September 2017 (*Chapter 4*), and two business conference organized by EPIC in November 2017 and April 2018 (Jones et al., 2019). Finally, I had also meetings with different firms from Cornwall (*Figure 19*).

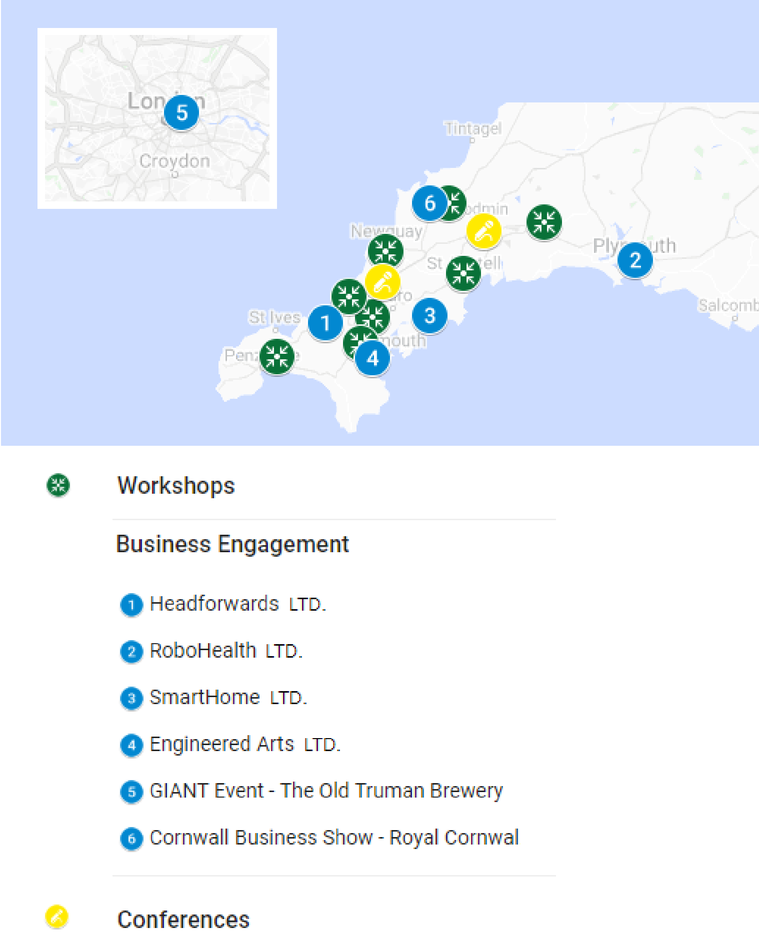


Figure 19; SME engagement events carried out during 2017-2018.

In addition to this face-to-face engagement, during May 2018, through an email programme, I contacted over 130 digital companies, digital designers and free-lancers identified by using business directories from Cornwall. Most of these individuals worked in software development activities, the closest industry in the region to RAS. Through this contact, I promoted the opportunities of AR and the eHealth sector in general.

However, I did not find a good reception from current businesses. Until September 2019, I did not get any SMEs from the region willing to start a project in the AR field. Many companies opted to start projects in the eHealth sector (Jones et al., 2019), but none of them in a robotics project.

This shows that firms are not willing to change their current business model goals for high-tech innovative ventures (Dyer et al., 2008). This might have been caused due to the state of the current AR market worldwide, the lack of successful AR examples in the region or the high-tech element of the ventures (*Chapter 3*). However, it showed that the intervention needed to explore other paths, entrepreneurship.

5.3.2 Start-ups programme

When the response from current businesses in the region was not positive, more work was put into the entrepreneurship side. As explained in Chapter 4, the process of raising awareness to support the adoption of AR turns into a largely theoretical task if there are limited or no producers or suppliers in the region. It was clear that I needed to work with a framework that could support the creation as well as the traction of AR markets; a Technology Strategy in other words. The intervention in Cornwall aimed to create an AR market and, through this experience, develop a Technology Strategy for building and orchestrating the creation of AR markets in other regions. Therefore, if existing businesses in the region did not want to be part of this, alternatives needed to be sought. On this basis, entrepreneurship formation was worth exploring. Previous studies in innovation and market formation have concluded that entrepreneurs can contribute by performing gap-filling (i.e. making up for market deficiencies) and input-completing (i.e., improve the efficiency of existing production methods or the introduction of new ones) functions (Hausmann and Rodrik, 2003; Spigel, 2017; Szirmai et al., 2011) and by supporting regional structural change (Gries and Naudé, 2010; Fischer and Nijkamp, 2009). As a result, I decided to design and run the EPIC Start programme to provide the region with its first AR companies and equally to raise awareness of the benefits and opportunities of the AR market.

This entrepreneurship programme had the aim to support students and graduates from the University of Plymouth creating and running their AR businesses. The programme adopted best standard practices from known start-up incubator programmes such as 500 Startups (Bonzom and Netessine, 2016), and (Google for Startups, 2019), and adapted them to the resources of EPIC. The programme also implemented the best practices for business incubators detailed by (Lewis et al., 2011). Finally, I also reviewed the RobotUnion programme structure that supports the creation of robotics companies for different industries in Europe, including the healthcare sector (RobotUnion, 2020).

The programme was structured as an iterative model (*Figure 20*). Each potential entrepreneur followed the programme that aimed to define the project proposal, partner entrepreneurs with relevant lead users, and apply to EPIC grant funding. For this, I developed an interactive manual for the programme participants to understand the process, including information on how to set up a business, how to develop a business model, other EU funded projects in the region that could support them and provide seed funding. The manual I designed and developed is presented in Annexe D.

In order to avoid creating an ‘unwanted market’, these new firms focused on challenges raised by the healthcare sector. As explained in the previous chapter, while raising awareness of the AR sector with our healthcare sector, I also collected challenges and desiderata for AR. To every potential entreprenuer, I gave a report of the challenges and desiderata collected during our workshops (*Chapter 4*).

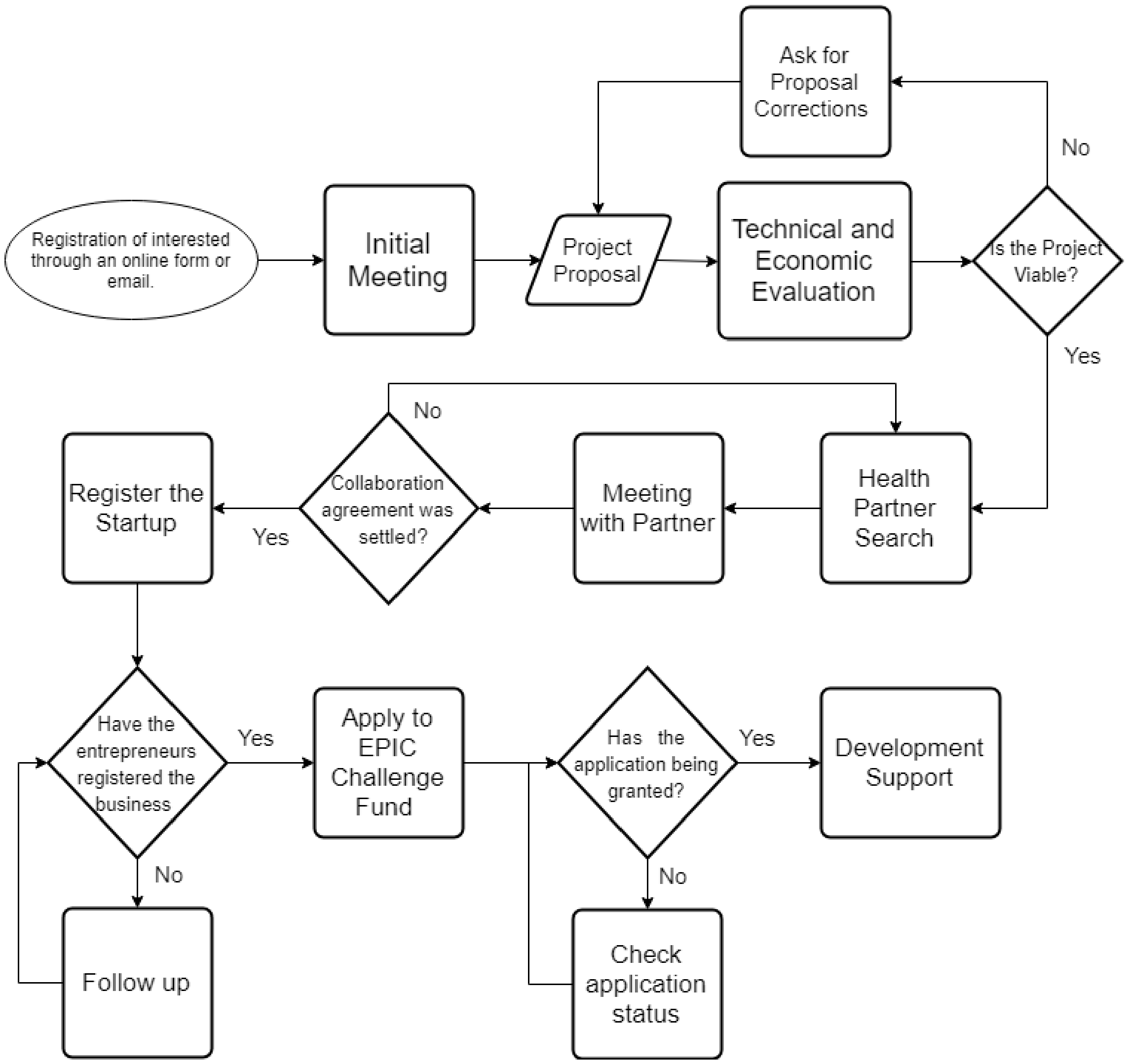


Figure 20; Support process for programme participants.

Recruitment to the programme ran from November 2017 to February 2018. The recruitment was via email invitations, social media promotion (Twitter and Facebook), and placing stands in the university. The recruitment targeted mainly students from the School of Art, Design and Architecture, and the School of Engineering, Computing and Mathematics. For instance, all the students from these schools received the email invitation (*Annexe F*). The implications of the recruitment activities were discussed in the next chapter.

The programme received 46 group and individual applications and it involved 58 people that at least attended the initial meeting or received the start-up guide. This included:

Table 6; Start-up programme participants. School of Art, Design and Architecture; SADA, the School of Engineering, Computing and Mathematics; SECM.

Category	SECM	SADA	Other	Total
Graduate Students	8	4	2	**14**
Undergraduate Students	29	4	2	**35**
Professionals	------	------	------	**9**

Ten project proposals were evaluated during the programme which resulted in the creation of four robotic start-ups (Robotriks, Olly Smith Research and Development, Access Robotics, Kernow Robotics, see *Annexe A – Case studies*). The projects ranged from AR for detecting and supporting panic attacks to devices to support users control daily devices such as computers. They were assessed according to their economic and technical viability. The technical evaluation considered the degree of technical difficulty to develop the first prototype. The economic evaluation focused on funding requirements to get to a proof of concept stage, matched against funding availability. From this initial evaluation criteria, the Technology Strategy presents in Chapter 6 a complete set of recommendations to evaluate AR proposals (see also *Annexe J*).

None of the project proposals received were excluded from the programme. As detailed in Figure 20, this was an iterative process, where proposals were assessed and improved accordingly to their technical complexity and cost. The aim was to support every single potential entrepreneur. Therefore, if the proposal presented a high degree of technicality or development cost, alternatives were sought, such as reducing the product features. Projects that had high technical difficulty were linked with academics and ongoing university research projects. Unfortunately, from the remaining six proposals, three could not find a Health Partner (see *Figure 20*), due to the lack of involvement of related healthcare organizations and charities. The remaining three were abandoned by their potential entrepreneurs who decided not to carry on with the ventures.

With the new four AR start-ups, part of my involvement in these entrepreneurship case studies was to provide business advice and economic and technical evaluation (*Annexe A - Case studies*). Through EPIC's network, I contacted those health organisations that could be interested in getting involved in these new projects as co-creation partners. Depending on the project, I also looked for postgraduate students or professors who could be interested in supporting the start-ups. The work also involved preparing the entrepreneurs for meetings with healthcare partners. This included what questions they should ask for the design of their project, how to present their ideas, and how to identify and define goals for the meetings.

I supported the start-ups seeking seed funding opportunities, improving their business models and guiding them on different business activities. Once they were granted the funding, mostly from the EPIC's grants (Jones et al., 2019), I kept supporting the start-up, not only in the development and testing of their prototypes but also identifying future opportunities for their business.

An overview of the four AR start-ups is presented in Annexe A - Case studies.

Finally, to promote the AR opportunities for entrepreneurs, I took part in several events. For instance, on 18 December 2019, we conducted one workshop for students in the Knowledge Spa. In these workshops, we engaged mostly with University of Plymouth nursing students, also some design and other students from the University of Falmouth. The event highlighted the opportunities for engaging with the EPIC project and the start-up process. The following list presents the events I attended to raise awareness of AR entrepreneurship as an invited speaker, in the region and worldwide:

- Power of People: making eHealth Work – Falmouth – 02/07/2018
- Software Cornwall TechConnect – Redruth - 14/03/2019
- Webinar - An EPIC webinar: Promoviendo la innovación, impulsando al sector salud - 13/04/2019
- Start-up Weekend in partnership with Google for Start-ups – Plymouth – 28/04/2019
- Venturefest South West – Exeter - 17/06/2019
- ATI Innovation for Businesses Conference – Redruth - 26/06/2019
- Cornwall Skills Show – Wadebridge - 08/10/2019
- Ageing Fit Conference – Nice (France) – 29/01/2020

5.3.4 External SMEs programme

As explained in the previous section, it was challenging to work with current businesses from the region. To overcome this, I decided to engage with other AR business from outside Cornwall. By bringing these companies into the county, I aimed to raise awareness among the local producer sector and to establish meaningful partnerships for the market. The final goal was to sell Cornwall as an ideal testbed for AR technologies. To do so, first, I needed to establish a strong relationship with the healthcare sector. As explained in Chapter 4, this was accomplished by several engagement activities. The result, a healthcare sector willing to support the development and the test of AR products and services.

In addition to this active network, I also provided external businesses with evaluation services and our on-ground support and funding (*Annexe A - Case studies*). This process started by identifying the goals of the product and company, and potential health partner organisations that could support the evaluations. Once the organisation was contacted, the goals of the evaluation were defined with the businesses. Different methodologies were used according to the needs of the evaluation.

Through this scheme, I supported four AR companies from outside the region: Service Robotics (TRL: 7; UK - Bristol), Pillo (TRL: 9; US), Amy Robotics (TRL: 9; China) and Akara (TRL: 5; Dublin). These case studies and the support provided are described in Annexe A.

During the first quarter of 2019, I contacted eight more robotic companies: five from the US, one from China, one from France and one from the UK (outside Cornwall) (*Table 7*).

Table 7; External assistive robotic companies contacted (Note: -- indicates that the company did not share the information. Table last updated the 12 of January of 2020).

No. of employees	Registration	TRL	Country	Product description
501-1000	2012	9	US	Home companion robot
11-50	2012	8	US	Home companion robot
51-100	2015	9	US	Telepresence robot
51-100	2015	9	US	Social companion for seniors
--	2016	7	US	Home companion robot
11-50	2011	9	China	Social companion
--	2015	9	UK	Telepresence robot
1-10	2015	9	France	Telepresence robot

Companies were at pre-sale and sale stage. Sampling comprised a mixture of purposive and convenience. The aim was to explore collaboration opportunities either by purchasing a device or receiving a prototype unit.

Most of the companies were contacted by phone calls with their CEOs. Follow-up communication was conducted through emails or calls. The calls lasted around 30 minutes. The respective follow-ups were conducted through emails or additional calls. From this engagement:

- One company from France and one from China mentioned that they were still trying to establish their companies in their current regions, therefore they were not interested in expanding yet.
- One of the five US companies was not interested in exploring healthcare applications yet due to the current global landscape of the AR market.
- Another US company working in the AR sector expressed that the EU is not an ideal market for AR and that their next market was Asia, even though that will mean modifying the entire interaction modality system of the robot (e.g.: language of the robot).
- The rest of the US companies were not supplying to the EU yet for not having completed the development process (two companies) or not having the CE mark (one company).
- The UK-based AR company was working on the development of a telepresence robot for children with long-term conditions. The robot allows children to take part in school activities. Unfortunately, I was unable to establish a partnership with the company, mainly due to the timeline of the thesis and the company's objectives.

Finally, in addition to the already mentioned engagement activities with AR companies, by September 2018, I conducted semi-structured interviews with 17 AR companies, including 12 firms from France (*Table 8*). The paper from this study can be found in Annexe C.

Table 8; Assistive robotic companies interviewed. (Note: -- indicates that the company did not share the information. Table last updated the 28 of September of 2018).

No. of employees	Registration	TRL	Country	Product description
1-10	Jul-18	3	UK	Wheelchair robotic arm
1-10	Jan-18	3	UK	Therapeutic robot
1-10	Nov-17	2	UK	Emergency drone
1-10	Sep-17	5	France	Medication reminder robot
1-10	Aug-17	7	UK	Care support robot
1-10	Aug-17	4	UK	Medication delivery robot
1-10	May-17	6	France	Smart wheelchair
11-20	Sep-16	9	France	Care support robot
1-10	Sep-16	5	France	Assistive robotic arm
1-10	Jul-16	9	France	Care support robot
1-10	Apr-16	9	France	Telepresence robot
--	Jan-16	5	France	Medication delivery robot
1-10	Jul-15	9	France	Patient monitoring solution
1-10	Nov-14	9	France	Therapeutic robot
30-50	Nov-12	9	France	Indoor projector robot
11-50	Nov-11	6	France	Care support robot
41-50	2007	9	France	Robotic air quality purification

These interviews explored companies' perspectives relating to the challenges they perceived and were facing during the product development and commercialisation process. Sampling, again, comprised a mixture of purposive and convenience. I interviewed companies between six months and 11 years old. This age difference was intended to map the different obstacles AR companies face during the market process/product development and life-cycle. I aimed to get companies covering different business stages: seed and development, start-up, expansion, and maturity. The interviews involved the owners of the company, wherever possible. Where this was not possible, interviews were conducted with senior managers.

The questions were designed following the study objective; explore AR market barriers from the perspective of the companies and the critical functions of the development process. Examples of questions include 'What was the most difficult part during the phase of product planning?', 'What was the biggest challenge in assessing customer needs?', 'Tell me about the problems you faced during your prototype testing phase'. Follow up questions were asked to explore the participants' answers in more depth. Interviews lasted between 20 to 50 minutes and were audio-recorded.

Interviews were transcribed using IBM Watson Speech to text. The transcripts were cleaned and put into a standardised format. The general inductive approach was used to analyse the transcripts to identify themes in the text that were related to the study evaluation objectives (Thomas, 2006).

Nineteen significant themes were identified, hereafter referred to as barriers, and are described in the next section. Following Painuly's framework for analysing market barriers (Painuly, 2001), these barriers were classified into five categories: market failure, economic and financial, institutional, technical, and social, cultural and behavioural. Their impact was analysed during the different stages of the development process, exploring how these barriers not only arrest the planning and conceptualization process but also the adoption of these solutions.

As the first author, I led the design and implementation of the research, the analysis of the results and the writing of the manuscript.

5.4 Findings

From the described interviews and work with the companies from the region and external to Cornwall, this thesis was able to identify several market barriers that explain the lack of traction of the AR market. These barriers are presented in this section.

Access to the healthcare sector was seen as the main barrier to overcome. This was evidenced in the interviews with AR companies and further work with the AR start-ups of the entrepreneurship programme. While there is entrepreneurship spirit toward AR and willingness from the start-ups to collaborate in the co-creation of technology, access to patients, carers and practitioners, in general, has proven difficult. This influenced the development process, the integration to current systems and the perception of the final users.

From the companies interviewed, it was mentioned that some health organisations charge for preliminary assistance, even up to '£1,500 for a 3-hour consultation'. Besides being an elevated price for new ventures, 3 hours is unrealistic about the actual time needed to gain sufficient understanding of consumer needs. Some companies mentioned that for conceptualisation, development and testing of their prototype product, consultation time ranged between 10 to 15 hours.

The alternative for entrepreneurs is to look for family and friends to become involved in the process. This is a reason why so many entrepreneurs innovate around the needs of their relatives. Participants of the interviews also mentioned the extreme option of having to "*look in the streets*" for potential lead-users.

Distrust towards entrepreneurs was also seen as a barrier. It was evidenced that there is an expectation for AR entrepreneurs to have an extended portfolio of developing robots as if they were app developers. In addition, companies mentioned that there is currently a distrust in AR, enhanced by a lack of understanding of how the final product works. The current distrust is also driven by concerns over patient safety, but also strong resistance from staff to change their current practices.

Furthermore, ethical concerns, mainly the robots' levels of autonomy, and more general concerns around automation, were perceived by the companies as barriers. This fear of automation and AR is leading to an industry that is technology lagging and consequently, the sector and crucially patients are missing out on these advances.

Besides, the complex structure of the healthcare system has a direct impact on adoption. From the interviews, it was mentioned that multiple people influence the procurement process, making it challenging to identify and locate who is, ultimately, responsible for making the final decision on a purchase or commission.

Funding was another barrier identified by AR companies and that I experienced supporting my AR companies. Certainly, this is not only a barrier to this market and a significant challenge for tech ventures in general. However, what makes this barrier different is the cost of prototyping, as explained in Chapter 3. It was clear that the main barriers focused on the lack of seed funding opportunities with further implications for scalability to the market.

Several companies explained that there is an underdeveloped capital market; scarcity of capital, restricted entry, archaic regulations and lack of access to affordable capital for AR ventures. Others mentioned that there were few investors and venture capital providers who understood hardware development and therefore, the seed capital needed. Those who are willing to invest perceive this as a high-risk involvement, demanding high-interest rates to offset the risks they take.

Moreover, the lack of openness from the healthcare sector makes it difficult for start-ups to prove the cost-effectiveness of their products. The use of assistive robots may have an impact on various aspects of the quality of life of patients (e.g.: therapeutic robots for reducing isolation, stress, or anxiety), making even cost-effectiveness studies difficult. To define the actual value of innovation without critical technological appraisal tools and multiple outcomes standards, is difficult and beyond the scope of most SMEs. As a result, young companies are unlikely to have the resources to undertake the sophisticated evaluation that many health care providers will require, will not understand the barriers to implementation, and so prefer to avoid supplying directly to the healthcare system. Evaluation support was one of the most significant contributions to the AR companies supported in this cycle.

As previously mentioned, there is a lack of business expertise by young entrepreneurs. Most of them shared a computing or engineering background, which explained their gaps in business planning. Furthermore, while this could be seen as a minor barrier, natural to overcome, the implications of poor planning impacts on user growth, the ability to raise funds, outsourcing, and even has technical impacts as the lines of code written (Gauthier et al., 2018). This topic is explained further in Chapter 7, where we focus on guidelines for AR development and value creation.

Finally, certification guidelines and standards that have not been developed by the relevant policy agencies are inhibiting the market. This has forced AR companies to pursue product certifications as toy devices instead of medical devices (e.g., Paro). This, of course, affects the procurement and adoption process of AR technologies. For instance, the robot cannot be prescribed or insurance firms will not recognize the device as a deductible charge if it does not have a medical certification (SBRI Healthcare, 2018).

A lack of planning and absence of policies to foster the development of innovations in the AR sector was clear. The opportunity to work with AR start-ups allowed me to face the absence of incentives for regulation and adoption of AR technologies.

All the identified and described barriers are summarized in Table 9.

Table 9; Barriers for the assistive robotics market.

Barriers	Barrier elements
1. Market Failure - *conditions needed for perfect competition in the market*	
Access to the healthcare sector	Access to patients for product co-creation. Disrupts the whole development process.
Highly fragmented healthcare sector	Different stakeholders and organisations. Slows down technology acquisition.
Poor market infrastructure	Lack of manufacture opportunities in Europe. Increases final product cost and slow technology acquisition.
Distrust in entrepreneurs	Disrupts development process and technology adoption.
High investment requirements	High seed funding needed to develop prototypes. Builds an entry barrier for entrepreneurs. Discourage entrepreneurs.
2. Economic and Financial - *access to finance and the conditions attached to financial backing*	
High cost of capital	Fundamental differences between software and hardware investment requirements. Creates a lack of capital, high-interest rates, and risk perception by financial organisations. Impacts on economic viability.
Lack of/inadequate access to capital	No awareness of hardware development implications. Impacts market competition and market efficiency.
High up-front capital costs for investors	High seed funding need increases risk perception. Lack of understanding of AR investments needs.
Lack of access to credit for the consumer	High product cost. Under-developed credit market. Reduces market size.
Market size small	Fragment healthcare system between regions and countries. Prevents product scale and potential gains, reducing the appeal for entry of newcomers.
3. Institutional - *underdeveloped or absent institutional structures which can hinder entrepreneurs*	
Lack of institutions and mechanisms	Missing agencies at the planning level to support AR development. Inhibits information dissemination between producers and consumers, creating extra costs for companies.

Lack of a legal/regulatory framework	Generates liability and concerns in the adoption of new technology.
Lack of stakeholders' involvement in decision making	No involvement seek of developers. Creates misplaced priorities, making policymaker bodies unaware of the market barriers.
Lack of universities' participation	Impacts on recruitment and R&D opportunities.
Lack of a transparent certification process	Not clear the path for certification of AR devices. Disrupts market entry of new products.
4. Technical - *barriers to the adoption due to the nature of the technology.*	
Lack of skilled care personnel	Slows down technology adoption, creates extra expenses.
Systems constraints	Integration problems with healthcare IT infrastructure. Producers cannot realise the market.
5. Social, Cultural and Behavioural - *the willingness of stakeholders to incorporate AR into their work*	
Lack of consumer acceptance	Fears surrounding the broader impact of AR, for example, fear of robots taking jobs. Reduces the market size.
Unfounded moral and ethical concerns of AR	Affects market size and technology adoption.

5.5 Discussion

This CAR cycle ended with new firms and external AR companies for the region, starting an entrepreneurship movement in the region for high-tech innovative ventures. In combination with the CAR cycle with the healthcare sector (*Chapter 4*), it has opened the door to strategic partnerships for AR development and testing. Therefore, we can conclude that Cornwall has today an emergent AR market.

An emergent market is not a mature market that delivers final products but one that at least has clear paths for AR development. Establishing a mature market would have taken far more than three years due to the time of the AR development process (*Chapter 3*). However, the intervention and the work and engagement with the AR companies, allowed this thesis to identify several gaps in the market and barriers for innovation presented in the previous section.

Several acceptability studies working with different healthcare segments have also found that access to the sector is one of the main barriers for innovation (e.g.: Broadbent et al., 2009; Glende et al., 2016; Huskens et al., 2015). These studies have also concluded the critical role that healthcare professionals, patients and families play in the development of assistive robots. Even more, in the developed eHealth market, many studies have expressed the importance of key health stakeholders in the development process of eHealth systems as a way of overcoming adaptability barriers (Broens et al., 2007; Goldstein et al., 2014; Kilsdonk et al., 2011).

However, what makes the impact of access to the healthcare sector different for assistive robotics companies compared to those producing software, is its combination with attitudes towards AR (*Chapter 4*). Is evident that digital technologies (software and apps) could also suffer from negative attitudes in the healthcare sector. However, individuals have been widely exposed to computers, mobile phones, apps and programs in their daily lives. This significantly improves users' perception of the innovation and adoption of these solutions (Goldzweig et al., 2009; Police et al., 2011). An awareness exists at least surrounding digital health products.

Robots, however, have not yet had the same market visibility. This was evidenced in Chapter 4. If you combine this poor visibility, that affects AR trialability, with the distrust towards entrepreneurs, we have then a market that closes its doors to technology and innovation-driven in part by ignorance, including uninformed ethical concerns as well as cultural barriers. This restriction not only influences the development process but also businesses' access to funding opportunities since health economics and outcome research studies cannot be completed without healthcare support.

EPIC was the only resource to establish contact between both parties. Our work with the healthcare sector, that required regular roadshows and workshops (*Chapter 4*), was the only way to raise awareness and change the region's mind-set. Several AR companies mentioned that they cannot afford to use their limited funding to work upon the healthcare knowledge awareness stage as well.

Furthermore, the lack of strategies or policies to challenge negative attitudes to robotics and autonomous systems (RAS), resound even more when specialised agencies are absent at a planning level, as explored in this CAR cycle and Chapter 3. Fostering a culture of collaboration, involvement, education and communication have been ways of overcoming healthcare stakeholders' opposition as described in Chapter 4. Previous studies agree that collaboration among all stakeholders is the way forward (e.g.: Broens et al., 2007; Castillo et al., 2010). For instance, the concerns about liability, patient privacy and security could be addressed through the introduction of institutes and legislation, designed solely for AR development. This also involves making a transparent, affordable, and accessible certification process for AR, and the development of critical appraisal tools for the technology.

Besides, better education has been a facilitator for health innovations (Orwat et al., 2008; McGinn et al., 2011). Skills-related barriers, such as healthcare professionals and end-users' technological abilities and experience, influence also the implementation and acceptance of AR. Therefore, various initiatives could be introduced to support both professionals and end-users in the AR learning process.

Dean and McMullen established that government intervention is needed to overcome market failure or inefficiencies that result from barriers (Dean and McMullen, 2011). From this CAR cycle, it is now evident that the AR market needs the intervention of governments to increase its traction. From the creation of legislation and policies to the establishment of open standards for the development of AR, governments could sustainably facilitate the implementation of AR in different healthcare environments. These recommendations were also given by adoption and use studies regarding health informatics technologies (Benavides-Vaello et al., 2013; Boonstra and Broekhuis, 2010). Governments can also subsidise the purchasing of AR and provide seed funding with positive externalities.

Finally, there are two general lessons for policymakers, may they be for the AR market or any other high-tech market for the healthcare system. First, innovation activities in this sector can occur with or without health care stakeholders' involvement. However, adoption and dissemination, from individual to organisational level, as well as the sustainability of these interventions will not happen without public policy support as explored in this CAR cycle. Second, the fragmented and complex healthcare landscape is severely limiting the ability to co-create and research the economic viability of technological applications to the healthcare sector, in the areas of assistive robotics, AI or blockchain, for example.

Chapter 6

AR Technology Strategy: Market Formation

This chapter presents the Technology Strategy for developing the AR market. It focuses on the market structure and dynamic, knowledge awareness and entrepreneurship programmes, cross-sector engagement and business platforms. This chapter provides recommendations, tools and policies to start the AR market.

As shown in the two previous chapters, the several actions executed in Cornwall allowed the region to shape an emerging AR market. From analysing and reflecting upon the intervention and its results, this thesis is only now capable of proposing the AR Technology Strategy. This strategy will allow the deployment of sustainable actions to start the AR market efficiently.

Since the AR Technology Strategy was built based on my experience in Cornwall, it could be recreated in regions that share Cornwall's baseline characteristics (*Chapter 3*).

The Technology Strategy aims to start the AR market within regions. Therefore, creating regions that will support the development of AR technologies from TRLs 1 to 4. It also includes strategies for attracting and managing the engagement of external AR companies from higher TRLs.

6.1 AR market structure and dynamics

During my work in Cornwall, I engaged with different actors, from council entities and NHS commissioners to funding bodies and policymakers. Also, as I advanced further in the next stages of the technology adoption process, the number of stakeholders involved also increased (Robert et al., 2009).

However, to start this market, the work should focus on three leading players: universities, healthcare organisations (HCOs) and the first AR start-ups (*Figure 21*).

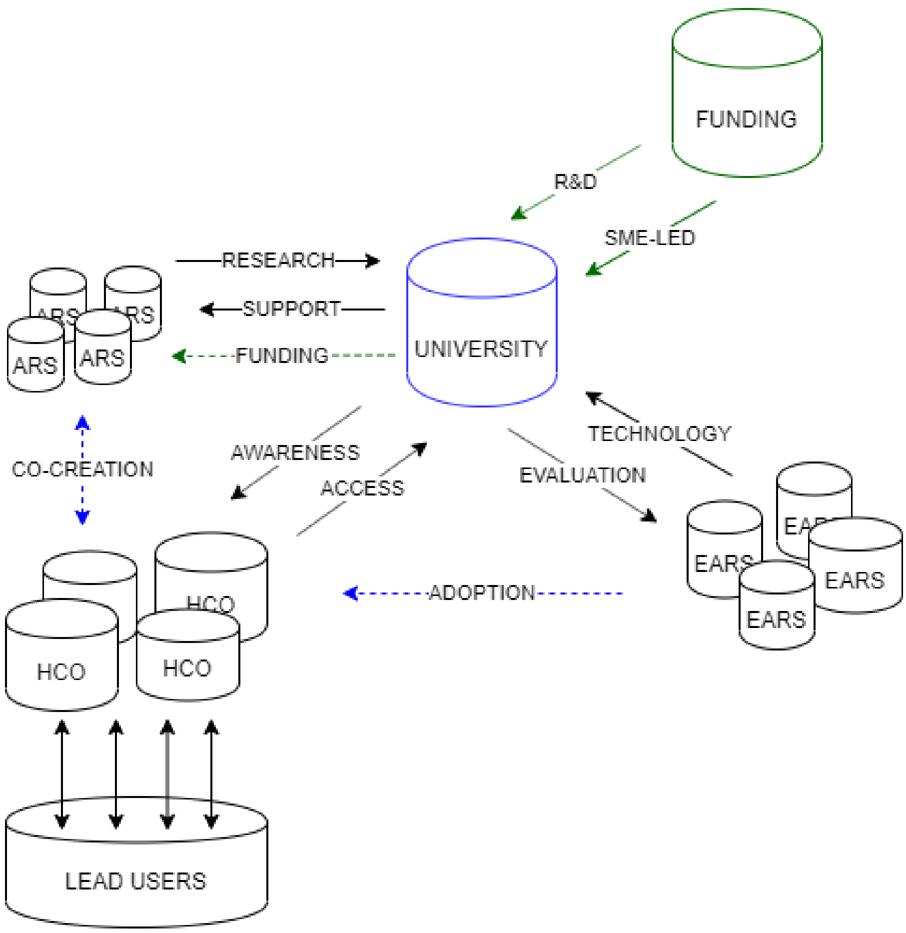


Figure 21; Structure of the assistive robotics market. Robotic Start-up; ARS. External Robotic Start-up; EARS. Healthcare Organization; HCO.

Since the aim is to start the market, there must be a leader of the intervention: the ecosystem developer (ED). I defined the ED as a public or private organization with the human resources to manage and act in the region to start the AR market. While we could draw some similarities between the term ED and others (such as integrator, orchestrator, intermediators, platform hub), the literature is broad and it does not yield a firm terminology and typology (Oh et al, 2016). Most importantly, there is no precedent in the literature of an organisation having been given the task of creating both a market and an associated ecosystem. We have studies that centre on bringing supply and demand together in a region, around an established technology and/or in an established ecosystem (e.g.: Feld, 2012; INNOVAHEALTH, 2012; COMODAL, 2015; Mulas et al. 2015). But we do not have studies that developed the supply for a high-tech innovation and created an ecosystem to support its development in regions that originally lacked the infrastructure to host the target market (*Chapter 3*). The described intervention in Chapter 4 and Chapter 5 is novel because it goes beyond just supporting the healthcare adoption process, the current innovation ecosystem in the region, the co-creation, development and evaluation of the technology, or creating the supply; it does all of them. This is the role of the ED for the AR market. Hence the term 'ED' is necessarily original since it describes the unique nature and role of the project.

EDs must have a high level of credibility since they will engage with several members from the healthcare sector raising awareness and accelerating the tech adoption process (*Chapter 3*). Credibility also needed since EDs should promote entrepreneurship and market opportunities for the producer sector (*Chapter 5*). Therefore, EDs should have access to entrepreneurs for establishing new AR ventures and the resources to support these businesses.

While funding is vital to start the market, the ED could also act as a link between different funding opportunities in the region and the AR companies. Take for instance the work with the AR start-ups described in Annexe A – Case studies. To support

Robotriks, Access Robotics and Stevie, I had to guide these companies during the development of grant applications. As a result, an ED that has experience searching and applying for R&D grants is useful for the development of the AR market.

Besides, the ED should have the knowledge and research resources to evaluate different technologies, AR proposals, and advice healthcare organizations in the adoption of innovations. All these requirements and how to achieve them are described throughout this chapter. For example, companies as Genie Connect and Stevie looked for support to conduct usability evaluations of their solutions. Therefore, the work with Genie involved mainly the evaluation and ranking of features. With Stevie it focused on the robot's usability from the perspective of the nurses from a day centre in Cornwall. The knowledge and resources around evaluation that the ED could provide to companies are important to the establishment of these partnerships.

For the AR market, this thesis has seen that universities are an ideal ED. As evidenced in this thesis (*Chapter 5*), universities have a talent pool of students, research facilities and ongoing research activities to nurture the AR field to not only support but also to create the first AR start-ups for the region. Through well-supported entrepreneurship programs, universities could improve the entrepreneurship landscape, provide the region with first start-ups, assist in the development of AR ventures, plus access seed funding for the companies. While doing this, universities will benefit from the new research projects driven by the start-ups, increasing KPI for academic institutions such as spinouts, business collaboration, applied research, and graduate employability. Additionally, universities have the resources for deploying the first engagement activities and manage collaborations. These resources and benefits are also described in previous research such as (Spigel, 2017) or (Neck et al., 2004).

Healthcare organisations' involvement can be stimulated by universities. It was seen during this thesis that universities have easier access to the healthcare sector than start-ups due to their knowledge transfer goals and ethos. This allows them to explore challenges and research opportunities, as evidenced in Chapter 4. Universities can also manage AR pilot deployments and reducing liability concerns from the healthcare sector, as evidenced in the case studies (*Annexe A – Case studies; Stevie*). The work of EPIC in Cornwall, and its involvement in the evaluation of Stevie, clearly supported the approval from the day centre Reflections to run the study in their facilities. The organization was open to host the robot and researchers for two weeks, driven mainly by the desire of exploring the benefits of the technology with their residents. Section 6.2.1 described how the ED should work on the knowledge awareness process, while section 6.2.2 describes how it could promote early AR adoptions.

Third, while funding has been a significant barrier for AR start-ups, universities have easier access to R&D grants compared to SMEs (Perkmann et al., 2010). This was evidenced in the seed funding application of my AR start-ups, where the involvement of universities sometimes dictated the success of a funding application. Even more, today there is a growing trend of governmental and international financing for applied healthcare research that requires universities to collaborate with SMEs (Dada and Fogg, 2016). Through these schemes, universities could support start-ups, first by guiding them through the writing up of applications, and while doing so, shaping the business model and project management as previously mentioned. Thus, adding a university to an SME-led application increases its standing, compared to a high-tech proposal led only by a new business.

Finally, universities can also attract external AR companies, as this thesis has shown (*Chapter 5*). By establishing strategic partnerships, in which external businesses could profit from the university research infrastructure and ecosystem resources, companies will see the benefits of investing and working with the region. With them, the region will start having examples of existing AR companies. This will promote entrepreneurship, raise HCOs' awareness of healthcare innovations, and even achieve early adoptions (Frank, 2017). Due to this effect on emerging markets, EDs should not look at external companies as barriers or competitors for the region's entrepreneurs, but as collaborators.

There could be other organizations that could take the role of the ED. For instance, open-source companies as Canonical, developers of Ubuntu, have a business strategy centre in the free development and use of technologies (Canonical, 2020). These companies, that are developing solutions for robotics R&D activities, are acting as technological platforms for the market. Companies are building their product around their offer. Therefore, the development of the AR market will have a direct effect on the development of their company. Besides, these companies have the resources to support AR ventures with the development of prototypes. However, further research is still needed to understand the implications in the dynamic between the ED and the healthcare sector when the role is taken by a business.

In the same way, corporate accelerators, incubators, and Venture Capital (VC) firms could also act as EDs. These organizations have the funding and resources to support AR venture creation. Previous studies as (Sun et al, 2018; Mulas et al, 2015) have evidenced how VC firms can transform weak innovation ecosystems into productive and robust tech clusters. By governing the resource flow and selecting market deviation, VC firms are strong candidates to incentivize the development of AR. Nevertheless, further studies are needed to understand how these corporations can affect innovation in an emerging market and, as with open-source companies, the impact in the relationship with the healthcare segment. While non-profit organizations could also act as EDs, for instance, the same EPIC project, revenue models need to be studied and developed to make such interventions sustainable. EPIC was initially funded in 2017 by a grant of £2.7 million from the European Regional Development Fund and the South West Academic Health Science Network (Jones et al., 2019).

Finally, while different innovations labs, research centres and membership organizations within the NHS and the government have a tracked record of establishing good relationships with healthcare stakeholders, it has been evident their lack of involvement in the creation of the AR market in the UK. Chapter 3 has already shown the influence of organizations such as Innovate UK in the development of the sector. Nevertheless, organizations such as Academic Health Science Networks, have proven vital allies for projects like EPIC (Jones et al., 2019). Unfortunately, their organization priorities focus on the development of the eHealth sector in general, therefore prioritizing technologies with high benefits for the user, but with low cost and time development.

Continuing with the description of the AR market structure and dynamic, one of the lessons learned working with start-ups and external companies is that in a nascent disruptive market, early victories of the competition represent early successes for all the other companies. Without the user's awareness and with all the regulation and adoption constraints, even a company working in the same healthcare challenge is by default a partner to another company, because it is breaking those barriers that are also affecting other companies. This represents the spirit of the market, collaboration and open innovation. Open Innovation implications and options for AR start-ups are discussed further in Chapter 7.

Moreover, at the heart of this market, we find the producers sector, the start-ups (*Figure 21*). One of the biggest lessons learned from the intervention in Cornwall is that established SMEs have business goals that do not allow them to explore near but innovative markets (*Chapter 5*). This might be for the characteristic of the region, the economic responsibilities of the business, the current state of the global AR market, or for their inexperience in innovative fields. Nevertheless, the ED cannot expect or rely on the idea that established companies will drive the AR market.

Instead, entrepreneurs motivated by their knowledge and daily engagement with technological advancement, have the vision and passion that might lack to established businesses. Most importantly, they have proven to be capable of adapting their goals to the challenges of the region, as seen with Robotriks and Access Robotics. Both were start-ups that decided to pursue challenges collected from the engagement with the HCOs (*Chapter 4*).

Yet, to promote entrepreneurship in the AR sector, different actions should be deployed first. For example, the ED needs to provide a minimum of initial support activities to these ventures (*Chapter 5*). Moreover, the structure of the start-ups and their dynamic with other companies are different from other markets. All of this is described in the sections 6.2.3.

The other key element for this market is the healthcare sector, the HCOs. Its involvement is essential for the conceptualisation, development and evaluation of AR. They are a source of knowledge on the how-to obtain the health outcomes for the patient, but also raising awareness of possible opportunities for start-ups (Kolko, 2015). They can work in collaboration or just crowdsourcing the challenges. Section 6.2.4 makes emphasis on different co-creation opportunities.

The nature of HCOs and start-ups interaction should be framed as collaborative participation, where both sides benefit from the development process. As explained in Chapter 5, AR start-ups need access to the healthcare sector to conceptualise, develop, and evaluate their prototypes. Moreover, HCOs need to offer quality and vanguard services (*Chapter 4*). As explained in the case studies, Access Robotics was a start-up that was partnered with Disability Cornwall, and organization that supports mainly people with different physical impairments. The organization helped the company with the development of the project concept, by sharing the needs of their potential users and general requirements for the technology. This support was only driven by the organization's ethos; support their members' wellbeing, which also represents the ultimate goal of the innovation. However, in the same way, we need a healthcare sector that promotes the adoption of the tech. Therefore, first, work is needed in the knowledge awareness stage of the region (section 6.2.1).

The HCOs will bring lead users for the design and evaluation of the concept and prototypes. The early involvement of lead users supports the fulfilment of design thinking methodologies (Kolko, 2015). However, it needs to be pursued and managed by the HCOs. The ecosystem can only flourish if all the different actors understand the opportunities of the technology and take active roles in the process. As evidenced by Markmann, with examples of collaboration, co-creation and development successes, the external investment will then follow (Markmann, 2012).

This is the general dynamic and core structure of an emerging AR market. This is a region that has minimal tools for supporting entrepreneurs through the first phases of the development process.

6.2 The AR Technology Strategy

The high-tech innovative element of the AR market demands a structure upon which the market can develop, adopt and attract this technology. The ED needs to support the creation of a barriers-free environment for the AR market. These are regions that understand the opportunities, the imperative needs and the role each of the market actors play. In addition to the awareness phase, the ED has to also manage the early AR developments, from their co-creation to their evaluation.

The figure below shows the main activities of the proposed AR Technology Strategy to build the innovation infrastructure for the region. These activities will become the tools that the region needs to support the development of AR technologies. According to the ED's resources, the time to deploy the strategy could vary (*Figure 22*). I recommend spending more time during the entrepreneurship programme, creating business platforms companies (section 6.2.3.5) and the co-creation infrastructure (section 6.2.4.1). Furthermore, other high-cost elements could also be added to the region as explained in section 6.3. Therefore, this strategy should represent a programme model for EDs, and a guide for HCOs and AR start-ups. In practical terms, the proposed AR Technology Strategy aims to prevent wasting assets and time of EDs and provides a detailed guide to understand the market dynamics and opportunities.

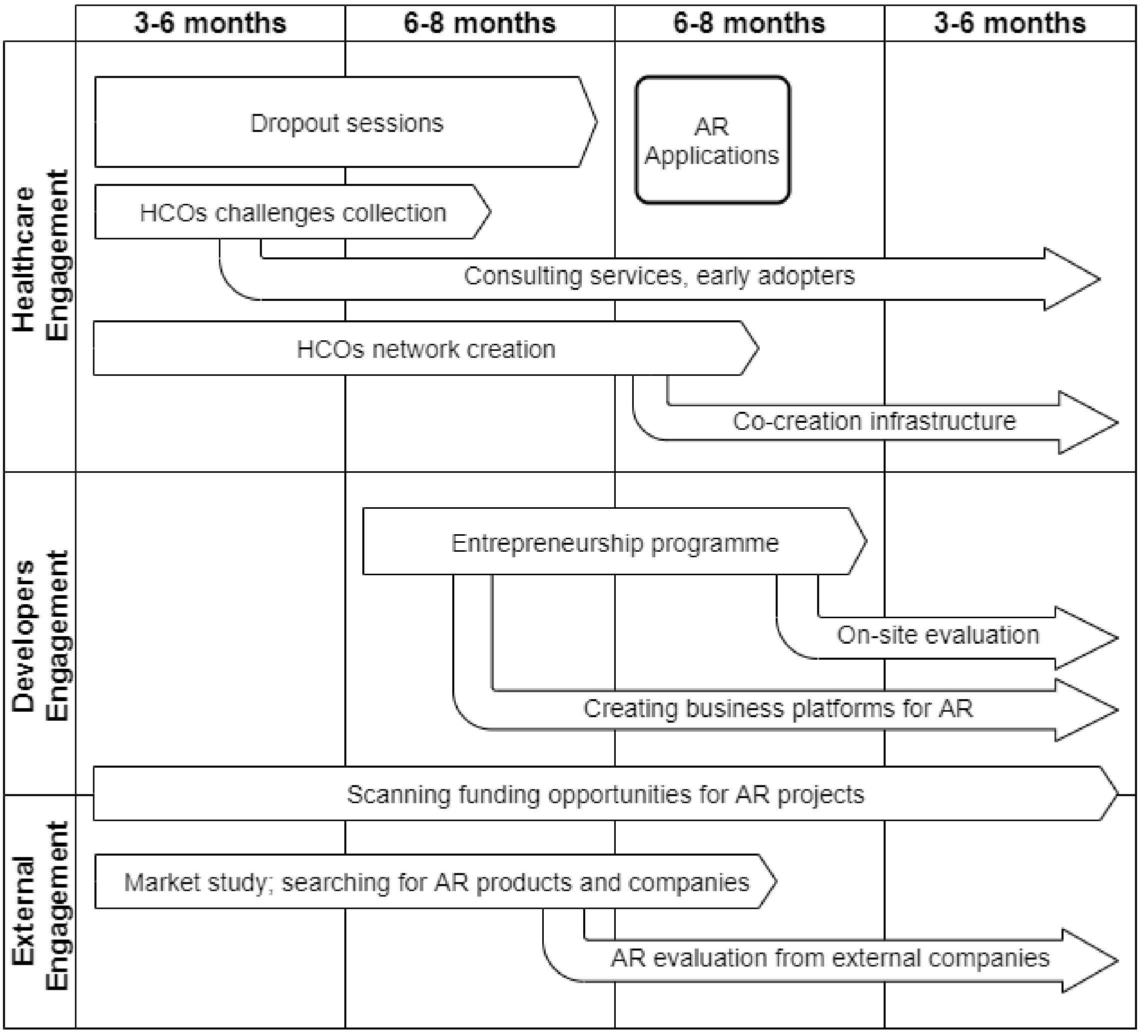


Figure 22; AR Technology Strategy programme.

The proposed timelines were designed base on EPIC's intervention in Cornwall building the eHealth market (*Chapter 4* and *Chapter 5*). Times that were also validated with the European robotics accelerator programme Robot Union (RobotUnion, 2020). This programme supports the creation of robotics companies for different industries, including the healthcare sector, and works in a 17-month programme structure with the companies (RobotUnion, 2019). The proposed Technology Strategy allocates a maximum of 16 months to the entrepreneurship program, the time it will take to recruit potential entrepreneurs, and support the co-creation and the development of AR proof of concepts. This is the core activity for the definition of the time frames. And additional of 3 to 6 months is given for the evaluation of those concepts/prototypes. Finally, the time allocated to the knowledge awareness stage comes from the described roadshows in Chapter 4.

6.2.1 Knowledge awareness

After the intervention in Cornwall, it is clear now that the most important activity carried out at the time was the engagement with the healthcare sector. As explored in Chapter 5, lack of access to the healthcare sector is one of the main barriers for the market. However, this access appears to be missing mostly because of the HCOs' lack of awareness of the opportunities that AR technologies offer to the health industry. Therefore, the first step of the AR Technology Strategy is to work with relevant healthcare stakeholders in the knowledge awareness stage: users learning of AR innovations and considering the advantages and opportunities it will bring.

The knowledge awareness programme with the healthcare sectors begins by identifying the healthcare challenges of the region (*Figure 22*). At first, positive interventions should be deployed to familiarise people with the technology (Rogers, 1995), and after that, it will be easier to change peoples' mindset towards AR technologies. Positive interventions target user needs to exhibit how the unknown technology could affect their work, delivery of care or daily living. By addressing the needs of HCOs and conducting demonstration experiments of AR prototype equipment at the early stage of development, the EDs will create an environment that stimulates practical use of AR technologies. Through this approach, innovative HCOs could become early adopters of the technology while the popularisation of AR technologies will also define new challenges for the producer sector.

Challenge identification should become a constant process of exploring, understanding and looking for solutions. For instance, to target the identified challenges on senior loneliness and isolation in Cornwall (*Chapter 3*), EPIC got a Paro. The robotic seal has systematically proven to ameliorate these conditions, with trials that date back to 2003 (Wada et al., 2003). Therefore, we started displaying the robot in Cornwall, targeting care homes, extra care housing and day centres.

However, the price of the robot and its unusual appearance were seen as a disadvantage. Therefore, in July 2017, after a market study, I advised EPIC to display the Hasbro "*Joy for all*", an animatronic dog or cat capable of responding to touch and noise. In the end, this device got further attention in the region and was even adopted by HCOs in Cornwall (*Chapter 4*). The device not only targeted the challenges of loneliness and isolation among seniors, but it also addressed further needs from the region. Ultimately, both Paro and *Joy for all* were seen to support the mindset change of HCOs towards technology and care innovation.

This example shows the importance of adapting to user needs, followed by market studies to find promising innovations. Furthermore, this intervention has created a domino effect. The first AR start-up that I created for Cornwall worked exploiting the opportunity that Paro and Hasbro *Joy for all* started, and this start-up was the example for future start-ups that saw in this first venture new market opportunities (*Annexe A – Case studies; Robotriks*). Through the success of Robotriks building their first prototype of an affordable AR companion, other entrepreneurs decided to take the risk of starting their business. Companies such as Olly Smith Research and Development and Kernow Robotics followed the example of the entrepreneurs behind Robotriks and created their businesses.

In Chapter 3, we described the TIS approach used for understanding a region functioning towards a technology. This constitutes a useful tool for EDs in order to map the market gaps, but also the HCOs' opportunities for the proposed technology. Therefore, I recommend the use of this tool before starting any intervention.

6.2.1.1 Awareness Events

Globally, the AR market is an emerging sector where its primary users run short of expertise in using robots and do not clearly understand where they could be used. Therefore, it is vital to the ED, SMEs, and researches to run dissemination and insight events so that every HCO and citizen can gain the necessary knowledge on AR.

While working in significant geographic areas such as Cornwall, you find several niches around the region that concentrate the population. First, to reach a broader audience, there is no other option than to identify strategic points. Second, it has been proven useful running events with the HCOs, going to their organisations and letting them interact directly with the technology. And finally, two types of events have been proven to be successful: dropout sessions and pilot evaluations.

The dropout sessions allow the ED to visit an HCO (e.g.: care home, day centre, surgery, hospital, extra care housing) and showcase AR technologies already available in the market in an informal atmosphere, all the while collecting and understanding the needs of the end-users. In the same way that this sector becomes aware of the technology, it represents an agile approach to evaluate the usability and acceptance of any device.

Nevertheless, the session should avoid disturbing the daily work of the target organisation. Interruptions in the schedule of patients could harm their wellbeing (e.g.: seniors with dementia, children with autism) and generate negative cognitive bias towards the technology. Consequently, it is recommended for the HCO staff to share with the patients initial briefings regarding the activity that will take place at least a day before attending the venue.

Then, it is recommended to structure the dropout sessions in three simple activities: a) setup, b) interaction, and c) discussion. When possible, arrange the technology in small rooms with a maximum of three participants per session, in order to allow higher controllability of the interaction with the AR productions being showcased and to record relevant feedback from the participants. The interactions should be structured according to the features/application of the AR product. For instance, if the main characteristic of the device is to allow seniors to video call their families, the interaction should let the participants use this central feature. Finally, end the session by discussing with the staff and the patients the pros and cons and opportunities for further development. This will allow the ED to win valuable insight at the end of each event.

I do not recommend to video record the interactions. Instead, administer open-ended questionnaires for the staff and patient groups, and insert strategic questions (find an example at *Annexe E*). Do not feel forced to ask all the questions, but instead use them as a tool to start and guide the conversation. The key is to explore how the technology could be improved.

The second type of interventions are pilot evaluations. For this thesis, pilot evaluations refer to in-depth usability evaluations of AR technologies in final environments. The activity involves putting AR prototypes or final products into practical use by placing the devices for long terms in HCOs. Since this represents a critical activity for the producer sector (firms and developers), we described AR evaluations in more detail in the next chapter.

The advantage of dropout sessions is their informal element that allows EDs to quickly contact and set up small events with HCOs that do not need special requirements compared to a pilot evaluation. Dropout sessions normally should take place during the first months of the AR Technology Strategy (*Figure 22*), once more aiming to cover the population niches.

6.2.1.2 Assistive robotics message

It is necessary to structure the dialogue between the ED and the HCOs. As explained in Chapter 4, there is a negative initial perception of AR. Therefore, during the engagement activities, the ED will be faced with difficult questions. Furthermore, the importance of defining and keeping a narrative that will become the essence of the intervention was evidenced in *Chapter 4*.

The main message to promote among the healthcare sector should be that robots are not here to replace people, but to perform labour-intensive and low productive activities. For example, these could include physical activities such as moving patients, or monotonous daily living tasks. With the aid of robots working on these areas of repetitive activities and heavy labour, practitioners, nurses and carers could spend more time working with the patients. In the same way, by freeing people’s time, robots could make up for shortages in the workforce. It has been shown that AR improves safety and could be used to deliver therapeutic sessions (*Chapter 3*), without ever excluding human contact. Therefore, AR should be seen as a tool to boost productivity, to enhance care delivery, and to improve work quality. Real examples of these applications can be found in Chapter 3. It was through this message that companies as Genie Connect and Akara (*Annexe A – Case studies*) found HCOs willing to open their doors to the evaluation of their devices. The first one had the support of twelve residential living establishments, with a collective total of 372 residents. The second was able to run a two-week study in a day centre with their residents and staff.

For the general public the message will be structured in the same manner: AR technologies are here to improve independent living and to aid in the delivery of care. It is necessary to stress the fact that care activities will be given by people, while AR technologies will increase work efficiency and quality. To accelerate the knowledge awareness stage, it should be emphasised that the development of AR is driven by patients’ needs, and achieved only by working closely with the end-user, carers and family members. From a regional economy perspective, a growing AR sector will create its own jobs too, generally of a more highly-skilled, higher-paid nature.

When talking about social isolation and loneliness, clarify that AR technologies are not here to replace human factors. Instead, the role of AR is to act as a bridge between those in need and their friends and family. Even more, AR could help users remember their loved ones. For instance, reminiscence therapies have been proven beneficial for people with dementia (Wada et al., 2003).

This last paragraph illustrates that several use-case scenarios could raise some ethical concerns about the technology. From the work in Cornwall, the main concerns of ED and SMEs should be surveillance, data collection and deception, and researchers should discuss the topics. The producer sector should understand their importance to the public and seek to minimise the impact of these views towards its work.

Finally, encourage HCO to adopt a more active role in the technology development process. They have to understand that without access to their knowledge and patients, the development of AR technologies will be inhibited. Robots must work with humans under a collaborative framework. Only then both parties will complement each other. Nurses and staff should also see this as an opportunity to keep growing their skill sets and add new qualifications to their professional portfolios. The use of robots will eventually become a desirable skill, and involvement in co-creation processes will represent rich experiences for their professional growth.

6.2.2 Consulting service and early adopters

As evidenced in this thesis, following the knowledge awareness events, HCOs will contact the ED requesting additional information about devices showcased or will share other challenges. The ED will become a healthcare innovation consultant for the region. This will involve a constant work of understanding user needs and market research to address problems raised. Providing this consulting service is beneficial for the region, the start of the AR market and the producer sector. ED should welcome questions, concerns and requests from HCOs. During the knowledge awareness events encourage HCOs to use the ED consulting service.

It is necessary to understand that, while the ED aims to create a market, it is crucial first to rely on devices available in the market instead of creating start-ups to address those first challenges. These will put in motion an early adoption phase. While the idea of creating start-ups to address the problem sounds logical, the AR development process will take years (*Chapter 3*). Besides, while you could solve the problem of one HCO, several others would not have access to technology until the company achieves scalability. Therefore, once more, you should first, perform a complete market study, not only looking for AR devices that could solve present problems, but also for other alternatives that could be adapted, either by an additional service or other technologies.

In the likely event that there is no solution available, then study the option of setting up a start-up.

The ED should recommend to the HCO products that are believed to be beneficial based on its knowledge and the state of the arts (another reason why the ideal ED for the AR market are universities). A quick google search will allow you to find products available or ready to market that the public could buy. Use these opportunities to identified external suppliers or producers, trends in the market, and the acquisition power of the HCOs.

ED should understand the funding landscape of the HCOs in the regions as well. While some HCOs will rely strongly upon the national system for funding equipment, some of them could have decentralised capital budget opportunities that the ED might not be aware of. Either way, ED should share this knowledge with early-stage SMEs that, normally, do not have this critical knowledge for developing their business model.

When acting as an AR consultant, have a clear picture of the work that should be done by people, the work that should be done by robots and the opportunities for cooperation. Analyse the entire process to be automated, as well as partial operations that could use AR to streamline the whole process. Identify system integration challenges and detail the process for tech adoption. Most certainly, the recommendation of devices should always be driven first by collaborative evaluations with HCOs.

Early adopters are those HCOs that act as an example for others in the region by purchasing the equipment that embodies the innovation (INNOVAHEALTH, 2012). These early adoptions could start with knowledge awareness events, co-creation activities, consulting services or pilot interventions. Ultimately, they represent KPI to understand the stage of the ecosystem and the market. This should become the final quantifiable indicator for EDs to measure the success of the knowledge awareness stage. In addition, this KPI will attract further investment for the AR field and the region, while attracting external AR companies.

ED should keep track of early adopters, follow up the reason for acquiring the technology and the benefits or drawbacks of the product. With this information, they could identify 'HCO champions' that will support future pilots and ventures of AR technologies in the region plus first-hand insight of medical evaluation of already available products. For instance, the Strategic implementation plan for the European innovation partnership on active and healthy ageing describes the positive impact of champions inside HCOs (EIP on AHA, 2011).

Finally, as shown in Figure 22, this thesis recommends creating an open call for HCOs to create early AR adopters. This could be a contest open to nurses, practitioners, and administrative staff from different HCOs. These open calls aim to encourage the healthcare sector to submit applications that they perceived as needed and available in the market. If there were to be a price, it will depend upon the ED budget. Alternatives include government grants for technology adoption opportunities or targeting product promotion opportunities with producers.

Either way, apart from attempting to produce early adopters, the contest will show to the healthcare sector the importance of actively searching the web for technological solutions for their challenges. This is the path for knowledge awareness sustainability: exercising HCOs to search for innovative solutions to address their challenges. Moreover, applications will keep revealing the needs and devices that are appealing to the HCOs of the region. This information will be useful during the work with the AR start-ups.

6.2.3 Health innovation entrepreneurship programme

The following recommendations are the result of the entrepreneurship programme EPIC Start that I developed and conducted (*Chapter 5*) and the follow-up work with AR start-ups (*Annexe A – Case studies*).

6.2.3.1 Initial requirements

As explained in the sections above, the recommendation for EDs is to first start working with the HCOs, raising awareness and exploring their challenges and needs, as described in the early work in Cornwall (*Chapter 4*). Only when the ED has completed this milestone (*Figure 22*), can start working with entrepreneurs.

First, it is recommended that the ED creates a report of the healthcare region challenges that could be solved by employing AR technologies, as explained in Chapter 4. It is also important to know which HCO raised the challenge and establishes the respective contact points among those organisations. It is expected that the ED builds an initial network of HCOs before starting the entrepreneurship programme recruitment. This network will be also appealing to external AR companies.

Then, develop a guide, explaining the process of the entrepreneurship programme. Here, it is recommended to explain the registration process of companies and their responsibilities. This was one of the most asked questions during the initial meetings of the EPIC Start programme (*Chapter 5*). The procedure and regulations for setting up a new company vary between countries. This is a relevant issue, and therefore, the ED will need to understand how the system works and the business obligations.

Entrepreneurs feel anxious about this first step, this was evidenced during the entrepreneurship programme (*Chapter 5*). Therefore, if the information is unclear, or if they do not receive this preliminary support, entrepreneurs will abandon the venture. During this initial stage is where the ED should provide much of its support, reassuring the programmes' participants and guiding them through the business setup process. A manual has proven to be a useful tool for entrepreneurs. The manual that I developed for the EPIC Start programme can be found in Annexe D.

Searching to create partnerships with other entrepreneurship or SME accelerator programmes or launchpads from the private or public sector has proven to be beneficial. These programmes have the fundamental goal of providing business support and early-stage decision making guidance. For instance, during the CAR cycle with the development sector (*Chapter 5*), I established collaborations with another EU funded project in the region: Acceleration through Innovation project. Finding these complementary supports is the key for capitalising from every resource that the region could offer. Building an innovation ecosystem does not mean building it from scratch, it should be an organic process that strengthens with the region's already existing resources as already described in Chapter 4.

Finally, funding will always be one of the main cornerstones for the programme. Unfortunately, AR ventures require high investment to develop prototypes as evidenced by working with Robotriks and Access Robotics (*Annexe A – Case Studies*). Since both companies were developing first prototypes; a companion animal and a soft-robotic arm, funding was clearly the main challenge for the start-ups. While in other fields you can "bootstrap" during the initial stages of the development process (i.e.: starting a self-sustaining process that can proceed without external funding), funding is always required to develop hardware. Both companies needed important pre-seed funding grants to start their work. This funding should cover manufacturing tools, off the shelf devices, and materials for building the first proof of concept. Through the work with the start-ups from the EPIC Start programme (*Chapter 5*), I evidenced that pre-seed funding of £6k was ideal for setting up strong AR start-ups with a chance of surviving at least two years towards developing a first prototype (TRL – 4). Robotriks and Access Robotics were granted a £5k grant from EPIC to develop small scale prototypes (*Annexe A*). This funding allowed them to establish their companies and start their ventures, but it was evident that further pre-seed investment was needed to improve their first prototype.

Even more, suitable AR seed funding should not ask for a financial private match. In the same way, it should provide first payments upfront. The funding should cover the development of prototypes as proof of concepts and provide a first step toward the feasibility, acceptability and usability evaluation of the AR technology. In addition, first-stage prototypes will help start-ups access further investment rounds.

The seed funding should also allow the start-up to get essential equipment for setting up the company. This could include mini PCs, 3D printers, sensors or actuators, equipment used by Robotriks and Access Robotics in the development of their prototypes. However, designing a compressive list of devices and suppliers could be beneficial for the ED since it could underline the funding requirements.

Loans do not constitute ideal seed funding opportunities for AR because of the high risks involved and unfamiliarity of the technology to potential lenders (banks). Loans have been seen to cripple the AR start-ups and condition the innovation ecosystems (Lelarge et al., 2010). Instead, equity finance has been seen by VCs as the right path to incentivise the development of the company while holding some of the revenues (Gompers and Lerner, 2005).

Furthermore, funding that requires unreasonable timeframes for the development of a final product could negatively impact the R&D phase. Then, the final product could be unable to fulfil its goal, damaging the reputation of the company and even harming the end user.

Innovative alternatives to protect the investment should be explored, such as work logs, the definition of clear milestones for the project, or clear guidelines on how the investment should be used. Work logs and milestones will allow the tracking of the entrepreneurs' work, intervene and support when necessary and gradually inject the funding while the venture progresses (Bruton et al., 2015). It will also add initial structure to the development process, and it could be linked to the quality control management of the venture (*Chapter 7*).

The source of the investment will depend upon the region's opportunities. Private or public sources should be studied before the application. The funding should support entrepreneurship and high-tech technology development. As explained in the first section of the chapter, universities are the ideal market actor to take the role of ED. Regarding funding opportunities, universities can apply for R&D funding or search for SME-led applications where they can be co-applicants with the start-ups. Finally, crowdfunding and peer to peer lending have been shown to increase funding opportunities for innovative start-ups (Bruton et al., 2015).

Unfortunately, there is no easy way around the funding question. Funding opportunities available and the number of AR start-ups funded will represent two KPIs for the region in its effort to establish a viable market for AR. Nevertheless, due to the increased relevance toward the senior market, the trends toward AI investment and the pressure that care organisations are facing, funding opportunities are increasing (AAMSCA, 2017). Further, the proposed AR Technology Strategy aims to increase the opportunities of the ecosystem to attract VCs and to further funding opportunities, due to its sustainability, barriers-free development and adoption for AR, and the deployed network of HCOs and entrepreneurs. Previous studies have found how these open market elements could attract external funding into regions. (Lerner, 2010; Sun et al., 2018).

6.2.3.2 Recruitment

Universities can provide much of the talent pool of entrepreneurs needed for the AR market (*Chapter 5*). During the EPIC Start programme, I explored different options for the recruitment of graduate and undergraduate students, such as email invitations, social media, and placing stands in the university. Email invitations and social media proved to be effective, as it is easier to reach a wider audience. However, a good design marketing campaign is essential in order to provide engaging content, that differentiates from newsletters and school emails. The AR market is an innovative offer, targeting young entrepreneurs, and the marketing of the programme should have an appealing proposal that stands out. When asking people to take a risk and start working in an innovative field, your communication programme should keep high standards. EDs should invest in marketing resources. Annexe F provides an example of media communication for my entrepreneurship programme.

Finally, invitations should allow students to register their interest. Annexe G shows a sample questionnaire template I developed in Google Forms and used during the EPIC

Start programme. The academic backgrounds to be target are explained in section 6.2.3.4.

6.2.3.3 Programme structure

In Chapter 5**,** I provided the diagram for supporting entrepreneurs used during my EPIC Start programme. While proven successful, it has been adapted and refined. Figure 23 shows the new scheme (next page). The main change is the addition of business platforms (section 6.2.3.5). During the entrepreneurship programme (*Chapter 5*), the aim was to create case studies; companies that will address one of the identified healthcare challenges in the region following a bottom-up approach. However, it was evident that this approach misses the opportunity of increasing the sustainability of the intervention by ignoring business platforms. Therefore, this new structure includes the evaluation of whether or not an applicant could establish a venture that will support the development of other AR companies.

The initial meeting aims to inform the entrepreneur of the goal and resources of the program. It is also a way to assess the knowledge and commitment of the participants. During the first meeting with the entrepreneurs, besides discussing their responsibilities towards setting up and managing their company, challenges and funding opportunities available should be discussed.

It is normal to have entrepreneurs with their own project proposals. It is essential, therefore, to have an open network of HCOs. While this might not be enough, section 6.4.2 establishes options for the region.

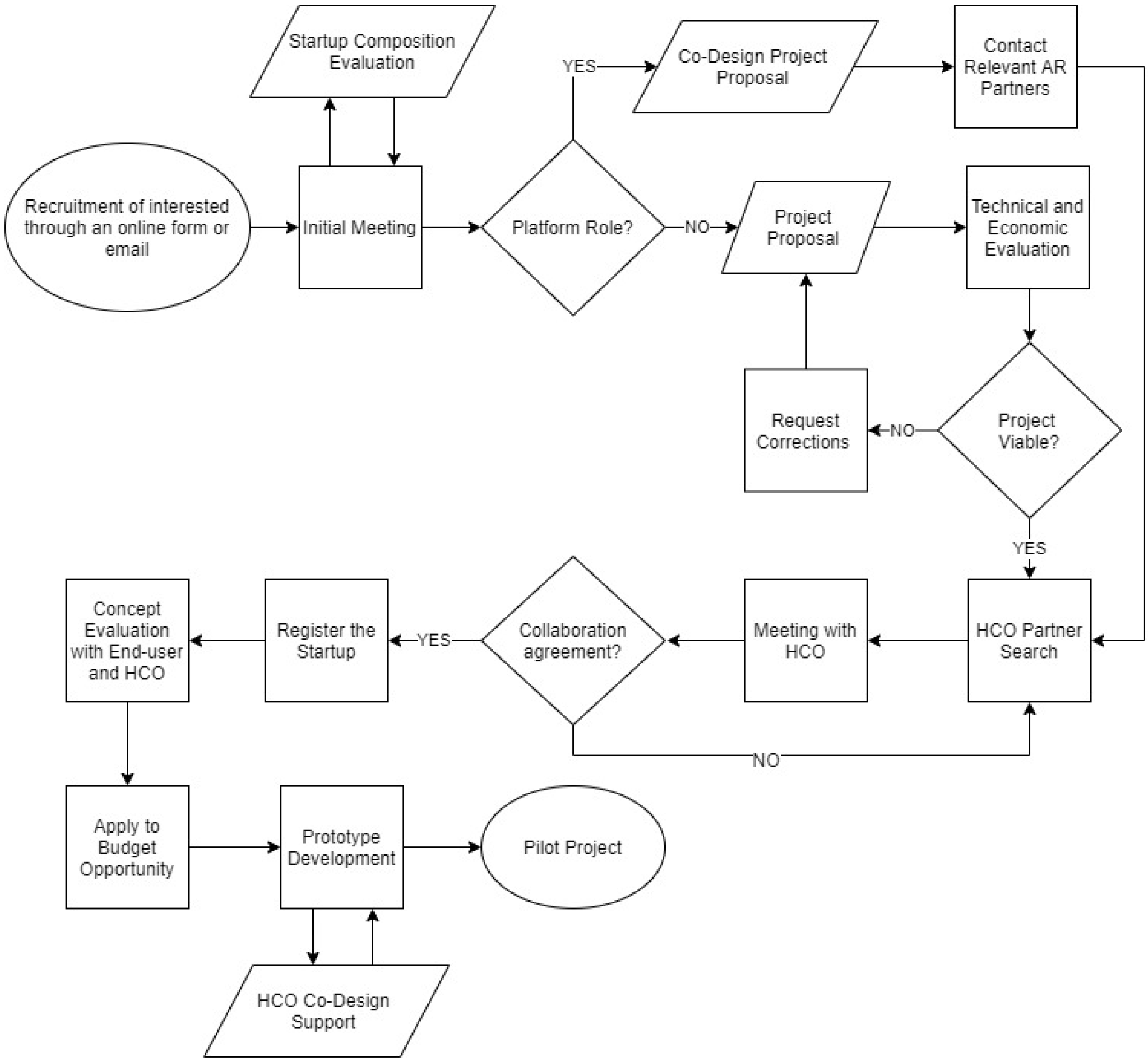


Figure 23; Entrepreneurial programme structure.

The project proposal should be two pages maximum, describing the challenge, innovation, and a brief market study (see Annexe H for an example of a proposal received). This proposal will be evaluated under three categories: region needs, economic and technical viability, and AR start-up success. In addition to the description below, Annexe J presents further guidance about the evaluation criteria.

The first criteria will be evaluated upon the collected HCOs challenges and the preliminary study of the healthcare sector in the region. If there is no documented need for the devices, the proposal should not be rejected, but instead, the other two criteria should be considered carefully.

The economic evaluation should focus on the seed funding available for the start-up, in order to produce the project's proof of concept. For instance, if the proposed project is the development of a humanoid robot, the expected cost of the project will be too elevated. In this case, instead of declining the support, explore the option of collaboration with an external AR manufacturer developing the high-cost technology. Through this approach, the start-up could focus, for instance, on the development of a complementary service for the company. This is explained further in section 6.2.3.5. Ultimately, the economic evaluation should focus on correctly using the seed funding available with two goals: supporting the start-up to set up a business and developing the first prototype of the venture.

The technical evaluation should consider the degree of technical difficulty to develop the prototype, including any AI component. If the project relies upon building a data set not currently available or difficult to access, this will become a significant down set to the project. For example, an AR device to predict and manage panic attacks that relies upon numerous and unavailable registers of people's heart rate to make predictions. The bottom line is: separate those projects ready to enter the start-up world and those which should flourish in academia. If the ED has a link with a university or research institution, it could connect these high-technical ventures to other projects.

Finally, the AR start-up success criteria should be measured upon the start-up composition (section *6.2.3.4*) and if the region has an HCO capable of supporting the AR development. In simple terms, if the region does not have the HCO to nurture, develop and test the technology, the AR proposal might be not adequate for the region.

However, if the core team of the start-up is not suitable for the venture, it is recommended to merge different ventures until reaching an appropriate team composition.

If the application is viable, it is recommended to link the entrepreneurs with an academic or HCO partner for the proposal. Depending on the AR start-up composition, the ED should also train the start-up on how to pitch their project proposal to external groups. Alongside, it is also necessary to talk first with the HCO about the nature of the activity, the expected outcomes from the project and the responsibilities of each party (section 6.2.4).

Only when the entrepreneurs feel comfortable with the support given and the project landscape, advice to register the company should be given. Once this is done, move forward to the seed funding applications.

For the ED it is critical to create quick start-up examples for the region. These first start-ups will drive other entrepreneurs to pursue new AR ventures. Because these early start-ups are considered KPI for the region (Feld, 2012), their stories should be shared as examples to others. We have already mentioned the positive impact Robotriks had over other potential entrepreneurs. The ED should drive the stakeholders' engagement while shaping and sharing their successes. The ED should create superstars and aim for superstars.

The types of AR start-ups to promote and create are described in section 6.2.3.5. While in the next chapter, we described value creation opportunities and market segments for AR in the healthcare sector.

6.2.3.4 Assistive robotics start-up composition

Several entrepreneurship studies have given different factors for the success of a start-up (Groenewegen and de Langen, 2012; Lasch et al., 2007; Watson et al., 1998). This section will only focus on the start-up organization characteristics since it is a main factor for the survival of start-ups driving a radical innovation (Groenewegen and de Langen, 2012), and its relevance with the AR entrepreneurship program. This section will then present an optimum structure for AR companies, based upon the companies engaged and supported (*Chapter 5*).

It comes without saying that, for a new AR business, the central element is the engineer. By engineer, we are referring to Mechanical and Electronic Engineer, but also Software Developers. The start-up needs technical knowledge to integrate off the shelf devices or develop their own components and code for the first stages of prototyping. Nowadays, it is common to find this balance in several undergraduate students. However, while the how-to knowledge is essential, the case studies included in this thesis have shown the importance of two key players: business management and product design.

Business managers are capable of understanding the need for well-structured and well-developed business models. They can see business opportunities of unattended sectors and ways of exploiting them, and their strong human profile allows them to connect easily with healthcare stakeholders. Finally, seed funding application and further management of the financial activities are areas where entrepreneurs with a business or economic background thrived. Again, it is important to mention the difference between the AR market from traditional health businesses. Fast prototyping incurs higher expenses than in digital companies, and it is common to see start-ups struggling to realise the amount of capital needed and how to manage it — a critical prerequisite for investors.

On the other hand, product designers will play an essential role in making the prototype appeal. In the AR sector, the aesthetic of the device will outline the acceptability of the devices (Riek and Howard, 2014). While engineers are capable of build devices, they usually lack the skills to make the product appealing.

The structure of the AR start-up does not include any health stakeholders. However, this does not mean they are not needed, or could not be included. This is just the fundamental structure of the start-up. From the companies engaged (*Chapter 5*), some companies had nurses, practitioners or even informal carers as founders. This is common due to their work and proximity with patients. However, while their healthcare knowledge on how to support the patient and passion have proved beneficial, they are not essential since the ED should always partner the venture with an HCO as explained in the sections above.

6.2.3.5 Start-ups and business platforms

The dynamic between AR start-ups is key to the sustainability of the market. What type of AR start-ups does the EDs need to create? How can start-ups work together in the market?

We can identify two types of early-stage AR companies, those who lead the development of solutions and those who assist the market: market pioneers and business platforms. The first type of AR start-ups are those who have access to seed funding, are developing prototypes and with time will move to an MVP. They work by solving one of the identified HCOs' challenges or by working on their own ventures.

Companies in this category require seed funding for acquiring the tools and equipment needed to grow their business. ED should understand that the goal will not be to guarantee the success of the AR project but to ensure the sustainability of the start-up. Therefore, the work should be focused on providing business advice, network connections and projection, all of this in the context of the AR project. These companies represent the heart of the region, and the ED should seek their early formation. In Cornwall, these companies were Robotriks and Access Robotics. Both were start-ups created with the main purpose of addressing some of the identified healthcare challenges in the region (loneliness and accessibility respectively. *Chapter 4*).

The second category of AR companies are those start-ups who support other AR companies and the market. These are known as business platforms: companies that develop products and services upon which the first type of AR start-ups will grow (Evans and Gawer, 2016). In this thesis, the term refers to those companies that provide either evaluation services, complementary features or satellite services.

The role of supporting the evaluation of AR technologies will be a significant task for the ED. This represents the assessment of proof of concepts, prototypes and products from external companies. This service accelerates the development and adoption of AR. It is a tool that has been proven to be useful for businesses to attract external companies. However, the ED should move from this role in order to make the market self-sufficient, and therefore sustainable. The way to achieve this is by setting up a start-up for the evaluation of AR technologies.

This platform company will contact internal and external companies, will continuously look for new product and innovations available in the market, and will attract talent to the region. The company will promote the region as a testbed for the development of

AR technologies. Finally, it will provide the evaluation service and act as a market distributer when needed.

This start-up will become a vital partner for the ED. Therefore, the ED should recruit entrepreneurs as soon as the first evaluations are taking place, for the future company to learn the process. Seed funding for this type of company is possible to be secured through grants that support technology adoption in HCOs.

During the described entrepreneurship programme (*Chapter 5*), I supported and guided the creation of the company Olly Smith Research and Development Ltd. to take the role as a platform offering evaluation services in Cornwall. The work with the company started with the evaluation of the humanoid robot Stevie (*Annexe A – Stevie*). Here, besides supporting the evaluation, the company started learning how to conduct these studies, and we designed a business plan for the company. It is expected that the company will remain in the region, supporting internal and external AR ventures with the evaluation of their technologies.

The second type of AR business platforms are the companies that provide complementary features to other AR companies. For instance, AR start-ups could focus on developing communication strategies and interaction modalities for a stationary robot that will deliver different therapies. Another AR company could see an opportunity and start offering mobile platforms to these companies. The latter was the case of the start-up Kernow Robotics, a company created to provide other product developers with mobility solutions (i.e.: three-legged robots). The company was created with that platform-oriented goal. Working with companies such as Genie Connect allowed me to identify a growing trend in desktop robots. While these robots have several applications, mobility, for instance around the house, is a limitation. It is expected that companies as Kernow Robotics could help companies keep adding added value to their products.

These companies will only surge once a clear need presents itself in the producer sector, not in the early stages of the market. Therefore, they do not constitute an imminent need for the region. Alternatively, the ED could identify external AR companies that could use a complementary feature and support the creation of such start-ups. While this new start-up will begin assisting an external company, the need for such service or feature in the ecosystem could arise later in the region.

Finally, start-ups that offer satellite services are companies that support the adoption of AR technologies currently developed or deployed in other regions. They work to provide either human or technological resources, and offer the AR service in another region. The company could also develop complementary services, such as adapting the language or adding modalities.

Genie Connect represents an example of these companies (*Annexe A - Case studies; Genie Connect*). The company settled up a call centre service for the use of the robot Genie. The robot, currently developed by a Chinese company, has had the opportunity to be used in the UK thanks to the contributions made by this company.

The ED should be the gateway between the external AR company and the satellite start-up. During the ED study of the region's health challenges and market study, the ED should also identify those companies that could work in the region through satellite companies. Usually, this category will include companies that setup local communication networks, or the deployment, activation and monitoring of other AR technologies.

To some extent, these companies could also be considered as suppliers. However, due to the nature of the technology, companies must have a deeper understanding of how the AR product works in the region. The platform company could support more than one AR product at the time, aiming to offer to the region a complete service of solutions, which are referred to as AR care packages.

6.2.4 Co-creation

The importance of HCOs and AR start-ups working together has been highlighted throughout this thesis. Co-creation is a fundamental requirement to achieve truly user-centred design outcomes (Kolko, 2015). The number of HCOs of the region that have engaged with AR projects represents another KPI for the market. Hence, this section will describe the co-creation collaboration dynamic.

The first milestone of the collaboration between both sectors arrives from the evaluation of the project concept or proposal. Here the AR start-up should discuss how the suggested AR technology would solve the raised challenge. Due to their experience, closeness with the patient or challenge, the HCOs are in the best position to provide feedback. The AR start-up should follow the advice as appropriate.

During the development process of the AR prototype, it is expected that the start-up will seek further advice from the HCO to check the feasibility, opinion and requirements for further components. Indeed, this will increase the HCO’s consultation time. Therefore, to fast-forward minor consultations, I have seen beneficial the use of ordinary communication tools such as WhatsApp, saving both the developers’ and the HCOs’ time.

Intellectual Property (IP) should rest with the AR start-up since it is the organisation established to develop and commercially exploit the innovation. The AR start-up should commit to respect the privacy of the HCOs and lead users involved in the development process. If necessary, both parties could sign a Non-Disclosure Agreement. Universities should also be more flexible about their current IP policies towards spin-offs, as some of the companies engaged in Chapter 5 have highlighted. Previous studies as Bekkers et al, have evidenced that IP-based spin-offs are an ideal mechanism for technology transfer (Bekkers et al., 2006). However, further research is needed to provide fair public policies for all the parties involved (Holgersson and Aaboen, 2019).

Nevertheless, HCOs have to understand that the development process of AR technologies takes time. Getting an MVP will take between four to seven years — reason why they should not consider this as an opportunity to solely make a quick profit. Although in the medium-to-long terms costs may be reduced due to increased labour and capital productivity, HCOs' involvement should be justified upon the HCO's goal of supporting their patients. Instead, the AR start-up should commit to giving first access to any device or service that result from this collaboration. In the same way, the HCO could advertise their involvement in the project, which has proven beneficial for the marketing of the organization in this thesis.

I recommend following the same guidelines outlined for the seed funding if the HCOs is willing to invest in the venture (*6.2.3.1 Initial requirements*).

6.2.4.1 Network Infrastructure

So far, we have discussed the importance of creating HCOs networks. While the ED has been the key element for connecting HCOs and developers together, this scheme is far from being sustainable for the market.

There are different methods for healthcare co-creation that allow HCOs and the developer sector to work together. For instance, these methods might include collecting and disseminating essential healthcare challenges, technologies opportunities, funding opportunities or consulting services (Nambisan and Nambisan, 2009). EPIC deployed a health forum inviting HCOs and SMEs to participate in co-creation activities. EPIC research assistants managed the different forum topics and incentivised members' discussion. However promising, this exercise proved to be futile. Despite having a mixture of HCOs and developers, the forum failed to deliver or support AR projects, failed to attract others, and, overall, failed to be sustainable without EPIC.

The main reason for this failure was the lack of a marketing programme to advertise the forum, followed by the absence of incentives for participation, content to create discussions and the poor feedback from the participants. However, for my AR start-ups, it was clear that a forum was not the way to proceed. The start-ups, despite asking for feedback in the forum through their posts, found that they were simply pitching the idea to the wrong people.

Entrepreneurs face difficulties identifying the HCOs from the region, their primary user or their patients, and most importantly contact points within the organisations' staff that are willing to support innovation development. These will be the people that have the resources, authorization and agenda that allow them to be part of the co-creation process.

Therefore, a simple website providing a list of HCOs and their main point of contact for co-creation activities could solve this problem. However, what will make this effort efficient is an agreement of participation by HCOs to support those innovators who contact them.

The website, besides allowing HCOs also to share challenges to entrepreneurs, could also display the current projects that they are involved in. This could open to opportunities for the public to submit donations towards those HCOs that they perceived have been supporting most entrepreneurs in the region. This represents an analogy to crowdfunding websites which have proven to be beneficial for innovative technologies (Bruton et al., 2015). However, instead of funding the project, people will fund the access and support from the HCOs.

Through this method, more HCOs will be keen to participate, not driven only by making a revenue, but instead due to the social impact trending HCOs have in the region. In the same way, this will encourage the collaborative spirit of the new market, provide further examples for future entrepreneurs and keep the ecosystem's centre, not upon physical infrastructure, but an affordable web platform.

Unfortunately, during my work in Cornwall, it was impossible to launch the proposed system due to several constraints within the EPIC project. However, this system shared within this thesis due to EPIC's experience with the forum, other co-creation websites, and the feedback obtained from my AR companies.

Finally, it has been beneficial to support co-creation activities that run public-private contests (Mulas et al., 2015). By presenting a problem statement and creating a challenge where SMEs, start-ups, and community members can propose solutions, the ED will approach people incentivising co-creation and supporting the knowledge awareness process. Adding an application clause to make it necessary for the producer sector (firms and developers) to have and HCO applicant partner will assure the activity goal. However, these initiatives will depend on the ED's budget.

6.3 Further entrepreneurship infrastructure

The chapter above discussed the concept, tools and strategies that were implemented and analysed during the three years of intervention in Cornwall. On this basis, I have made a series of recommendations to build the AR market. However, there are further strategies to accelerate market formation that were not implemented in this thesis.

While most of the next recommendations given in this section could not be evaluated due to the funding and EPIC project plan, they could be incorporated into the AR Technology Strategy provided. This set of recommendations were used in other innovation ecosystems around the world for innovative technologies. Due to their success and relevance they could have a positive impact on the AR market.

6.3.1 Co-working spaces

Traditional innovation ecosystems build upon a physical infrastructure (Iyawa et al., 2017). Think tanks, hubs, clusters, they all share a physical centre that gives the region a reference for the ecosystem location, and a sense of community and collaboration.

Usually, these spaces are co-working stations, buildings or offices that host members working in different companies and projects (Mulas et al., 2015).

Co-working stations are a tool to gather knowledge and increase the probability of encounters in the ecosystem network (Garching, 2014). Through them, members can exchange knowledge and the challenges faced in the AR development process. In more practical terms, it also gives start-ups a company address if needed. The co-working space could also provide services as business support or other amenities, such as access to conference rooms and IT infrastructure.

6.3.2 Prototyping facilities

The development of prototyping facilities depend upon the ED budget, but this investment could become sustainable in the long run (Niitamo et al., 2016). Since EPIC did not provide this opportunity, I encouraged start-ups to buy manufacturing equipment through their seed funding. As already discussed, the equipment will let the start-up set up their company.

However, prototyping facilities will allow start-ups not to finance the manufacturing equipment with their seed funding and invest only on the project. This could open new funding opportunities and reduce venture risk for investors. When the start-up grows, they will have their own resources to buy the needed manufacturing equipment.

The ED could charge medium size companies for the use of the equipment to start getting a return of the investment made. This could also mean another channel to attract entrepreneurs by offering design and development services to third-party organisations looking to create new devices.

These facilities should provide access to manufacturing equipment such as 3D printers, laser-cutting machines, PCB board printers or CNC machines. Also, off the shelf devices like microcontrollers, motors and actuators, motor controllers, sensor and power systems would be useful resources for any AR project as well.

The installation could also be used as a showroom for the market new AR developments. Ultimately, it could also offer evaluation and testing facilities for the AR market, as described in Chapter 7.

6.4 Regulation and policy

Regulation is a topic that few EDs can address. Economic policies towards entrepreneurship, funding, and product certification are areas that strongly influence the market, but few EDs will have the resources to work on these topics. However, this thesis has identified the importance of regulations for the AR market, and this section aims to raise awareness of this global issue.

The current EU landscape regarding regulation for AR is quite fragmented and incomplete. For instance, we see countries developing guidelines for the development of AI for healthcare applications (Winter, 2016). However, some of them are quite superficial, touching only on the importance of data acquisition. Take, for instance, the NHSx AI report for safe data-driven innovation in healthcare (NHSX, 2019). This report constitutes a good introduction for developers working in the field, outlining the importance of user-centred methodologies, data privacy, and the importance of evaluation and evidence. However, as they clearly explain, the NHSx is still working on guidelines for developers that will define a set of processes to undertake in order to build transparency and trust.

This is what the AR sector needs, this is what Augmented and Virtual Reality needs, this is what blockchain needs. It is no longer acceptable for policymakers to wait for a technology to struggle to get into the market to start making the appropriate regulation, not when patients are the ones ultimately being affected by this. Policymakers need to get ahead of the developers and the market needs, regulating, guiding and supporting the adoption of health innovation.

On the other hand, the current European Conformity (CE) mark for medical devices, in its three categories, does not offer any clarity for the categorisation of AR. Due to the opportunities that AR provides for the diagnosing, monitoring, treating of diseases or handicaps, is not sure how to categorise the technology: either as class I, class I(a) or class II. Then, the current EU directives to be applied are those of machinery and medical devices, the same to be used for the development of wheelchairs or pacemakers (McCulloch, 2012). As a consequence, it comes naturally to ask how do you regulate and guide developers dealing with autonomy, deception, trust and responsibilities of AR technologies while you benchmark them like wheelchairs. Take, for instance, the British Standard BS 8611:2016 Guide to the ethical design of robots and robotic systems (British Standards Institution, 2016). It is a tool for designers to undertake an ethical risk assessment of their innovations. These guidelines should be further developed and added to the current EU directives for the CE mark of medical devices, to guide robotic companies.

The EU commission has been trying to adapt the tech to the current regulations and not the regulations to the technology. Yes, the electronic and mechanical system of AR technologies are similar to other machines, but the autonomy and decision making that AI gives to these machines is something we have not seen before. Once more, AR is not mHealth, it is not an app. A machine that is capable of understanding the environment, taking real-time decisions, and physically or social-psychology interacting with the user and the environment has not been seen before. The evolution of the state-of-the-art will only bring new opportunities for AR, disrupting traditional care, and our lives.

Furthermore, the current regulation was aimed at companies with the resources to withstand a long and financially demanding process to get the certification (McCulloch, 2012). It was never conceived for start-ups and this new generation of entrepreneurs. As mentioned, drastic changes are needed to face today's healthcare challenges. We cannot expect start-ups to follow the same path that big manufactures face, we are only inhibiting innovation from small and young groups.

Understandably, the regulation will have to follow the functionality of the technology, which represents another challenge due to the broad scope of AR applications (*Chapter 3*). For instance, we cannot impose the same regulation of exoskeletons to robots that will assist in cognitive or talking therapies. One could be used for physical rehabilitation, the other will impact mental and emotional problems like stress, anxiety and depression. Their interaction and effect on its user are different. There is simply not a one-size-fits-all solution. Therefore, it is imperative that regulatory agencies keep looking for innovations in the field and, working with the product developers, start establishing early guidelines for their technologies.

Today, were constant, complex and disruptive innovations are being developed for the sector, knowing how to structure regulatory interventions has become more challenging. However, we need to seek for alternatives to avoid reinforcing the status quo that only avoid new solutions from reaching the market. Moreover, while the International Organization for Standardization (ISO) has been trying to generate safe risk assessment and hazard reductions strategies for the robotics sector, there is still room to grow (Villaronga, 2016). ISO 13482 is the current standard that outlines safety requirements for personal care robots. However, it does not apply to devices that *"have the purpose of diagnosing, preventing, monitoring or treating diseases or handicaps"* (Jacobs and Virk, 2014). Therefore, it only focuses on mobility and navigations. For any other AR application, there is no other standard. IEC 80601-2-77[6] deals with rehabilitation robots and the IEC 80601-2-78 with surgical robots. Figure 24 shows the current gaps in safety standardisation (next page).

Standards provide a methodology for risk assessment as well as a list of significant hazards. This information is needed for the AR sector, to support developers in their aim of creating efficient but safe devices for everyone.

To advance the use of AR, this thesis claims the importance of developing directives and standards for the sector. It is essential to create new evaluation and appraisal tools to reduce certification and approval time. This could be seen as deregulation, but the establishment of new rules should be prioritised since the technology and its scope is entirely different from any other technology.

In the same way, governments should encourage and facilitate the use of AR. It should also regulate the acquisition of data, prioritising user privacy without hampering technology developments. Cooperation between countries should be seeking to explore the effect of AR technologies with different cultures and healthcare systems. The fragmented EU system has to lay down rules for the adoption of AR, including

[6] International Electrotechnical Commission (IEC)

benchmarks that will allow decision-makers to compare different alternatives and make informed decisions.

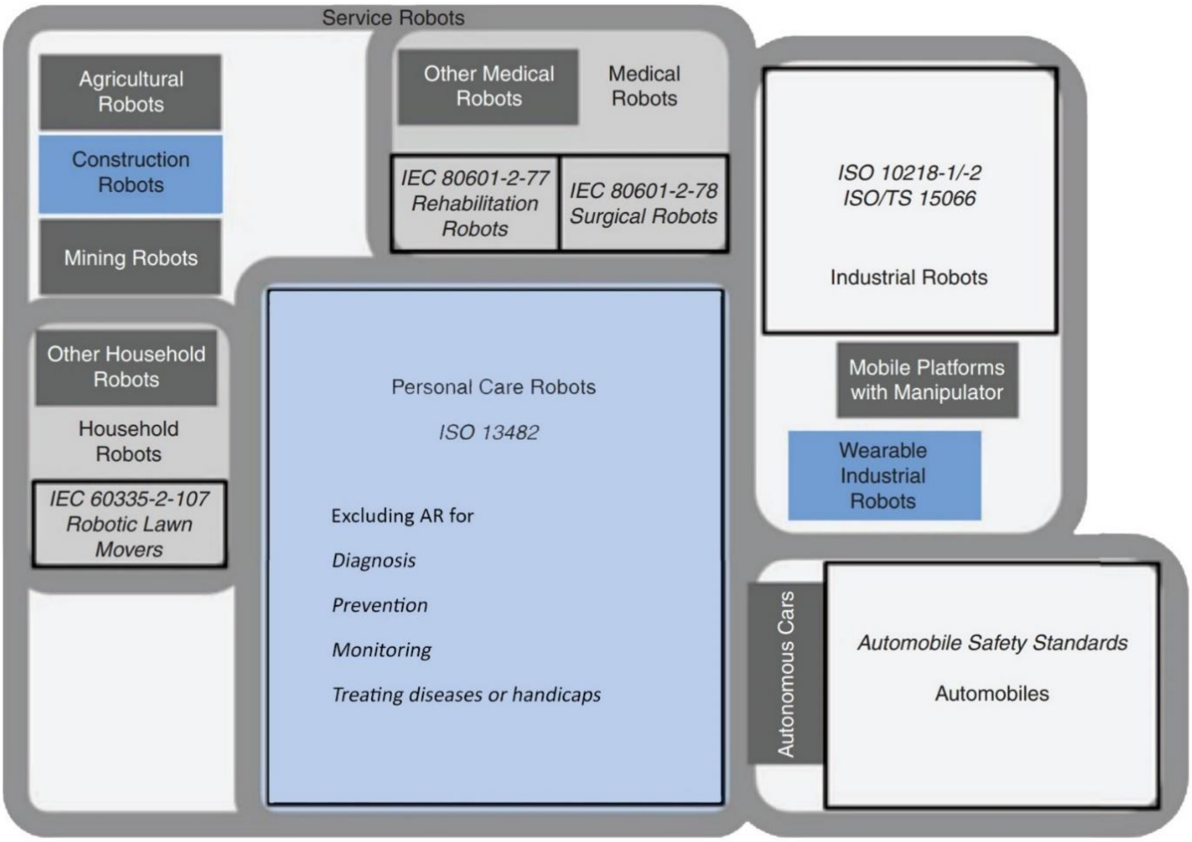


Figure 24; Current safety standardisation map. Based on; (Haidegger, 2016)

The only way to achieve all this is by working closely with the producer sector, with the start-ups and companies that are pushing this market forward. For instance, the Food and Drug Administration (FDA) is an exemplary institution in collaboration with AI companies. In 2019, through their discussion paper (FDA, 2019), they released an open call to companies working in the sector, to present their concerns and notions for a regulatory framework. Similar approaches are what we need if we expect policymakers to be at the forefront of technology innovation.

Chapter 7

AR Technology Strategy: Technology Development

This chapter gives practical recommendations to AR start-ups for the development of their business and technology. The recommendations presented are based upon the work and reflections of the companies that this thesis has interacted with: 28 AR firms, including eight case studies (*Chapter 5*).

This chapter provides guidelines around market segments, followed by an analysis of value creation opportunities, and open innovation strategies for the companies. Then the chapter proposes a model for the development process of AR. It ends by providing an analysis of AR evaluation and the design and development of the Robot Home lab.

7.1 Ideal market segments

There are, of course, some specific segments more willing to accept AR. While I have described the importance of assessing the regions' healthcare challenges in order to contribute to the organic growth of the market (*Chapter 6*), we cannot overlook worldwide market trends. By understanding these trends, the ecosystem developer (ED) and AR start-ups could anticipate customers' needs.

One of these market segments is the ‘silver economy’. The growth of the ageing population is changing market behaviours (European Commission, 2014). We are seeing more spending on health, tourism and leisure for seniors and new requirements and services related to older people living independently (Wittenberg et al., 2004). Meanwhile, care delivery will have a deeper impact, with shortages in staff to address the population increase (European Commission, 2012). Workload will rise for carers, while the quality of senior care will decrease unless we can meet the requirements of this new demand (Czaja et al., 2013). This is a significant opportunity for AR technologies and companies that are targeting the silver sector. Even more, the first AR start-up from the EPIC Start programme (*Chapter 5*) developed a companion solution for this sector (*Annexe A – Robotriks*). The company decided to work on this application due to the segment openness and need for innovations.

Senior care in its different forms (i.e.: care homes, day centres, retirement apartments) is a sector that has been more receptive to AR (Dahl and Boulos, 2014). For instance, most of the challenges collected from our workshops focused on supporting seniors (*Chapter 4*). Cognitive decline, muscular dystrophies, hearing and sight impairments are some of the challenges that were raised at these events. As a result, there exist opportunities for AR start-ups to develop dedicated solutions for the ageing population.

Robots can automate daily physical activities for seniors, but also support the management of medicines, finances, medical controls, social interaction, shopping (Prescott et al., 2012). The AR sector also aims to enhance seniors’ mobility, promoting independence. It also includes market opportunities for technologies that explore companionship to help seniors stay mentally and socially engaged.

Overall, every activity of daily living brings an automation opportunity for companies (*Chapter 4*). Moreover, while seniors could be the end-user, other segments such as people with multiple sclerosis, Parkinson or physical disabilities could become side customers.

At the same time, empowering carers with the tools to deliver a quality job has become the focus of multiple R&D projects (EUrobotics, 2017). These include AR for supporting the transfer and monitoring of patients (CHIRON, 2016) and also robots for keeping them engaged in group activities so the staff could focus on one-to-one support. Even more, administrative and logistic tasks bring new opportunity for start-ups. For instance, sorting medicines or conducting and assessing different wellbeing and clinical assessments.

All these opportunities and the imminent need for improving traditional care makes the senior care sector more open to AR.

In this line, household appliances and housing devices are open segments as well. Since robotics brings the opportunity to automate every activity of daily living, it is not surprising to see companies working in kitchen automation (e.g., (Moley, 2020)), house control (e.g., Ballie (BBC, 2020)) or handicap assistants (e.g., iEAT (Assistive Innovations, 2020)). People with learning disabilities, cognitive decline or people that suffered from cerebrovascular events can benefit from smart homes enhanced by AR (Ehrenhard et al., 2014).

It is in this field where robots could take a central role at homes soon. Acting as central hubs, sensing and interacting with other devices, robots can manage smart homes and physically interact with the environment. Start-ups will have a bigger market size working in this sector since their devices could also support the public in general. It also allows companies to follow regulation paths for electronic devices and machinery instead of medical devices (Jacobs and Virk, 2014). The Internet of Things (IoT) market also opens the doors to AR technologies willing to work with current standards and communication protocols, allowing easy integration of third-party devices and IoT services (e.g.: IFTTT). Moreover, it is easier to develop and test devices to be used in a home setting rather than hospitals and clinics.

Conversely, developing robots for the delivery of therapies with children with autism, down syndrome, learning disabilities, communication impairments, or psychosocial impairments have proven challenging. The French company Leka (Leka, 2014) is a clear example of the difficult path for companies working on these sectors. The company was founded in 2014 to support children with autism to improve their communication skills using AR. Since then, the company has gone through some rounds of funding, securing $590K (Crunchbase, 2020). In 2018, the company was able to launch their alpha programme, offering not yet a final product for consumers, but a prototype for HCOs and education centres to pilot their device. Currently, the company has not started continuous production yet. It has been more than 6 years.

This is the story of AR start-ups working in this challenging field: going through several rounds of funding, launching a viable prototype in a control scheme, and improving the device accordingly. This should not be read as a discouraging message but as a warning.

7.2 Development recommendations

While the market's perception of assistive robots shapes around a dynamic platform capable of supporting people in several activities of daily living (i.e.: 'a robotic butler'), we are still far from delivering this dream. First, researchers and entrepreneurs must address current technological challenges around AI, sensing and recognition, autonomy and security, and human-robot interactions. Then, the AR market needs to win a global presence by exploiting market opportunities. Finally, companies should learn to grow together to increase their success opportunities. These three topics are analysed in this section.

7.2.1 Technology challenges

It is a challenge for robots to operate closely and physically with people (Dahl and Boulos, 2014). Advances are required in high-performance actuators, tactile sensors, grippers, and manipulation. Besides, for AR to fulfil social isolation challenges, improvements in automatic speech recognition are needed. Noisy environments, places with echo, or even big rooms, interfere with speech recognition systems. Even more, speech recognition must support a broader range of voices, accents, intonation, and dialects.

Research is also needed in cognitive robotics. If we want to deploy robots that will help people remain in their homes, robots must be able to operate in these environments. This requires work in three areas: locomotion, active sensing systems and AI capabilities. AR technologies must be capable of mapping and understanding human environments (SPARC, 2014). They must be able to understand where they are in any home and how to navigate around. This is not an easy task due to changing environments (i.e., people and objects moving). Then, stairs, carpets, irregularities on the floor, are some of the well-known locomotion challenges for AR. On the other hand, object recognition must cope with different problems as natural and artificial light interference, or the full range of designs, shapes and colours of everyday objects. However, we have seen computer vision capacities improved by AutoML Vision or using pre-trained Vision API models (Google LLC, 2019).

Autonomy and safety are also a leading area of research. Assistive technologies must operate 24/7 with full autonomy. Companies have to improve self-monitoring and failure-detection systems of robots, but also failure protocols. If the platform is going to fail, it must know how to fail. Developing failing protocols will not only ensure the safety of the user but also of the technology. In the same way, AR devices should be skilful at dealing with unpredictable events, always prioritising the safety of the user.

7.2.2 Value creation opportunities

The work with the AR companies engaged in this thesis (*Chapter 5*) evidenced that robots that perform simple tasks instead of providing a set of applications for people are more likely to see the market. Developing a technology that addresses a singular activity, rather than a set of options, is faster to develop. In addition, if the company focuses only on one primary function, it will be easier to achieve a higher level of autonomy. Besides, the learning curve for users will be shorter and therefore, the usability and acceptance of the device will be higher (Winter, 2016).

Therefore, I encourage developers to focus on the automation of routine, monotonous and hard labour activities. Start-ups should work on specific activities rather than in a set of capabilities.

The market has provided some clear examples of this subject. For instance, Jibo; a robotic company that secured $72.7M on funding (Crunchbase, 2019), but after deploying their first batch of products in 2018, negative reviews ended the company the following year (van Camp, 2019). While developing this home assistant robot, the firm promised a product that will entertain the family, support you with your shopping, cooking, video calling, security, reminders, and more high interactivity activities. The result was a product that could not live up to its expectations.

You cannot add value to your product if this cannot deliver first its primary function flawlessly. By working on one activity, you clearly explain to your healthcare sector what they will get and what they should expect. It will also allow firms to plan a coherent development process and secure the appropriate funding.

By taking this approach, the company could build internal platforms. A mechanic system, a code, a design, could become the base for future products (Gawer and Cusumano, 2014). AR technology infrastructure must be designed to enable simplified system integration and flexibility to satisfy diverse needs. To tackle these challenges, developers should enlarge the application of module-driven robots from both the hardware and software perspective.

If the hardware and software functional elements of a robot could be modularised, robots could be constructed at a lower cost. New modules could be used in a wide variety of AR technologies, different applications and different user groups. Additional, these modules could undergo independent CE mark validations, allowing developers to use modules already certified in future developments, saving time to market. This also represents an opportunity for achieving an economy of scale.

One way to achieve modularization is by working with already available solutions in the market. While Google Assistant and Alexa currently control the voice assistant market, we still see start-ups developing their own clouding solutions for speech recognition. Take, for instance, Softbank's speech recognition solution. This is a company far from being a start-up, but stills failed to realise this mistake. The system that is used in the Pepper and Nao robots, used during this thesis, was hugely ineffective, unable to work in crowded environments or open rooms as I evidenced in the engagement events with the HCOs. Besides, the speech recognition in autonomous mode was useless when the speaker is in a frail condition. The problem increased with the word-to-word recognition system (instead of a context recognition) and its poor microphone arrange. Therefore, while Softbank invested plenty of resources, it ended up delivering a poor recognition system that decreased peoples' acceptability to the robot. Google and Amazon offer superior platforms for developers to build their speech applications, and some big robotic companies have chosen to work with them (e.g.: UBTECH with their robot Lynx).

The same applies to machine learning libraries and cloud computing packages. Of course, working with third-party services mean sacrificing some ownership of the innovation. But instead of reinventing the wheel, and struggle in the process, companies could start focusing more on their AR application. In addition, the device will have a better adoption opportunity if it integrates third-party services that are already known, trust and used by the final user.

For instance, IoT for smart home automation. We currently see in the market two options: you develop your own hub or you apply the communication protocols used by Google Assistant, Amazon Alexa or IFTTT. Phillips and their smart devices have their own hub, which connects with several devices such as smart lights, sensors or smart plugs. If the user wants to control one of these devices, it does so through Phillip's hub. However, since people are using Google Assistant and Alexa hubs for controlling their smart devices, Phillips realised that they needed to be compatible with these two systems. Now the Phillip hub is just redundant for clients.

AR start-ups should avoid making these mistakes and integrate popular third-party services from the beginning.

Even more, the current structure of robots is evolving due to developments on digitalisation, cloud computing and other network foundations. The conventional structure of seeing robots as a machine equipped with sensors, control unit and actuators is no longer the rule. Now robots can be driven by remote intelligence (AI system running on the cloud). Also, interconnectivity with smartphones allows developers not to rely on a significant control unit in the device. New smart sensors being used on house automation (e.g.: cameras, movement detectors, temperature) allow developers to integrate their data to the AR application. Entrepreneurs need to explore these opportunities and keep a broad perspective of what constitutes a robot.

Finally, robots are also bringing opportunities for business around data collection. I already mentioned the role AR could take as central hubs in smart houses, receiving people's commands and sensors data. Through this, robots are key devices for gathering data in an already data-driven society. This data could be used to develop new applications. For instance, if an AR technology is already monitoring the progress of a patient's condition, data could be collected to predict when someone with the same condition will need an intervention. Take for instance the current pandemic we are facing due to COVID-19 and the opportunities that AI monitoring will bring to control the disease proliferation.

While start-ups should address privacy and ethics issues in the design and production of their inventions, it is naive to overlook the opportunities that data collection brings to the market. New products, opportunities of diversifications or monetizing data are strategies that AR firms should consider and plan since the early stages of the development.

7.2.3 Open innovation

This has been the topic of policymakers for the last twenty years (Chesbrough, 2003). Still, open innovation is a concept difficult to adopt (West et al., 2014). The term is used to promote an information age mentality toward innovation that opposes the secrecy and silo mentality of traditional industry (Chesbrough, 2003).

In markets where the added value of products relies on an algorithm, secrecy is the defence mechanism of several start-ups. Furthermore, the substantial rights for inventors to appropriate the returns of their inventions has reduced openness and collaboration. However, seeking IP protection is an expensive process that could take five years (Intellectual Property Office, 2019). According to the Intellectual Property Office, only one in 20 applicants get a patent without professional help, in a process that typically costs £4,000, without including the annual renewal cost and the costs of legal action if you need to defend it. Therefore it is clear that early-stage start-ups are often better off if they "free reveal" their inventions to others rather than seeking formal IP protection. For instance, when companies share their technologies as part of a reciprocal exchange with other parties using non-disclosure agreements (West et al., 2014). Through these agreements, companies will have enough protection if the product is likely to sell for only a short time. Nevertheless, it is understandable why start-ups are not willing to work with other companies for the same fear of losing ownership of their developments.

Big corporations have been the ones driving the concept of open innovation, by externally acquiring and exploiting technology (Chesbrough, 2003). However, firms could choose openness strategies to build a reputation, gain market share, attract contributions, or grow the market. This last benefit of open innovation is the one that AR companies should seek.

Open innovation for the AR market should be understood as the collaboration between industry, SMEs, academia and HCOs to create intellectual and economic impact. A collaboration that will focus on co-creation principles as explained in the previous chapter, but also in raising awareness of the AR opportunities. Currently, AR start-ups have to invest financial and human resources, not only on advertising their product but also the AR sector in order to increase public awareness and break misconceptions of the technology. This openness strategy aims to help AR start-ups grow their market.

7.2.3.1 Private cooperation

Technology literacy is one of the barriers that inhibits technology adoption in HCOs (Ross et al., 2016). It was evidenced that delivering training on staff and public around digital dexterity improves people's attitudes towards innovation and the usability of devices (Llewellyn et al., 2014). This is something I evidenced with AR technologies during the drop out sessions described in Chapter 4. Hence, when AR start-ups are training an HCO on the use of their device or even during a pilot evaluation, they are contributing to the knowledge awareness process and improving the skills of the market's future costumers.

I encourage AR start-ups to work together on user literacy by sharing good practice around AR manual design and training programmes. For instance, a caregivers' manual for robot therapy use or protocols for using an AR technology with children with Down

Syndrome. Designing manuals and training programmes is not an easy task, even more when we are talking about technologies that our end users have not seen and interacted with before (Wada et al., 2010). Therefore, the structure, wording and overall design should be carefully considered and evaluated first.

By sharing findings around manuals and training programmes, companies will not be disclosing IP material. Instead, they will be helping other start-ups deliver documents and training programs that will increase the overall skills of future clients.

It is highly recommended for companies to work together on this, collaborative arranging training programmes and workshops, and visits to HCOs, universities and schools. Publications, reports, social media, are channels that AR start-ups could target as well as providing material for increasing the technical skills of the region. This will also promote the companies' philanthropy-marketing strategy. Therefore, the collaboration should go beyond just sharing guidelines, to working together, raising awareness and openness.

AR start-ups need to be aware of this, no one is going to help you developed the technology literacy of your user group. Waiting for universities or schools to change their curriculum and add AR subjects is certainly something out of their hands. It has been more than twenty years since the market saw its first smartphone, nevertheless, we are just starting to include digital tech literacy into nurses' curriculum.

In the same way, risk documentation is another area for collaboration between AR firms. If you are placing a product to the market, you should conduct a risk assessment of your device (section 7.3). Here companies should document the hazards identified, safeguards and protective measure to reduce risks (Jacobs and Virk, 2014). While AR start-ups are not asked to share this information with the public or HCOs (they will have to report residual risks with their final users (Jacobs and Virk, 2014), it is recommended to share the hazards found with the AR start-up community.

First, this will help start-ups identify possible issues they did not consider during the design process. By reducing risks, the AR company now will be less likely to harm a final user, including the evaluation process. In the long run, if an AR device harms a user, the whole image of the market suffers and therefore the image of your device. By sharing risk reduction strategies, your company could be preventing a fall in the process of AR acceptability. Even more, by promoting this spirit of openness, you could identify risks or even support the creation of a platform company that will address your shared challenges.

Finally, it is essential to start joining a standard frame for the development of AR technologies; standardisation of parts. Nowadays, you could make an analogy between the AR market and the early automobile sector. During the 1890s, all car manufacturers were developing their own parts without any consensus, without any standards (Kaplinsky, 2010). This translated into poor complexity management, increase production costs and increased time to market. The same cases apply to the AR market.

Standardisation reduces the number of suppliers start-ups need and will eventually assist in lowering acquisition costs. It also decreases the production cost when seeking economies of scales. Standardisation supports developers mitigating risks and accelerates the certification process and entrance to market (Lichtenthaler, 2008).

Due to all these advantages, I encourage AR start-ups to keep development alongside normalisation and standardisation of individual devices and software including middleware interface for building networked robot system and communication protocol for device interoperability. Since we currently lack production standards, the first step is to establish a centralised AR group who can aid in developing production standards. At a micro-scale, this will represent AR firms interacting in an ecosystem.

7.2.3.2 Public-private cooperation

The previous chapter has extensively shown the role that universities can play for the AR market while working as EDs. It also presented the collaboration that is needed between HCOs and developers to foster innovation. Now, this section will only make emphasis on evaluation support for the AR market to overcome ethical concerns and safety.

Collaboration between firms and universities has proven beneficial for both parties as a mechanism to accelerate the development process, apply innovative research and provide real case scenarios for researches (Hottenrott and Lawson, 2014). The most important asset that AR start-ups will encounter in public-private cooperation with academia is the creation of user-case studies and their evaluation.

As explained in Chapter 6, researches count with the knowledge to run complex evaluations such as randomized control trials that companies without the experience would find extremely demanding to undertake. They also have the workforce to run these experiments and the resources to collect and analyse the experimental data. AR companies could use this support in order to generate critical evidence about the health outcomes of their innovations or economic analysis.

It will allow developers to test the acceptability and usability of their devices through parameters as psychophysiological or behavioural measures. While working with participants with specific conditions (as genetic disorders or cognitive impairment), academics have the experience and knowledge to correctly interpret participants' answers. All of these serve as an essential tool for start-ups willing to open their innovations to universities.

7.3 Development process

This section aims to provide a process that will allow start-ups to include quality management systems (QMS) during their early stage of development. This is the main contribution of the proposed model. QMS is a set of processes and procedures companies define and implement to describe how your product is fulfilling user requirements and safety (Nanda, 2016). This has the main objective of reducing the risks for users (Jacobs and Virk, 2014).

Early studies from product development research date from 1969 where Myers and Marquis, studied the development of 567 in-market products and processes (Myers and Marquis, 1969). Since then, different models have been described for different industries (Brown and Eisenhardt, 1995). On that balance, this section aims to deliver a model for the development of the emerging AR market building upon QMS.

Current start-ups have entirely overlooked the importance of QMS, most importantly, those innovating in the healthcare sector. The agile philosophy for start-ups has been mistakenly taken as a process that overlooks quality; fail fast and iterate quickly. In the race to develop an MVP, developers forget to spend time looking at how current regulation could be implemented, how this could help them develop a better product and how it could reduce risks for users. This cannot be overlooked in the AR market. Take, for instance, service robotics companies offering monitoring solutions. In the UK, the Care Quality Commission has established several guidelines for the monitoring of patients to protect people's privacy, dignity and respect (CQC, 2018). Companies working on this segment cannot overlook this and other recommendations and guidelines.

The current regulation for AR is quite vague and incomplete as explained in Chapter 6, and it is certainly not clear for companies. Nevertheless, that does not mean that start-ups should just wait for regulatory agencies to respond.

It was evidenced through my work with the AR start-ups (*Chapter* 5) that even in the early stages of development, entrepreneurs can follow directives, from other technologies if necessary, to frame the development process, assure the safety of the prototype and guarantee that the prototype meets user needs. The quality of all the parts and pieces of your devices depend upon the process for developing them, and the quality of the process can only be improved if you refine it since the beginning of the development process, starting with your first prototypes (Nanda, 2016).

In an attempt to frame the AR development process under current QMS standards, the model proposed in this section followed Design Control parameters ISO 13485 (ISO, 2016). I did not use FDA 820.30 due to this thesis being linked with the European community. Either way, due to the strong similarities between them, and recognition of ISO by the FDA, this development process could also guide entrepreneurs working in the US.

This model does not focus on things like budget, timeline, production/ramp-up, business development, marketing, sales, and so on since they are inherited from the AR application of each venture. This section will not focus on the standards for electrical, flammability or biocompatibility either. They are described in:

- ISO 14971 and IEC 60601 series; for robots used as medical electrical equipment.
- IEC 80601-2-78; for robots used in rehabilitation, assessment, compensation or alleviation.
- IEC TR 60601-4-1: for general medical devices with a degree of autonomy.

Moreover, the presented process does not include the co-creation process between the start-up and the HCOs since it was already described in Chapter 6.

Instead, this section presents a model for AR product development that adopts QMS terminology and methodology. This v-model involves feasibility testing, concept development, system-level design, prototyping and testing. The model is shown in Figure 25.

The critical element of QMS is the documentation. ISO 13485 requirements expect developers to keep documentation and records through the product development process (ISO, 2016). The proposed model incorporates this. Documentation will also allow companies to define their project goals and support the communication of the project to funding organizations. Having said that, entrepreneurs should not get overwhelmed or stuck with the requirements or process documentation: learn, practice and improve.

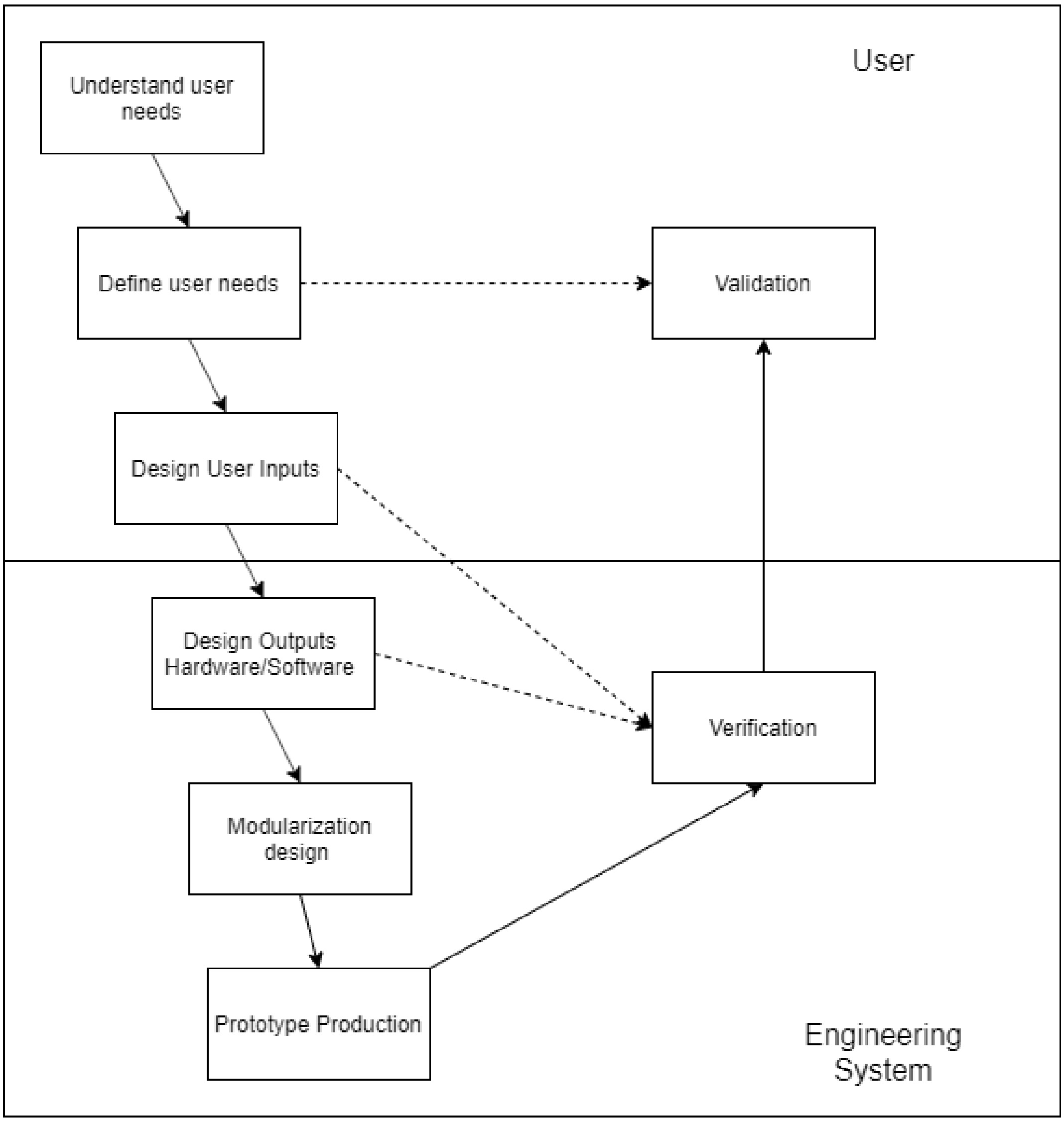


Figure 25; Assistive robotics development process.

7.3.1 Defining user needs

The first stage of the development process involves understanding and defining user needs. In the design thinking methodology, this stage is known as empathy (Kolko, 2015). That is an accurate name since it is needed that start-ups seek to understand how the final user is experiencing the challenge to solve. This could be achieved through interviews, co-creation workshops or shadowing the user (Kolko, 2015). It also involves exploring carer and clinical needs and constraints, since they represent important requirements for the design of the innovation.

Once we have understood the user needs, including the needs of the family and carers, we enter the first documentation stage: defining user needs.

Defining user needs means describing how your AR technology is going to be used. The intended use; what exactly your AR product will be used for. Do not focus on what it could or could also be used for. Instead, define what the robot will do in as few words as possible.

Here are some questions that will help start-ups define their user needs:

- What do you want the AR product to do?
- Who is going to use it?
- When will it be used?
- Where will it be used?
- How will the user interact with the AR device?
- What inputs will the AR technology collect?
- What decisions will the device take?
- How will AR technology interact with its environment?
- What other products will the AR device interact and interface with?
- What level of autonomy will the AR devices have?
- What data should be collected/required from the user? (e.g.: medical records)
- How will private data be stored and processed?

7.3.2 Design inputs and outputs

Design Inputs are the physical and performance characteristics of the device (Nanda, 2016). This includes:

- Device functions
- Physical characteristics
- Performance
- Safety
- Reliability
- Human-Robot Interaction
- Maintenance
- Sterilisation
- Compatibility with other devices
- Environmental limits
- Operating System
- Middleware
- Type of Data
- Access to Data
- Privacy and handling of data
- Training method
- Ethics

Designing inputs is planning your product roadmap: explaining everything essential and required for your device. It follows the step of user needs definition since this is the primary input for this stage.

Here we will also define what elements require more research. The key is to establish clear and objective design inputs that can be measured. These inputs will iterate, evolve, and be thoroughly defined throughout the whole development process.

Design Outputs are commonly known as the recipe for building the prototype. A design output could be a drawing, a specification or an assemble instruction. When you are describing the components, parts and pieces that go into your prototype, you are working on design outputs. This includes all assemblies and subassemblies of your product: the processor, actuators, controllers and sensors.

For the AI element, this constitutes the data cleaning, the training set, the development set, test set, training method, testing method, optimisation methods, techniques for reducing bias and variance. Companies need to be as transparent as possible with the training of their algorithms; explainable AI (section 7.4.2).

Once we have reached this stage, we will be able to build the prototype budget. Developing an AR prototype will demand substantial seed investment as explained in the previous chapter. Without a clear cost plan, we will not be able to understand the funding needed and could run out of budget before completing the prototype. We could also overstate the amount needed.

7.3.3 Modularization and prototyping

Here we focus on the ***modularization*** of the design. For software, modularization is organising the code in smaller part (i.e., modules), and for hardware the subsystems. Start-ups should focus on what could be independently created, modified, replaced or exchanged between different modules. It is also an opportunity to explore which module could become a product platform for further developments.

Each prototype will have different requirements, different goals and different challenges. We cannot give a list of challenges that the start-up will face while developing their prototype. This is when an AR company takes competitive advantage from others, employing the talent and skills of their team, minimising cost and time, and achieving prototypes that are ready for evaluation.

7.3.4 Verification and validation

Verification is assessing if the design outputs fulfil by objective evidence the objectives defined in the design input stage (Nanda, 2016). This means that we go back and evaluate whether or not the prototype fulfils the initial requirements we defined. In this stage, you answer the question: did I build the right prototype?

We need to be sure that the prototype is in optimum conditions to go to the validation stage with the user. This is the aim of this stage, reduce risks before the evaluation.

First, plan your design verification assessment, addressing the question: what are you going to evaluate? Focus on how the detailed ***designed outputs*** are meeting the requirements set in the ***design inputs*** by assessing the prototype built. Then define how you are going to assess this and do it.

Start-ups must document this process. Only then, start-ups can enter to an HCO and show evidence of how the prototype they want to evaluate has followed a QMS, and how the company has made everything possible to reduce any harm while testing the device with a patient.

Until fulfilling desired verification results, keep iterating, either by improving design outputs, modularization or prototype production (*Figure 25*).

Validation is testing if the prototype meets the defined user needs and intended use with the user. Since validation has been seen as a significant task for the entrepreneurs and AR companies engaged in this thesis, the section below focuses on this subject.

If the validation is not successful, review user inputs and continue the process again (*Figure 25*).

7.4 Evaluation

A knowledge gap around AR evaluation was identified working with the start-ups in Chapter 5. Furthermore, evaluation support was the main service I provided to companies, internal and external to the region. Therefore, this section provides some recommendations and tools for AR start-ups to evaluate their AR prototypes. In addition, I describe the development of the Robot Home for the evaluation of AR, an attempt to support entrepreneurs with the testing of their devices in a controlled environment.

Through this entire thesis, the need for a regulatory framework for AR has been argued. For developers, the absence of a critical appraisal tool prevents ventures from fully exploring the benefits and risks of their devices under industry standards, including healthcare outcomes. Test and experimentation platforms are a significant tool for developers towards bringing technology into the market (Ballon et al., 2005). Even more, benchmarking devices are vital for HCOs and decision-makers in their pursuit of cost-effective equipment (Mieczkowska et al., 2004). However, while robotics evaluations have adopted and modify methods from the field of human-computer interaction, human-robot interaction is similar, but not identical (Kidd and Breazeal, 2005). We need to develop protocols as an open research issue in assistive robotics. This sections also aims to start contributing to this issue by providing recommendations and guidelines.

7.4.1 Mechanics and material

Mechanics and material testing have been perfected in the last century. However, modifications should be done to testing facilities, not the methodologies, for assessing AR.

An excellent example of facilities suitable for AR evaluation is the AIST Robot Safety Centre in Japan (AIST, 2015). While they mostly provide safety evaluation services to their members developing exoskeletons, mobility aids and mobile servants (robots that assist moving/getting objects), they have set up the required equipment for the mechanical evaluation.

The lab offers:

- Collision avoidance test,
- Collision test,
- Durability test,
- Environment test (temperature, humidity and vibration),
- Dynamic stability test,
- Electromagnetic compatibility test,
- Optical sensor test.

These are the assessments expected for companies to go through in this category. Some of these evaluations could be overlooked while doing the first iterations of the AR prototypes. However, the MVP is expected to pass and document the results of these tests.

7.4.2 Data for AI

With the implementation of the General Data Protection Regulation, we see more nations trying to regulate how companies acquire data from their users. Data is the foundation for AI and machine learning since without it we cannot train our models. Therefore, the regulation of data acquisition has a direct impact on the development of

AI applications, and in its regulation. Take, for instance, the NHSx and their recent report on Artificial Intelligence (NHSX, 2019).

The report aims to start framing the development process of AI for digital companies. It is an attempt to raise awareness about the opportunities but also the risks of developing machine learning algorithms for the healthcare sector. However, the report focuses on data acquisition and not on the technical requirements for the training, optimisation and evaluation of AI.

The NHSx has already established the importance for firms to comply with the *"algorithmic explainability"* to provide *"clarity to patients, users, and regulators on the functionality of an algorithm, its strengths and limitations, its methodology, and the ethical implications which arise from its use"* (NHSX, 2019).

Currently, they are still developing the elements that will be part of the explainability requirements. Due to complex mathematical theory, the impressive practical success of AI in different application domains is comparable to its ongoing inability to"explain" their decision-making in an understandable way (Core et al., 2006). For AR, explainable AI is allowing healthcare professionals to understand how and why a machine decision has been made (Holzinger et al., 2017). However, this is not an easy task.

This highlights the importance for start-ups to start documenting the machine learning process and be aware of how they collect and process the data of people.

7.4.3 Social assistive impact

AR devices could be designed to support psychosocial behaviour of users, cognitively stimulate patients, therapy interventions, life management and more (*Chapter 3*). This brings one main question to firms: how we assess the healthcare benefits of our device?

Traditionally in human-robot interaction studies, there are three main methods to collect participants' feedback and assess outcomes: self-report measures, behavioural measures and psychophysiological measures (Bethel et al., 2007).

Self-report measures are one of the most used methods (e.g., questionnaires). However, start-ups need to understand the importance of spending time designing and testing questionnaires before beginning an experiment. They have to identify guidelines for the wording and the structure for their questions. They should define what they want to assess and how to measure it (see section 7.3).

This is when reviewing clinical assessment tools supports entrepreneurs. For instance, questionnaires as ICECAP-O (Makai et al., 2012) or the WEMWBS (Tennant et al., 2007) constitute a useful source for start-ups to adapt questions that will explore the wellbeing effects of the robot intervention with seniors. For ventures focusing on exploring depression and loneliness, the CES-D (Radloff, 1991), the CEL 3-question scale, the Giervald scale, or the UCLA scale constitute useful resources (de Jong Gierveld and van Tilburg, 2016). For assessing social isolation, start-ups could rely upon the Duke Social Support Index or the Lubben Social Network Scale (de Jong Gierveld and van Tilburg, 2016). In more general terms, the SF-36 questionnaire represents a sensible source for researches studying robot intervention impact in users' general health (Ware and Sherbourne, 1992). This is not an exhaustive list, but by reviewing these tools, entrepreneurs without clinical training can understand how they should approach the design of their questionnaires.

In the same way, I recommend using UX and UI tools developed by the digital industry for the evaluation of their device interface. For instance, structuring the questionnaire upon scales such as Perceived Usefulness, Perceived Ease of Use, Satisfaction, System

Usability and Features Rating will allow benchmarking the robot with another digital interface. Annexe I shows a questionnaire guide I developed for the evaluation of UX and UI for assistive robots, plus some practical examples on how to incorporate some of the mention clinical assessments. These tools were used during evaluations such as Stevie and Genie Connect (*Annexe A – case studies*), where we explored the usefulness and features rating of their respective devices.

Behavioural measures, on the other hand, focus on the conduct, functioning and actions performed by the participants (Sidner et al., 2004). Body language and physical contact become one of the main ways to communicate while working with people with different conditions. For instance, (Sidner et al., 2004), (Breazeal et al., 2005) or (Swangnetr et al., 2010) are some of the multiple examples of communication research studies that gather behavioural measures. Here, entrepreneurs could use an open coding system to classify gestures, facial expression and body language. I recommend using a five-point Likert scale assessing valence and arousal (*Annexe I*). Arousal and valence scales can label quality and intensity of affective body language by utilising a broad range of affective states disregarding if the participants are standing or seated (Kapoor et al., 2007; Kleinsmith et al., 2011; McColl and Nejat, 2012; Sanghvi et al., 2011; Savva and Bianchi-Berthouze, 2012). These scales are useful in describing a persons' affective behaviours during social interactions and can be used to measure the appearance or interaction modalities of the technologies (Carney and Colvin, 2010).

Finally, the use of psychophysiological measures (e.g. electroencephalogram) is challenging and difficult to analyse for start-ups without prior experience in the field. While they constitute a quantitative source for the evaluations, using electromyography techniques, for instance, is a difficult task. While some devices offer alternatives (e.g., Emotiv EPOC+), the data could be challenging to interpret. It is advisable to request support from trained researchers. (Bethel et al., 2007) presents a compressive experiment design tool for firms exploring psychophysiological data.

7.4.3.1 Dedicated Facilities, The Robot Home

Facilities are needed to objectively collect data that will allow ventures to assess the outcomes of their innovations, but also to inform the healthcare sector. We can categorise six concept categories: traditional labs, testbeds, field trials, living labs, market pilots and societal pilots (Ballon et al., 2005). Firms' decision should rely upon two significant factors: commercial maturity and level of design focus (Niitamo et al., 2016).

For instance, traditional labs experiments and living labs enable researchers to generate single and control interventions with high levels of observation and creation. This increases the level of design focus (Niitamo et al., 2016). Conversely, firms pursue societal and market pilots with high commercial maturity, studying the technology in an emerging context (Ballon et al., 2005).

In the same way, experiments in a controlled environment allow to trial AR prototypes that cannot leave the premises due to technological requirements (e.g., energy supply) or their mounting (e.g., hoist systems).

Due to the emerging state of the AR market, few companies have achieved that commercial maturity needed for societal and market pilots. I was only able to work with one company at this stage, but still, the collaboration agreement was focused on lab experimentation (*Annexe A - Case studies; Pillo*).

Companies should first start with the evaluation of their devices in a controlled environment, to move then to a field test. However, Cornwall lacked a space for AR companies to evaluate their prototypes. In order to address this challenge, through the funding of the Interreg 2 Seas Mers Zeeën Age'In project, I designed and built the Robot Home lab at the University of Plymouth (AGE'In, 2019) (*Figure 26*).

Figure 26; University of Plymouth Robot Home.

This is a dedicated facility for the evaluation of AR with vulnerable participants. The lab offers start-ups of the region the opportunity to assess their devices in a controlled environment while working with state-of-the-art-technology related to smart homes and independent living. This is an effort towards improving Cornwall's AR infrastructure.

The project counted with the support of two interior designers (undergraduate students from the School of Art, Design and Architecture), one multimedia engineer and three occupational therapists academics from the University of Plymouth. The Robot Home development started in May 2019 and finished in September 2019.

The primary function of the lab is to provide psychosocial support for research participants (i.e., seniors experiencing cognitive decline). To achieve so, the lab followed care environment guidelines. Care environment research analyses how the surrounding environment affects health and well-being. It covers the objectively visible background, but also the subjectively perceived environment; the psychosocial dimension (Mooney and Nicell, 1992). The first refers to the measure features as the size of the room and furniture, light atmosphere, internal weather, views and nature. The second to the atmosphere and ambience in the room; the way it feels.

Any human-robot interaction evaluation starts choosing the site, the location where the experiment is going to take place. In this context, the room setup is far from being just a mere aesthetic need. The experiment room is a vital element for the evaluation of any technology. Researchers must ensure that experiments will take place in a safe, relatable and comfortable environment for the study participants, to reduce cognitive biases during the experiments. For instance, psychological and health-related stressors often escalate in advanced ages, making new places, people, activities and technology negatively trigger seniors' perceived stress (Petersen et al., 1999). The colour pattern of the lab, materials and layout were key elements to reduce perceived stress.

The lab counts with eight cameras to record the interactions, as well as a dedicated studio microphone. Four Azure Kinect cameras support fully articulate tracking of multiple participants, face recognition and identification of emotions. It also allows firms to integrate Azure services into their products. Also, an Apple Watch Series 4 and the Samsung Galaxy Watch let researchers monitor participants resting heart rate, while also supporting multiple platform integration.

The lab also encourages companies to explore the integration of their device with third-party technologies. This includes smart homes devices controlled by Google Assistant and Alexa, such as smart switches to control the heating and air conditioner of the room, indoor weather, light, and noise sensor, smart speakers, smart displays, smart lights. This will allow firms to explore future applications for their devices.

By March 2020 this lab has hosted: Stevie; the humanoid robot developed by Akara Ltd., Pillo; the medicine dispenser robot, and Amy A1; a telepresence robot (*Annexe A – Case studies*)

Chapter 8

Conclusions

This chapter provides an overview of the findings and topics covered in this thesis, the contribution to knowledge and suggestions for future work.

8.1 Overview

This thesis presents a Technology Strategy for building and orchestrating the development of an assistive robotics (AR) market. As described in Chapter 3, AR has the potential to change the way we perceive and deliver healthcare. Researchers and start-ups are continuously developing the field, building new prototypes capable of supporting patients' independent living, managing their condition and impairments. These innovations will become tools for a healthcare sector that is starting to feel the effects of the demographic changes described in Chapter 1. However, while other industries have been able to adopt robotics and automation, we are not witnessing similar levels of penetration of AR in the healthcare sector. As a result, the question that then arose was 'How we can support the development of the AR market?'

The gap between inventions, innovation and improving the lives of patients will be bridged through better planning, coordination and proactive intervention (House of

Commons Science and Technology Committee, 2013). We need to encourage and frame optimum collaboration strategies between the public and private sectors to enhance the much-needed commercialisation of health innovations (Oh et al., 2016; van Praag and Versloot, 2008). Although an abundance of literature exists on entrepreneurial and innovation ecosystems, these studies have not addressed the emerging AR innovation process and challenges (*Chapter 1*). The best way to explore how actors in an ecosystem shape the development and commercialization of innovations is to learn from new interventions, understanding the AR development process from conception to adoption (EURobotics, 2014). This thesis thus contributes to the development of the AR market in Europe by proposing a Technology Strategy that builds upon our market actors' needs and challenges.

By adopting a collaborative action research (CAR) methodology, this thesis worked with entities in the healthcare sector and AR firms and developers in Cornwall to create an emerging AR market, with new start-ups and external companies engaging with the region. Consequently, reflecting on this 3-year intervention, the thesis describes a Technology Strategy for building and orchestrating the creation of AR markets in other regions that share this thesis baseline defined in Chapter 3.

The first results of the thesis came from the pre-intervention Technology Innovation System (TIS) analysis (*Chapter 3*). This showed a complete absence of the AR market in Cornwall before the intervention, also evidenced by the initial engagement events with the healthcare sector (*Chapter 4*). For instance, none of the care homes, residential care, day centres, surgeries, hospitals or practices visited during the first year of the thesis had an AR device (*Chapter 4*). In addition, by interacting with the event participants, I verified that they were not aware of and had generally overall sceptical initial attitudes towards AR (*Chapter 4*). However, the public generally seemed open to listen and to consider the potential of AR technologies once shown what AR could offer.

The TIS analysis was conclusive: there was no AR producer sector (firms and developers) in the region before this thesis. This lack of new firms showed the need to start creating a critical mass. Even more, there was a lack of knowledge and understanding of the benefits of AR by the healthcare sector which constituted an implementation barrier (*Chapter 4*).

The findings from the initial engagement with the healthcare sector placed AR in the first stage of the Technology Innovation Adoption processes, the knowledge-awareness stage (*Chapter 4*). Therefore the work with the healthcare sector in Cornwall focused on raising awareness of the AR market and the role healthcare organizations (HCOs) play in the co-creation process. We decided to adopt a roadshows methodology: drop-in events located in different areas of Cornwall to reach a wider audience. In these events I let participants interact with real AR devices while sharing some use cases. Several events were conducted in the region with the healthcare sector from July 2017 to December 2019 (*Chapter 4*).

In addition, we also held eight workshops in September 2017 where I explored and identified AR acceptability and the healthcare challenges for these technologies perceived by the healthcare sector (*Chapter 4*). The workshops produced 78 challenges suitable for AR technologies, in three main areas: maintaining independence at home, social isolation and rurality (*Chapter 4*).

The intervention with the healthcare sector had several implications. More than 900 workshop and roadshow participants were introduced to AR and their benefits. This learning stage took eighteen months, and the primary outcome was HCOs willing to consider using AR. It was also evidenced an initial spirit of entrepreneurship among our health and social care sector, who start taking an active role in the development of AR (*Chapter 4*). Likewise, the intervention also influenced healthcare authorities more broadly (*Chapter 4*). From these interactions, I built a network of healthcare professionals to support the co-creation of AR.

With the AR producer sector, first, I conducted a diversification plan for digital companies in the region from July 2017 to June 2018. Through development grants offered by EPIC to companies in the region, I encouraged companies to start projects in the AR sector. However, after contacting more than 100 digital companies, digital designers and free-lancers, through events and media promotion (*Chapter 5*), many companies opted to start projects in the eHealth sector, but none of them in a robotics project.

Therefore, to support the creation of an AR market in the region, following the rationale described in Chapter 5, section 5.3.2, I decided to start an entrepreneurship program: EPIC Start. The programme aimed to establish first businesses in the field that could address some of the identified healthcare challenges from the region (*Chapter 4*). The programme received 43 group and individual applications and resulted in more than 58 interviews with professional, graduate and undergraduate students from different academic backgrounds (i.e., software design, product design, robotics) (*Chapter 5*). Ten project proposals were evaluated which resulted in the creation of four robotic start-ups.

The programme offered business advice and technical evaluation of the AR venture. I supported the application to obtain seed funding and access to patients and healthcare professionals.

To boost the ecosystem being developed further, I engaged with 28 robotic companies from the UK, France, Ireland, US and China (*Chapter 5*). The aim was to bring more examples of AR entrepreneurship to the region while addressing some of the healthcare challenges raised. Through this, I supported three companies outside the region in the evaluation of their AR products (*Chapter 5*). Moreover, from the interaction with these companies, the thesis explored and identified 19 main market barriers (*Chapter 5*). These market barriers were classified into five categories: (i) market failure, (ii) economic and financial, (iii) institutional, (iv) technical, and (v) social, cultural and behavioural.

Based on the described work, this thesis presents a Technology Strategy for creating an AR market. The Strategy outlines a clear programme with objectives, principles and actions for ecosystems developers (EDs) to develop the AR market and support the adoption of the technology in the healthcare system. This thesis describes an ED as an organisation with human resources to intervene in the region in the quest to create, via a technology strategy, a market for AR in healthcare. This thesis concludes that for an innovative field such as the AR market, universities are the ideal leader of the intervention (*Chapter 6*). Through this approach, the thesis starts structuring the market composition and dynamics with the market actors.

The AR Technology Strategy builds upon collaboration between market actors. Through this, it focuses on aspects such as co-creation and open innovation for AR, not only addressing them as topics but offering practical recommendations on how regions can adopt these tools. This includes tools for boosting the healthcare sector's awareness and participation in the development of AR (i.e. through incentives, knowledge awareness events or networking infrastructure), plus stakeholders' dynamic and collaboration requirements (i.e. intellectual property) (*Chapter 6*). These principles and actions will allow regions to develop an understanding of the opportunities of AR while framing cooperation systems between HCOs and start-ups.

In the same way, by presenting open innovation principles, the thesis contributes by describing how AR start-ups could benefit from developing joint healthcare literacy initiatives and sharing AR risks assessments towards growing the market. (*Chapter 7*). This allows companies to address the current knowledge gaps among their final users while sharing resources. It also lets companies identify possible issues they did not consider during the AR design process, improving their prototypes while preserving the image of the AR field. The open innovation principles designed have been lacking in other high-tech markets, where secrecy is the defence mechanism of several start-ups.

Even more, the thesis explains how start-ups and academia can work together, from seed funding opportunities to evaluation services (*Chapter 6*). This establishes paths for cross-sector collaboration, where universities can profit from new research projects driven by the start-ups, increasing key performance indicators (KPI) such as spinouts, business collaboration, applied research, and graduates' employability. Moreover, this contribution also supports start-ups, detailing the collaboration dynamic that should be sought and the opportunities it represents for their firms.

The thesis describes how EDs could work with external AR companies for establishing viable AR markets for healthcare (*Chapter 6*). It is acknowledged that in the early stages of the market, EDs should empower the region's producer sector by promoting available

AR products from other regions. Paradoxical as it may sound, by attracting external companies to the region, EDs can accelerate the knowledge awareness stage as evidenced in this thesis (*Chapter 4*). External companies will also become examples for the region's entrepreneurs.

Additionally, this thesis also establishes business platforms for regions for other start-ups to build upon existing companies (*Chapter 6*). There are two types of early-stage AR companies: market pioneers and business platforms. The first are those AR start-ups that have accessed seed funding and are developing prototypes to address the healthcare challenges of the region. The second category are those start-ups that develop products and services upon which the first type of AR start-ups will grow. I defined the AR business platforms as those companies that provide either evaluation services, complementary features or satellite services (*Chapter 6*). By building these companies, AR wins on sustainability and new paths to mark. This also opens opportunities for external engagement.

The thesis also provides detailed plans for running an entrepreneurship programme for AR and the AR knowledge awareness programme for the healthcare sector. These two programmes were described step-by-step, reflecting upon the work done in Cornwall, providing a framework that aims reducing resources and time for EDs. Therefore it includes the initial work (i.e.: healthcare network, seed funding requirements) that the ED has to undertake before engaging with the region's entrepreneurs. The knowledge awareness programme is vital for the region since the organic participation of the healthcare sector becomes a strict requirement for the AR market. The entrepreneurship programme of AR is essential to build the producer sector. These two programmes are described in Chapter 6 as a key part of the AR Technology Strategy.

In Chapter 7, the thesis suggests practical guidelines for the producer sector. This starts by detailing the healthcare challenges and ideal market segments for AR: 'silver sector' and care automation segments. Besides, the thesis provides concrete advice for the development of AR products and services, focussing in particular on reducing time to market and value creation. The ensuing recommendations range from targeting specific automation activities to internal platforms and compatibility opportunities. Therefore this insight could deeply benefit AR start-ups, from avoiding initial mistakes to profiting from new market opportunities.

Moreover, the thesis offers a model for the development of AR that incorporates principles underpinning quality management systems. This was done in order to familiarize entrepreneurs with these principles and associated practices, thereby reducing risks while evaluating this technology with users (*Chapter 7*). This new model highlights the importance of working with design controls and a structure for AR pre-assessment. This will contribute to companies once they want to place a product to market.

Additionally, an overview of the AR evaluation landscape was provided, suggesting recommendations for assessing the impact of AR (*Chapter 7*). Start-ups will benefit from this insight since it provides recommendations for performing mechanics and material evaluation, good practices for AI and evaluations techniques for AR.

The thesis highlights the need for AR regulation by exploring the current landscape (*Chapter 6*). As explained, on the one hand, we see countries developing guidelines for AI development that focus on data acquisition and not on explainable AI. On the other, standardization initiatives have been trying to generate safe risk assessment and hazard reduction strategies for the mobility and navigation of robots. Currently, we are neglecting regulation and guidance for developers around subjects such as autonomy, deception, trust and explainable AI.

Finally, while funding for AR ventures is an absolute necessity, funding should not be the limitation for the creation of AR markets. Ultimately, if a region proves that it has the tools to foster innovation in a specific sector, funding will follow (Mulas et al., 2015). This is the desired effect of the AR Technology Strategy to achieve wider scalability to other regions. The AR Technology Strategy aims to attract further investment from outside the region (i.e.; VCs). The KPIs described in Chapter 6 will support this process: early AR adopters, HCOs engaging with AR projects and platform-based start-ups. The AR Technology Strategy also provides some options for the funding and guidelines to prevent inadequate access to seed capital (*Chapter 6*). The AR Technology Strategy also shares recommendations for start-ups to reduce the requirement for high levels of investment and as well as to avoid market failure (*Chapter 7*). Finally, as the cost of fast prototyping tools decreases and technology development makes the acquisition of IT equipment more affordable, seed funding requirements for AR start-ups are also likely to drop.

8.2 Summary of the contribution to knowledge

This section summarises the contributions presented through this work.

Subject to further empirical testing (section 8.3), the AR Technology Strategy has several potential uses:

- To guide public and private economic and healthcare development organisations, as well as universities and research centres, to start the AR market in regions that shared the defined baseline (*Chapter 3*).

- To guide healthcare organization, producer sector (firms and developers) and academia in the development of AR through co-creation principles and collaboration strategies (*Chapter 6*).
- To guide private partnerships between the producer sector to support companies address AR market barriers and grow the market (*Chapter 7*).
- To support the producer sector during the conceptualization, development and evaluation of AR prototypes (*Chapter 7*).
- To explain and learn from programme failures (*Chapter 4* and *Chapter 5*).

Following two of the five critical high-level research priorities established in the 2014-2020 Strategic Research Agenda for Robotics in Europe (EURobotics, 2014), this thesis aims to contribute to a major economic and societal challenge, while building strong links between academia and industry. AR has the potential to ease the healthcare challenges brought about by an ageing demographic, the rise of individuals with one or more long-term health conditions, and the shortages of qualified nurses and residential care (*Chapter 1*). These are part of the societal challenges that we are facing in the 20th century. Therefore, by empowering regions to build the AR market, they will be able to address their healthcare challenges by either adopting external AR technologies or developing their own solutions.

In the same way, by empowering the actors of the AR market, the new entrepreneurship ecosystem and favourable market conditions will eventually support the economic development of the region (Malecki, 2012). Entrepreneurs will overcome market barriers and external companies will offer new opportunities. Therefore, the AR Technology Strategy proposed will influence the region’s economic development as well. The strategy recognized the role that entrepreneurs played in the development of

AR technologies. It provides tools to increase the success rate of start-ups such as open innovation actions for companies to grow together while addressing market gaps and value creation opportunities, enhanced by a new model of AR development and practical recommendations for developing and evaluating AR prototypes (*Chapter 7*). The AR Technology Strategy also describes funding frameworks and opportunities for entrepreneurs, which will allow start-ups to target funding rounds that will benefit their companies (*Chapter 6*).

Furthermore, as explained in the section above, this thesis builds strong links between academia and industry, exploring the benefits of collaborative development and evaluation of AR technologies. The AR Technology Strategy places universities and research centres at the heart of the entrepreneurial ecosystem for AR in healthcare (*Chapter 6*). In the same way, the thesis outlines how universities and healthcare organizations can benefit from managing the development and accelerating the adoption of AR technologies, while businesses benefit from academic state-of-the-art technology, knowledge infrastructure, and professional expertise. Thought this, the thesis impacts AR translational research in an attempt for promoting openness, collaboration and commercialization of AR research projects.

These contributions also address key targets from the 2014 -2020 Strategic Research Agenda for Robotics in Europe (EURobotics, 2014) including creating regions where SMEs can flourish, cross-sector engagement to strengthen and promote the uptake of robotics technology can occur, and raising awareness among policymakers to understand the importance of robotics and its potential impact is fostered. The thesis offers a foundation for understanding policy recommendations to support these technology-based ecosystems. Chapter 6 and Chapter 7 describes the programme, principles and actions of the AR Technology Strategy. Chapter 5 describes the market barriers for AR companies in the EU by interviewing companies from the UK and France. Even more, the engagement with the 28 AR companies allowed this thesis to present the landscape that these firms face working for the healthcare sector.

For the field of robotics, this is the first thesis of its kind that embodies the key tenets of the AR innovation phenomenon such as complementarities, technological interdependencies, distinct roles played by market actors, and the multilateral nature of relationships between them. Instead of focusing solely on the user, the thesis centres on the companies driving the technology to the market and empowering regions to drive high-tech innovation to the healthcare sector. This aligns with action research in relation to supporting the development of real-world applications (Whyte and Cole, 2012). As well as raising awareness, the AR Technology Strategy also offers insights to academics. As researchers, we cannot keep overlooking the analysis of paths to markets of our work and identify social, economic and technical barriers for the technology we study and develop. For instance, Chapter 7 raises awareness of the need for protocols to assess AR technologies in order to produce critical appraisal tools and benchmark tools for the healthcare sector and decision-makers.

Finally, the local focus and impact of the thesis have contributed to the development of an innovation ecosystem for the broader health technology field in Cornwall (Jones et al., 2019). The region is starting a community with competitive assets in its knowledge-based economy that can profit from the socio-economic development of high-tech innovations for the healthcare sector. The intervention, explained in Chapter 4, drove a mentality change and deployed the tools for the community to benefit from health innovations. Now, Cornwall is more capable of driving innovation and not only in the AR field. More companies are starting ambitious ventures in the region that will support the whole healthcare system (Jones et al., 2019).

8.3 Future Work

Finally, it is worth acknowledging that the actions taken to develop an AR market in Cornwall, the experience of which has led to the proposed Technology Strategy, was dependent on EPIC grant funding. Awareness-raising, networking, and supporting ventures during the development and evaluation phases were vital in the development of the market as evidenced in this thesis. The innovation infrastructure created most certainly supported entrepreneurs and future ventures. However, without seed funding, it would not have been possible for the AR firms in our sample to start production. All of the AR start-ups benefited from the EPIC grants to start their companies.

The approach taken by EPIC has been the traditional path non-governmental organisations follow to build or boost a market sector (European Commission, 2007). However, this thesis provided a framework to support AR development in other regions, regions that cannot always count on the support and funding of projects like EPIC.

Nevertheless, further studies are still needed that focus on the development costs and adoption of these technologies. Further research is needed in studying innovative models for social initiatives, capable of supporting a profitable business while financing or subsidizing the cost of AR.

Based on the findings of this study, this is undoubtedly the path to take. Ultimately, what we need to avoid is inhibiting already deprived regions from harnessing the healthcare benefits associated with AR technologies, while in wealthier regions the known tech clusters keep growing. We need to be aware of healthcare inequality and work to diminish its spread.

In the same way and as already mentioned in Chapter 6, this study did not have the resources to run or build co-working spaces and prototyping labs. It is clear that physical sites have a positive impact while promoting and building innovative regions (Mulas et al., 2015). Even more, prototyping facilities will deeply accelerate the development process of AR ventures. Therefore it would be worth studying how the mentioned further entrepreneurship infrastructure on Chapter 6 could impact building the AR market, but most importantly, how these facilities should be built and run to support this innovative field.

Moreover, the transferability of the described AR Technology Strategy to other regions is subject to the regions sharing this thesis' baseline. Chapter 3 described the region studied, Cornwall, and its similarities with other regions (i.e.: population profile and projection, healthcare challenges, degree of urbanisation and gross domestic product per inhabitant composition). Most importantly, Chapter 3 concluded by detailing Cornwall's Strengths, Weaknesses, Opportunities, and Threats profile for the AR market before the intervention. Through this, the thesis established an applicability baseline for other regions seeking to follow the presented AR Technology Strategy.

The AR Technology Strategy proposed builds upon the weakness and threats of the region and the market barriers identified from the engagement with AR companies presented in Chapter 5. If a region has any added value (e.g.: national entrepreneurship programme, co-working spaces, healthcare openness) the AR Technology Strategy could also be used since it will benefit from these positive characteristics. However, if the region does not count with the strengths detailed, mainly a policy that supports the creation of businesses, it is imperative to focus on these deficiencies first.

Moreover, the strategy also built upon the challenges and market barriers collected from a sample of some AR companies working in the UK, France, the US, China and Ireland (*Chapter 5*). Therefore, the thesis has a ground for claiming its transferability to other regions, but most importantly, it established requirements for this transferability. Nevertheless, exploration of its applicability to other regions is also worth exploring.

Finally, the thesis has deeply discussed and covered the need for AR regulation to develop, evaluate, certificate and adopt AR technologies (*Chapter 3*, *Chapter 6* and *Chapter 7*). Ultimately, this missing regulation has been inhibiting the growth of the AR market in Europe (*Chapter 6*). Regulation that changes accordingly to the AR application. Chapter 6 makes a detailed explanation of the current gaps. Further research will be needed once the respective authorities start defining the AR regulatory landscape, to understand how this could impact the proposed AR Technology Strategy and how new regulations could be adopted into the model.

Glossary

AI Artificial Intelligence

AR Assistive Robotics

B2B Business to Business

CAR Collaborative Action Research

CE European Conformity

CEO Chief Executive Officer

ED Ecosystem Developer

EPIC Ehealth Productivity and Innovation in Cornwall and the Isles of Scilly

EU European Union

FDA Food and Drug Administration

GP General Practice

HCO Healthcare Organization

IEC International Electrotechnical Commission

IoT Internet of Things

IP Intellectual Property

ISO International Organization for Standardization

IT Information Technology

KPI Key Performance Indicator

MVP Minimum Viable Product

NHS National Health Service

OSRD Olly Smith Research and Development

QMS Quality Management System

RAS Robotic and Autonomous Systems

SME Small and medium enterprise

SWOT Strengths, Weaknesses, Opportunities and Threats

TIS Technology Innovation System

TRL Technology Readiness Level

UI User Interface

UK United Kingdom

US United States

UX User Experience

VC Venture Capital

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Annexe

Annexe A - Case studies

Stevie (Akara LTD)

Stevie is a humanoid robot developed by Akara LTD, a spin-off from Trinity College Dublin. The robot aims to support seniors in care homes by delivering a range of therapeutic sessions, most of which focus on music and speech therapies. The firm is currently working on the third version of the robot, and it was the cover of TIME magazine in Novemeber2019.

Figure 27; Stevie, the humanoid robot. Source; (TIME, 2019)

The director of the EPIC project, Ray Jones, and I, went to Dublin in November 2018 as part of an exhibition gallery of AR. There we met with the director of Akara, Dr Conor McGinn.

Since then, I started a plan to bring the company into Cornwall for the evaluation of their device. After several months of planning and phone meetings trying to reach an agreement, I was able to offer the company a solid plan that will allow them to win new insight about Stevie, promote their company in the UK, and study the UK market. This contributed to the development of a strategic partnership with the University of Plymouth.

In April 2019, I secured the funding for running the first pilot of Stevie in the UK (€6k). In November 2019, we ran a two weeks pilot in Reflections day centre, an organisation that works with seniors with different levels of dementia. The pilot aimed to evaluate the acceptance and usability of the social assistive robot from the HCO's staff perspective. This included understanding the workload impact of the robot, and the companies' ability to remotely teleoperation the device. This was the first pilot for Akara without members of their team in the field.

Besides managing the pilot, I designed the evaluation protocol and applied for ethical approval. The on-field study was performed by EPIC robotics research assistant Lloyd Taylor, and Olly Smith Research and Development LTD (OSRD Ltd – see case study below).

The intervention was programmed from the 18th of November to the 3rd of December. We divided each day into a morning and an afternoon session. During the morning session, Stevie led group activity sessions. This included a group of 10-16 guests in one room accompanied by some members of staff. The robot ran different apps around reminiscence and recreation in order to improve the emotional wellbeing and communication of Reflections' guests. For instance, storytelling, music therapy, and leading recreational games as bingo or trivia were some of these apps. The session lasted around one hour, after which staff completed a short questionnaire and had the opportunity to provide further feedback.

The afternoon session was focused on one-to-one activities, sometimes including a group up to three guests. Here the robot had small interviews with the guests, where it explored the challenges and needs of the participants. The exploration was a balance of mental and physical needs. The aim was for Reflections staff to increase their understanding of their service users, and for Akara to evaluate the use of Stevie's exploration of user needs. After this session that lasted around 30 minutes, staff involved in the intervention had an interview with the evaluation team in order to collect their feedback around the intervention and the day in general.

During the pilot, Akara provided 24/7 online support. This included monitoring the performance of the robot, the operating system status and troubleshooting support. However, their involvement was kept to a minimum as possible.

Figure 28; Stevie robot at Reflections. Hosting a game of musical bingo and dancing to music.

Besides the questionnaires, the staff made use of a suggestion box and a personal diary to keep providing feedback about the robot.

Before the pilot, Stevie stayed in the Robot Home lab for its assembly, initial setup and testing.

Figure 29; Stevie in the Robot Home.

This evaluation supports Akara LTD developing the future versions of the robot. The data collected is still under analysis, and a publication is being pursued. We will compare this intervention with another trial that Akara deployed in the US.

Media resources of the intervention can be found here;

- 04 December 2019, **BBC note on Stevie project** (BBC, 2019).
- 27 November 2019, **Daily Mail note on Stevie project** (Daily Mail, 2019)**.**
- 26 November 2019, **Telegraph note on Stevie project** (Telegraph, 2019)**.**

Olly Smith Research and Development LTD

Olly Smith Research and Development LTD (OSRD) was the first AR business platform I delivered for Cornwall. It was founded after the EPIC Start programme in March 2019. The company was created to fill the current market need for supporting developers to evaluate their AR technologies. While digital technologies (e.g., apps) were starting to have the opportunity of testbed services in the region via Kernow Health CIC, such support was missing for the emerging AR market. The final goal of OSRD was to boost innovation in the region and support the adoption and widespread of AI and robotics.

To define the working models and written processes of how the evaluation service will be provided, I integrated OSRD to the Stevie case study (see above) while personally supported the development of the company. By shadowing the researchers during Stevie's evaluation and being involved during the planning, analysis and reporting of the project, OSRD shapes its evaluation services to future AI and robotics companies.

This first pilot evaluation allowed OSRD to establish a clear framework for supplying this service to future AR companies. The evaluation follows three main categories;

- Technology
    - Safety
    - Usability
    - Integration
- Interaction
    - Autonomy
    - Acceptance
    - Privacy
    - Learning
- Assistance
    - Impact on user's care
    - Impact on caregiver
    - Cost-effective analysis

The OSRD evaluation service has multiple routes to market by collaborating with other institutions, not only in Cornwall but nationally and internationally as well. Companies external to the region could also benefit from the start-up since it offers access to the market HCOs while exploring system adoption challenges and user evaluation insight. OSRD will continue to draw upon all of these means as a route to market.

Finally, OSRD intervention in the region will keep increasing the awareness of health innovations among HCOs and facilitate the technology adoption process in Cornwall. Through this, the company will keep leading the engagement with the healthcare sector. Companies like this will increase the sustainability of interventions.

Robotriks LTD

Robotriks was the first start-up from my entrepreneurship programme; EPIC Start. The entrepreneurs responded to the recruitment opportunity in October 2017. They decided to address one of the challenges that I collected and refined from the workshops' activities with the healthcare sector. The project aimed to carry out a feasibility study of the development of a therapeutic robot such as Paro, but affordable for the Cornish reality.

Since then, I supported the company through constant follow up meetings where we defined the concept of the project and the further application to the EPIC funding grant (£5k awarded). I then linked the project to an ongoing PhD study developed by Hannah Bradwell. Her study aimed to benchmark some animal-based therapeutic robots, including Joy for all that I identified from my market study. Hannah became an academic partner for the company, providing feedback around the features that are perceived as attractive by seniors, carers and family members.

The start-up did not need technical support, but they benefitted from the network of HCOs and the opportunity of being part of some roadshows activities, winning early insight about the care homes settings and their user's needs. For instance, on January 29th 2018, with Robotriks, we visited Wesley Court Retirement Apartments. There we evaluated EPIC's robots and some animatronic toys with the senior residents and staff. Wesley Court Retirement Apartments became one of the many other HCOs involved in the co-creation process of this project. More information about the HCOs involved can be found in; (Bradwell et al., 2019).

The project ended on the development of the therapeutic robot COM pet (*Figure 30*). Robotrix has not quite finalised the design and production of the device. The intention is that the device should be capable of changing its exterior appearance to meet the desired choice of the users through a range of skins (i.e., the robot could look like a dog, cat, lion, depending on the skin). This will allow users to personalise their device. The goal of the robot structure was to give a feeling of an underlying bone structure.

Therefore, the main outcome of the project was a prototype of around £500, with the opportunity of lowering the price in further versions. Paro's price is about £5k. The feasibility projected concluded in November 2018.

The company constitute a vital example for other entrepreneurs in the region.

Some media about the project can be found in;

- https://www.bbc.co.uk/news/av/uk-england-cornwall-44945933/animal-robots-comfort-cornwall-dementia-patients
- https://www.youtube.com/watch?v=NuWRgtZP_N8

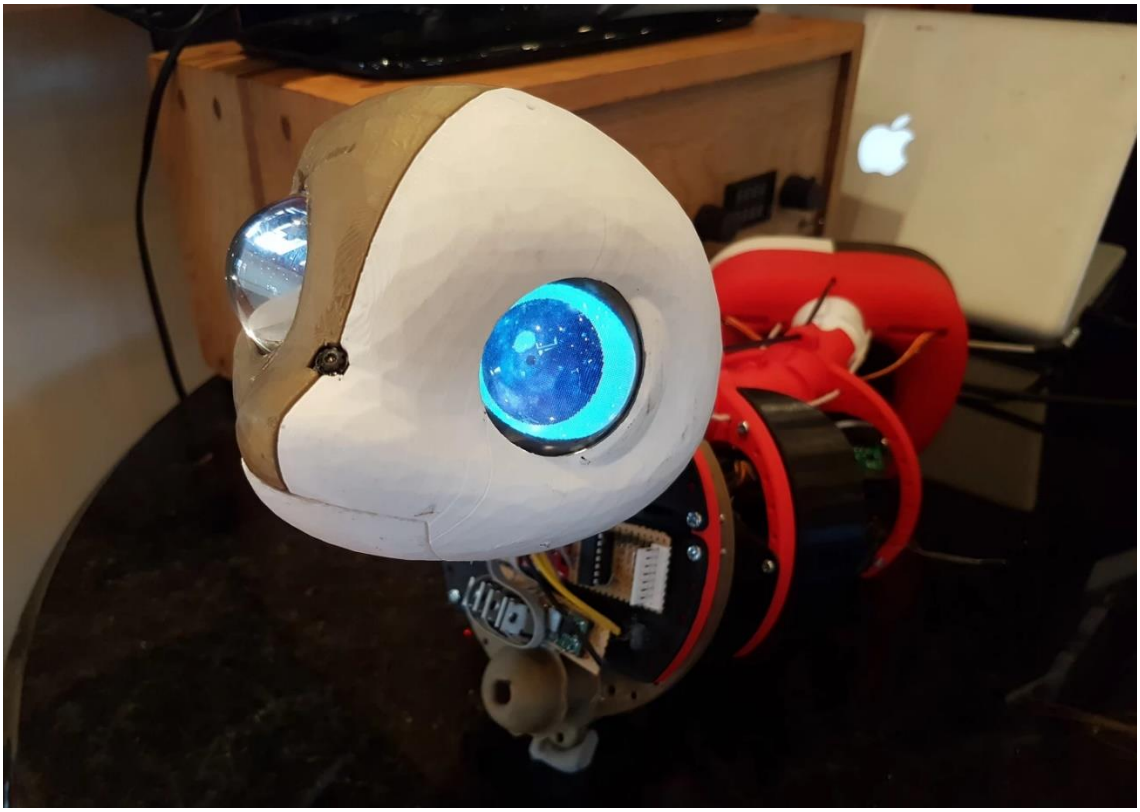

Figure 30; COM Pet Public Prototype v1.1. Taken during the Newquay 'EPIC' Conference (November 2018).

Access Robotics LTD

This was the second start-up from my entrepreneurship programme; EPICStart. The entrepreneurs answered to the recruitment opportunity in November 2017. They received the healthcare challenge report of Cornwall and decided to develop a soft robotic arm for people in a wheelchair to support them with pick and place activities.

The project aimed to carry out a feasibility study of the mechanic system. The proposed arm was a cable-driven, 3D-printable, modular, low-cost soft-robot.

The company required additional support defining their business model. Through several follow up meetings, I supported the entrepreneurs framing their company's goal and a strategy to achieve it. Besides, I help the company in the development of the EPIC grant application that ended up awarding £5k to the project.

I linked the project with Disability Cornwall, a charity that represents, supports and empowers people living with a long term health condition or disability. Through some meetings with the HCO, the company was able to understand the opportunities of their device and further design requirements.

The project ended with the development of two segments of the robotics arm, plus the mountable platform. The project was a finalist in the UK national contest Engineering for Access 2019 (Claims.Co, 2019).

Kernow Robotics LTD

This was the last start-up I supported. It was registered in the Company House in March 2019. But this company was not an outcome of my entrepreneurial programme. Instead, the entrepreneur contacted me directly after seeing the work undertaken by the other start-ups; Robotriks LTD, Access Robotics LTD and OSRD LTD.

This shows the impact that early start-ups have over the entrepreneurial community. By creating examples, entrepreneurs can follow their journey and realize that it is not impossible to work in the robotics field.

The entrepreneur had some initial meeting with me since February 2019. After supporting him with the business model of the company, we aimed to apply for seed funding to start the development of a service to support other companies through robotic mobile platforms.

Unfortunately, EPIC grants were no longer available and the company decided to explore other funding opportunities. Since then the start-up secured funding for other robotic projects, especially in the agri-tech sector.

Nevertheless, we are still exploring further collaboration opportunities with the start of EPIC2 in May 2020.

Genie Connect

Service Robotics LTD is a company based in Cheltenham (UK). The business offers the Genie Connect service; a desktop robot that allows seniors to contact a call centre while providing the advantages of socially assistive robots to seniors. The company do not manufacture the robot; acting as an AR platform, the company is in charge of the distribution and call centre service for the UK market of the robot.

I met the CEO of the company in the GIANT health conference in London, November 2017. Since then, we have explored collaboration opportunities that ended in an application of an EPIC grant for the evaluation of the service Genie Connect.

In this pilot, I only acted as a consultor for a third party organisation (A Cornish SME, Clinical Affairs Consulting Ltd) conducting the evaluation. My job was to provide recommendations and frame the methodology for the evaluation. Through several meetings, I supported the planning of a scoping study that examined the feasibility of the Genie Connect service in twelve residential living establishments, with a collective total of 372 residents.

The study focused on the UX and UI of the Genie robot interface. The findings were reported to the company but cannot be disclosed to the public. The final project worked with 11 Care homes from the Bude area, collecting staff feedback around the robot.

AMY Robotics LTD

This is the last international cooperation established in the thesis. Amy Robotics, a Chinese company, contacted me through an email, eager to explore collaboration opportunities in order to strategically deploy their telepresence robot Amy A1 in the UK.

Figure 31; AMY A1 in the Robot Home.

The robot arrived in December 2019. Telepresence robots are a technology that has been available since the ’90s. We have seen applications supporting online consultations and patient monitoring (Michaud et al., 2007). However, the business models of these companies have not yet met the needs of the healthcare sector and its service users.

While some companies have been adopting renting models and providing complementary services, few companies have succeeded in the AR market. The goal of the ongoing project is to explore innovative services and costing models for the company; market opportunities in the UK.

Besides, since January 2020, I have been working with the robot to assess its current navigation system. Besides, with the company, I was planning some evaluations of the robot with lead users in the Robot Home lab. Unfortunately, due to the coronavirus, scheduled evaluations for the first semester of 2020 were put on hold.

Pillo LTD

Pillo is a medicine dispenser robot developed by an American based company. Pillo reminds patients to take their medicine and automatically dispense it in a cup. The robot allows carers to monitor the intake of patients' medicine, while also checking the stock and changing the doses if needed. The device is marked as a class 1 medical device by the FDA and is currently being distributed by Black & Decker in the US.

Figure 32; Pillo in the Robot Home.

After initial contact with the companies' Director of Cloud Services and AI, in July 2019, we established a collaboration agreement with the company. The first partnership in the UK for the company.

My first task was to evaluate the safety of the device. As a medicine dispenser robot, the impact that a system failure could have, from a hardware or software perspective, could be catastrophic. After several tests, I could not find any failure or concern. After all, the device was granted market approval.

Therefore I moved to the second stage of the collaboration. Currently, I am designing a pilot in the Robot Home with some lead users to evaluate the acceptability and trustiness of the device with seniors. Unfortunately, due to the coronavirus, scheduled evaluations for the first semester of 2020 were put on hold.

I used examples of activities carried on in the region to persuade Pillo Ltd the benefits of trialling their product in Cornwall.

Annexe B – Workshops Paper

User-defined challenges and desiderata for robotics and autonomous systems in health and social care settings

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User-defined challenges and desiderata for robotics and autonomous systems in health and social care settings

Abstract. We report the needs and challenges identified by health and social care professionals and service users for robotics and autonomous systems that are of importance to researchers and policymakers. To this end, we held eight workshops in different locations across Cornwall (UK) in which we raised awareness of the applications and opportunities of assistive robots. The 223 participants could interact physically with four robots, watched a multimedia presentation including video and use-case scenarios and then took part in 33 focus groups. Content analysis was carried out based on summaries written by facilitators during the focus groups. The focus groups produced 163 challenges that may have digital solutions including 78 suitable for robotic assistive technology, in three main areas: maintaining independence at home, social isolation, and rurality. Although further research is needed with technology and its implementation, this study shows that health and social care professionals, patients, carers, and students are willing to consider using robotics and autonomous systems in health and social care settings.

Keywords: health and social care, evaluation of needs, robotics, assistive technology.

1. Introduction

Robots as assistive technologies form an emerging market with increasing impact [1]. From supporting patients' cognitive abilities, to providing remote monitoring of their health status and support in activities of daily living, assistive robots have the potential to change the way we perceive and treat a range of impairments and conditions [2]. That said, to bring robotics and autonomous systems (RAS) into health and social care, research needs to be grounded in an understanding of user needs [2].

Despite ongoing research, the need for a stronger understanding in the European context has been made evident in the plans and roadmaps of several organizations. For example, the *Robotics 2020 Multi-Annual Roadmap* by SPARC (the Public-Private Partnership between the European Commission, and European industry and academia) highlighted the importance of exploring user needs and requirements for each RAS market domain [3]. Further, the *European Civil Law Rules in Robotics* study by the Directorate General for Internal Policies of the EU Parliament, called for attention to a participatory design approach and user-defined desiderata around RAS in care applications [4].

The main questions addressed here are thus: (1) what are the challenges for robots in the health and social care sector according to european communities? and (2) what are the perceived implications of technologies proposed to address these? Addressing these questions will help guide designer groups, entrepreneurs, and governmental organizations in their effort to create robots to support carers and patients according to their needs. Moreover, it could motivate researchers to continue or start projects that address the technological challenges.

To this end, we identified RAS care challenges seen by health and social care stakeholders - health and social care professionals, patients and service users, and students - in Cornwall (UK) [5]. So that participants could better understand opportunities and limitations of RAS, we ran workshops including first a technology showcase in which participants had the opportunity to interact with some of the most representative assistive technologies currently available and then participants were allocated and took part in focus groups.

2. Background and Previous Research

We begin by describing some of the existing applications of RAS in health and social care. We do not aim for an exhaustive review, but focus on representative studies that illustrate the current state of the art, in particular with respect to the exploration of user needs.

2.1. Present-day application domains of RAS

RAS have a wide range of application domains in health and social care, and and have been developed and evaluated in various research projects (Table 1). Mostly, the effort focuses on the automation of activities of daily living, such as reaching and manipulating objects, and assisting user mobility and self-care. For instance, there are robotic arms capable of attaching to wheelchairs [6], or assisting a person with their personal care [7] as well as modular robots that move around a users' house using a rail system of hoists for transferring people [8], and robotic shower systems to assist frail persons [9]. Exoskeletons are used in the recuperation process of patients with severe muscular dystrophies or as walking aids [10] while robotic assistant platforms are used to set alarms [11], remind people to take medication [12], provide real-time information [13], and to promote healthy habits or behaviour change therapy [14] , for instance, to encourage exercise [15].

RAS further have applications in addressing social isolation. For example, the robot seal Paro has been shown to reduce loneliness among old people [16], and to improve mood, anxiety, and quality of life [17]. Telepresence robots promote social interaction [18], while supporting remote diagnosis and monitoring of patients.

In sum, the application domains of RAS are rich and varied, and RAS have the potential to change the way we perceive and treat a range of impairments and conditions, and how we actively support those in need [2].

Table 1. Examples of RAS in health and social care.

Robot	Description	Benefits	Status
JACO 3 Fingers [6]	Robotic arm that can be installed in any electric wheelchair	Support activities of daily living (i.e.: drinking from glasses, opening doors, picking up objects, scratching itchy parts of head and body)	Commercially available
ASIBOT [7]	Robotic arm that can operate in bathrooms	Support with self-care (i.e.: shaving, brushing their teeth, cutting their hair, putting make-up.)	Laboratory research state
JUVA [8]	Modular robot which moves around houses using the standard rail system of hoists	Support transferring people (i.e.: stand up from bed, move around home)	Laboratory research state
I-SUPPORT [9]	Robotic shower system to assist frail persons	Support with self-care	Laboratory research state
I-Dress [19]	Robotic system that will provide active support for dressing	Assistance with Dressing	Laboratory research state
Obi [20]	Robotic arm that support feeding	Support activities of daily living	Commercially available
CyberLegs++ [10]	Robotic cognitive orthoprosthesis for lower limbs	Support rehabilitation therapy	Unavailable
SEM Glove	Robotic glove to improve the grip-ability	Support activities of daily living (i.e.: grabbing things)	Commercially available
Cyberdyne [21]	Upper and lower limb exoskeletons	Support patient mobility	Commercially available
Buddy [13]	Home robot	Support activities of daily living (i.e.: medicines reminder, real-time information, promoting healthy habits)	Commercially available
Paro [22]	Robotic seal to reduced loneliness	Reduce loneliness and social isolation	Commercially available
Leka [23]	Robotic smart toy for children with ASD	Support social skill therapies	Commercially available
Cutii [24]	Telepresence robot for old people	Reduce loneliness and social isolation (i.e.: online courses)	Commercially available

FriWalk [15]a	Robotic walker	Support patient mobility and rehabilitation therapy.	Unavailable
Zipline [25]	Drone for blood bag delivery	Support emergency respond	Unavailable
LUCAS [26]	Chest compression system for cardiac arrest	Support emergency respond	Unavailable

2.2. Understanding user needs and supporting key objectives of health and social care using RAS

Previous work [1][2] has established a roadmap of promising applications of robotics, including RAS, in health and social care. They highlight the potential of RAS to support people to live independently, maintain activity and promote healthy habits. In addition, they describe the crucial role of robots in rehabilitation, medical assistance at home and surgical robots and discuss how robots could reduce the burden for carers, mostly in physically demanding activities.

When it comes to assessing user needs, most literature comes from acceptability studies of different socially assistive robots that collected desiderata from their participants (e.g.; [27–30]), but these studies often focus on specific conditions or impairments, or technologies. For example, Huskens et al. evaluated the effectiveness of a robot-mediated intervention based on Lego therapy for children with autism spectrum disorder (ASD) [31], discussing practical implications and directions for future applications around robots as therapy partners for children, and affective computing applications. Pino et al. analysed the attitudes and opinions of persons with mild cognitive impairment towards socially assistive robots [32], concluding that participants acknowledged the potential of RAS in cognitively stimulating and entertainment applications, support of daily tasks, and patient monitoring.

Huijnen et al. explored how a specific technology, the socially assistive robot KASPAR, could be introduced into therapy interventions for children with ASD [33], finding that

RAS could be used in social skill therapies, providing communication and social support. Zubrycki and Granosik explored the needs of ASD therapists and found how RAS could improve their work environment [34]. Lehmann et al. explored which parts of everyday life RAS could help old people [14], identifying opportunities for RAS in activities such as housekeeping, compensating cognitive impairment, communication, and isolation. Michaud et al. [35] highlighted the importance of RAS for telemonitoring in homes to decrease health care system load, reduce hospitalization period and improve quality of life and independence.

In terms of evaluating RAS in healthcare, Martin-Ortiz et al., for example, developed different criteria to evaluate end-users' willingness and capacity to use RAS in a healthcare application [36], while Feil-Seifer et al. designed benchmark parameters to measures the effectiveness of RAS systems in the healthcare industry [37]. Both studies outline important social implications for RAS applications, including privacy and ethical issues.

3. Procedure and Methods

Motivated by the existing work that focused on a specific condition, impairment or stakeholder, the procedure and methods selected by this study allowed us to explored community needs for RAS in health and social care settings without any initial restriction. Furthermore, while most of the previous work relied on video or image-based methods, we gave users the chance to interact physically with the technology they were supposed to explore and assess.

3.1. Particularities of Cornwall in assessing RAS user needs

This study took place in Cornwall in the South-West of the United Kingdom. From an economic and population perspective, Cornwall is similar to other less developed regions in Europe (Figure 1), where the necessity to address user needs, perhaps through RAS, is most acute [38]. Cornwall is a thinly populated area (Figure 2) and has an ageing population [39] [40], a primary health and social care challenge of most European countries [41] [2].

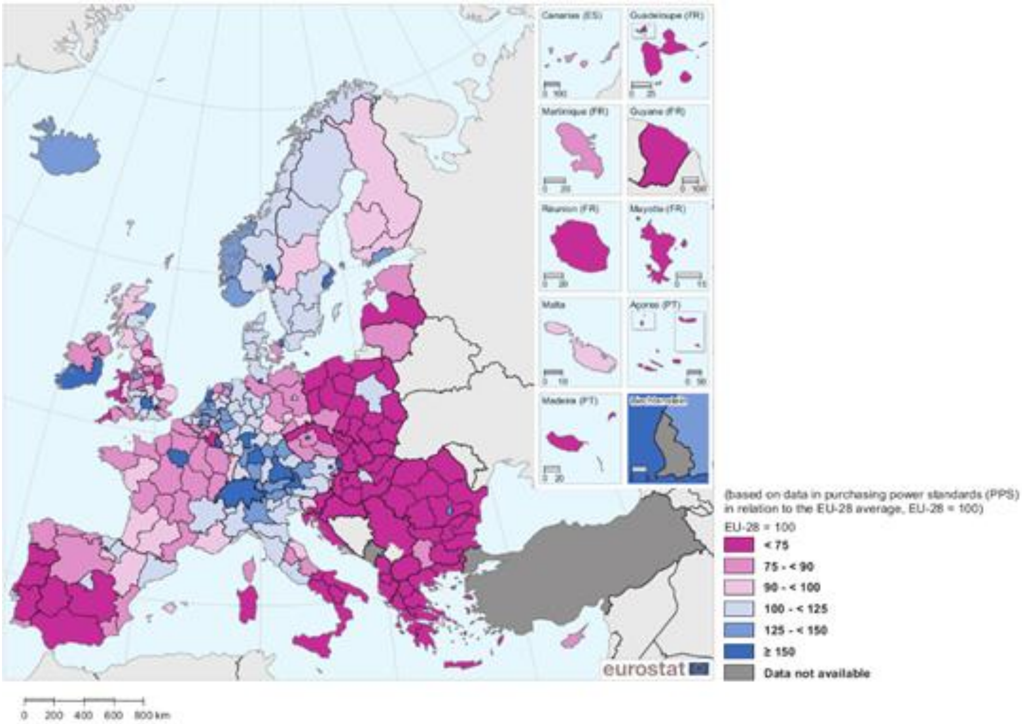

Figure 1. Gross domestic product (GDP) per inhabitant, 2016. Source: Eurostat [38].

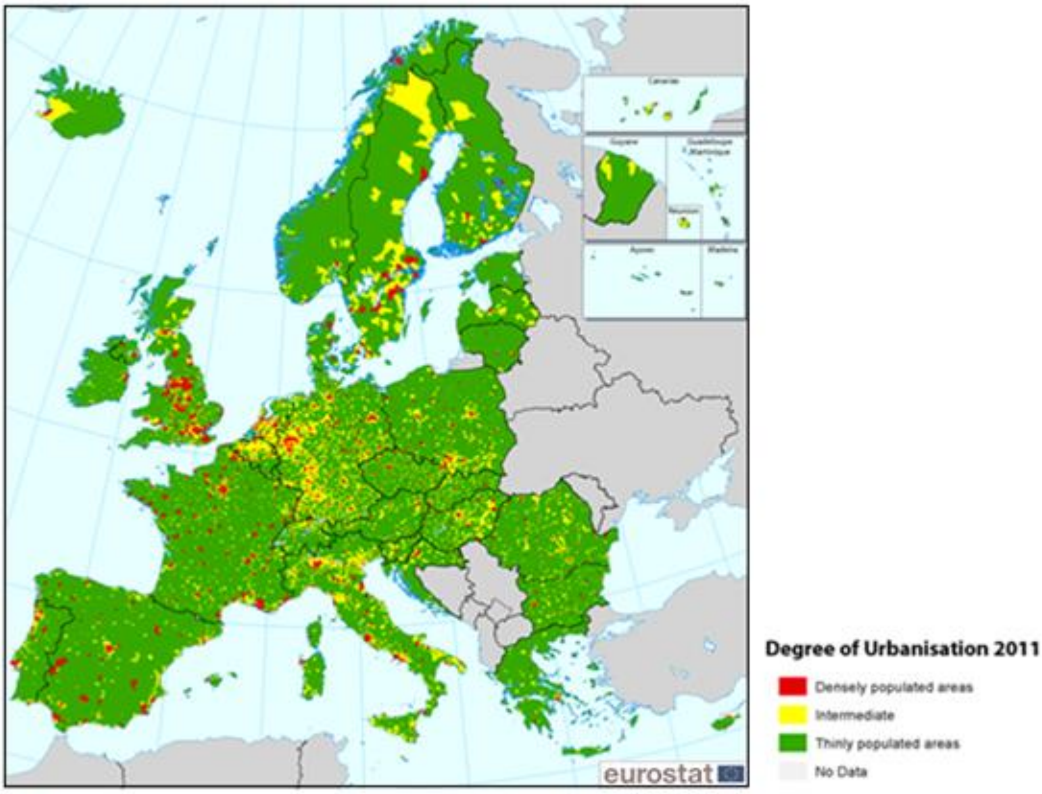

Figure 2. Europe degree of urbanization, 2011. Source: Eurostat [42].

3.2. Participants

Participants were recruited, and the workshops organized, by the Ehealth Productivity and Innovation in Cornwall and the Isles of Scilly (EPIC) project [43] so as to gather a representative sample of Cornwall's health and social care community. These workshops, comprising a technology showcase and up to five focus groups (Table 2), were held at eight different locations across Cornwall (Figure 3), giving geographical coverage of the region.

In total, 223 participants with various backgrounds (Table 2) contributed to this study. Health and social care professionals included domiciliary care, residential care, general practice, hospital doctors and nurses, pharmacists, mental health specialists, and health-related charitable organizations. Service users were recruited through online advertisements, newspaper articles and advertisements, support groups and public engagement events in some locations took part. Service users were further recruited from Patient Participation Groups from general practitioner (GP) practices. University students from different backgrounds were also recruited via online advertisements and emails. Finally, representatives from small and medium enterprises (SME) related to the healthcare industry were also invited via online advertisement and emails. Table 2 shows that our focus groups had participants from a range of backgrounds so giving a rich interaction.

We were not aware of any participants having been diagnosed with cognitive impairment. The Faculty of Science and Technology Ethics Committee at the University of Plymouth granted ethical consent for the research in September 2017.

Table 2. Participants' classification according to their background.

Workshop Location	Total Attended	Type of participant					Focus groups
		Health or social care professional	Service User	Student	Small and medium enterprises (SME)	Other	
Liskeard	44	16	14	4	3	7	5
Truro	36	13	8	5	6	4	5
Redruth	26	17	1	2	2	4	4
Ludgvan	22	10	2	2	4	4	4
Newquay	19	12	1	1	0	5	3
Falmouth	25	10	3	7	1	4	4
Wadebridge	24	14	2	0	2	6	4
St Austell	27	16	3	3	2	3	4
Total	**223**	**108**	**34**	**24**	**20**	**37**	**33**

Figure 3. Workshop locations.

3.3. Technology showcase

All workshops began with a technology showcase with two sections: robotics and apps/virtual reality, including home, and smart toys. The robotics showcase involved a large room containing various technology stations at which participants were invited to visit and interact with the technology.

Four different robots were presented to participants (Figure 4): Pepper and Paro are commonly used examples of socially assistive robots [44][17][45][46]. Miro is being evaluated for its potential as a robot companion at home, and for applications in robot-assisted therapy [2]. Finally, Padbot is a commercially available telepresence robot used to explore how RAS could address social isolation issues.

Figure 4. Robots presented in the showcase and design category: (from left) Human-like, Pepper; Animal-like, Paro and Miro; Machine-like, Padbot.

This initial showcase session lasted 40 minutes. Participants approached stations voluntarily, and researchers provided information and demonstrations of the technology. General robot features, such as size, autonomy, weight, and interaction modalities were presented. Participants were given the opportunity to interact with the robots themselves. With each robot, several use-case scenarios were presented to explore the uses of present-day socially assistive robots.

3.4. Focus Groups

Focus groups[47] in which the different types of stakeholder can interact were considered the best way to explore views and identify current and emerging issues in the health and social care sector [48]. Participants can develop their ideas together, stimulating idea generation and dialogue guided by a facilitator. After the showcase, participants joined an allocated break-out focus group (Table 2). Each group comprised of 4-10 people and was facilitated by a team member from EPIC with a colleague keeping notes on a standard proforma (Appendix). The task set for each group was to identify areas where they thought that digital technologies, including apps and RAS, might provide the basis of a ‘solution’.

First, all groups listened to an overall presentation. The presentation included: a video introduction of the EPIC project, the aims of the focus groups, examples of eHealth solutions such as the telepresence robot Giraff and internet of things applications.

Facilitators then started their focus groups by asking broad questions about the participants' backgrounds and primary concerns. Participants were encouraged to explain daily life challenges that they, their patients or relatives face, and to imagine possible solutions, including RAS that could help them solve those problems. Once participants had described their challenges, facilitators moved the group discussion onto exploring possible solutions by asking the participants questions such as "*Do you have any idea of technology solutions*?", "*What is the nature of the technology?*", and "*How do you want it to help?*". Each challenge had different levels of suggested solutions for the problems raised, design aspects, and conditions for technology adoption.

Group discussion encouraged respondents to explore and clarify individual and shared perspectives, benefiting from the multidisciplinary nature of the groups [49] [50] [51]. The discussion lasted 100 minutes.

Finally, the facilitator and scribe for each group identified up to five challenges while with the group and summarised these themes in a short paragraph. For the purpose of this analysis, we have used the themes written by the facilitators. From the focus groups, we identified 163 challenges.

3.5. Data Analysis

The analysis builds upon Thomas' general inductive approach for analysing qualitative data, comprising of three main stages; search, evaluation, and classification [52]. First, an open coding system was used on the 163 challenges to search for suggested solutions recorded that explicitly or implicitly referred to RAS using the query tool of Nvivo 11 [53], qualitative data analysis (QDA) computer software. The result from this stage was a sub-list of 87 challenges.

Second, all 87 identified challenges were evaluated individually to validate that they represented possible robotic applications. Two researchers (GA, HB) read the 87 challenges and assessed if they had or not an explicit robotic solution. Nine challenges were excluded leaving 78 challenges for RAS for further analysis.

Finally, we ran a standard cluster analysis of all the 78 challenges for RAS using the cluster analysis tool of Nvivo 11 software to combine similar ideas [53]. From the NVivo cluster analysis-dendrogram (Figure 5) we defined three main groups represented there by the upper branches: *independent*, *rurality* and *isolation*. In each group, we can see the most frequent themes. For instance, *monitoring* and *medication* were mentioned mostly around the main *rurality* issue. Figure 6 shows the NVivo tag cloud of all the themes mentioned. These three main groups, hereinafter referred to as opportunities for RAS, are described in the next section.

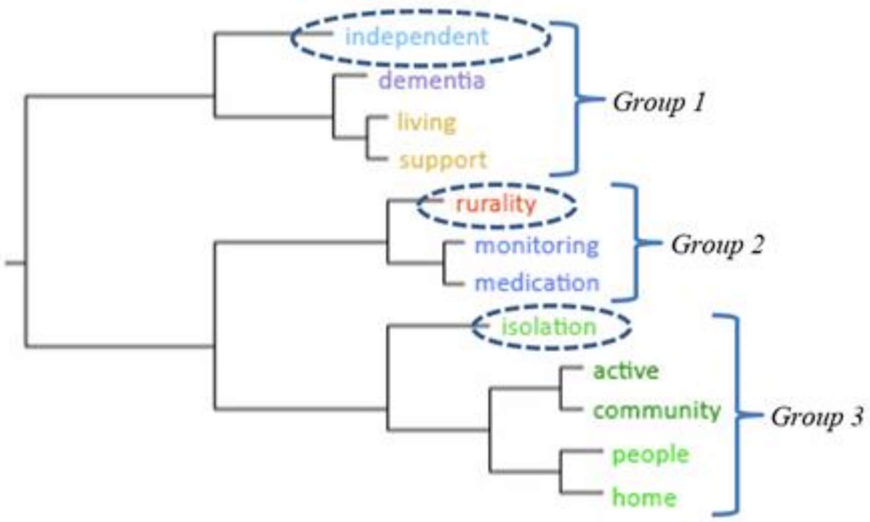

Figure 5. NVivo cluster analysis-dendrogram using Pearson correlation coefficient. From which we defined three main groups: *independent*, *rurality* and *isolation*.

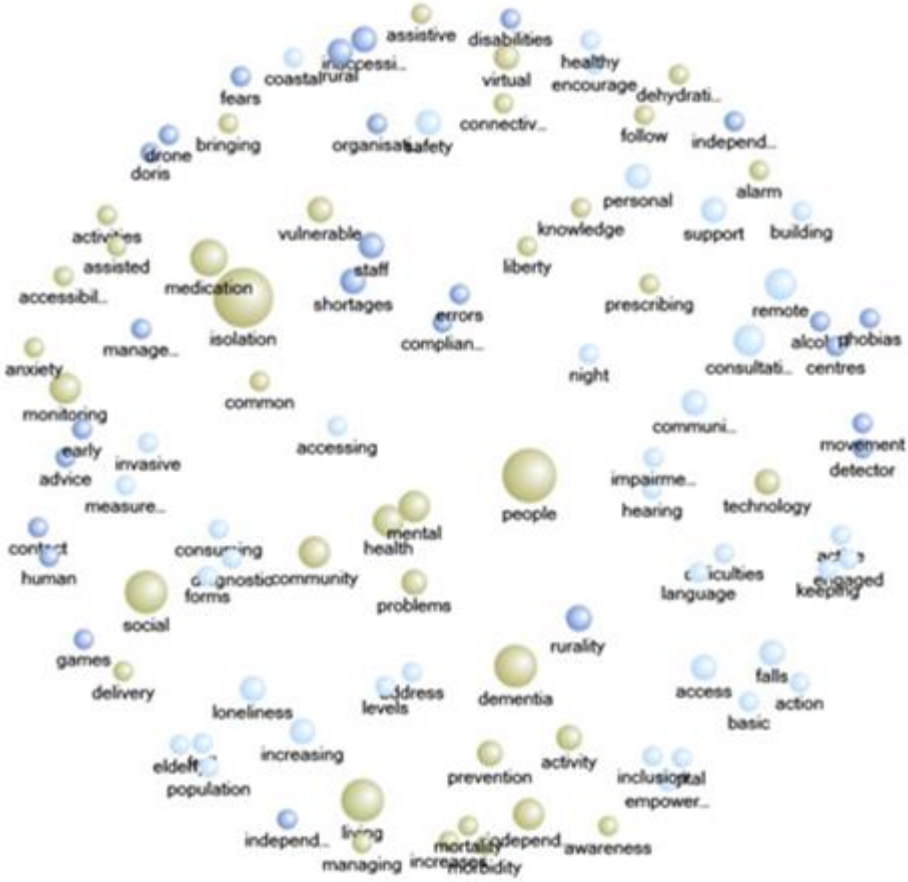

Figure 6. NVivo tag cloud showing the themes mentioned around the three main groups; blue; *rurality*, sky-blue; *independent*, and brown; *isolation*.

4. Results

The 33 focus groups produced 163 main challenges overall, of which 78 were relevant to a robotic solution. They were analysed and classified into three main opportunities for RAS in the health and social care sector; maintaining independence at home (36), social isolation (20), and rurality (22). Figure 7 shows that discussions in 6 of the 8 locations were varied; they did not have a predominant topic. Also, after the analysis, two locations (Newquay and St Austell), did not produce desiderata in one of the three main opportunities.

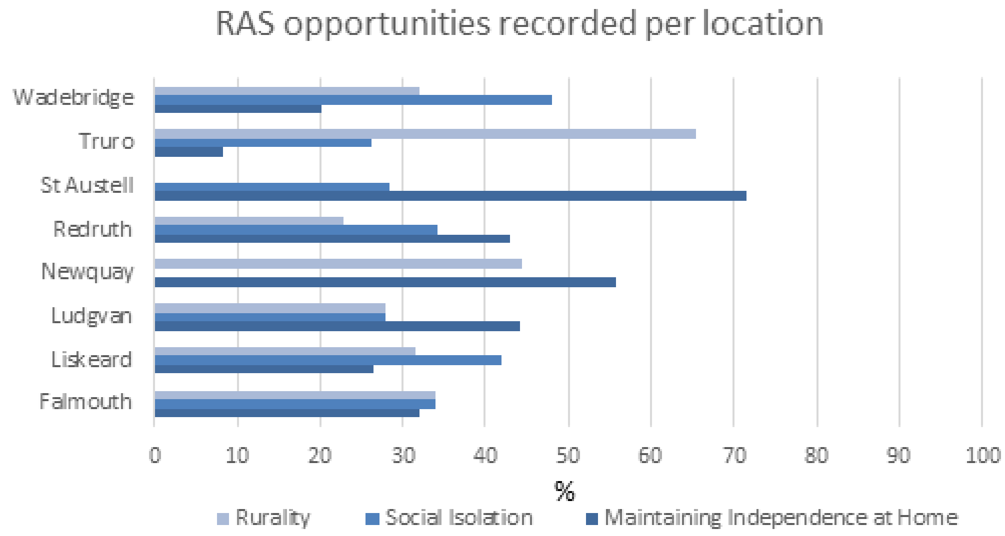

Figure 7. Distribution of the three main opportunities for RAS as recorded at each location

4.1. Maintaining independence at home

Developing and maintaining the capabilities that empower all people to be and do what they value in their own homes was one of the leading robotic opportunities identified by focus group participants. Three vulnerable groups were identified and discussed.

The first vulnerable group comprised people with cognitive impairment resulting from dementia, traumatic brain injury or stroke who struggle to live independently. Examples of problems included people forgetting to turn off the oven after use, disorientation, mobility problems, dressing and undressing. Other examples included issues with patients being unable to remember to take their medicines, keeping themselves hydrated, or remembering appointments. Participants discussed how this dependence leads to an increasing burden on social care services.

The second group comprised people who require over-night support. This includes patients who suffer from night rumination, anxiety, or epilepsy. Participants said that this group needed one-to-one support and ‘waking-nights’. This limited independence creates more workload for social care services, which NHS commissioners find expensive and difficult to arrange.

Finally, people who lived with a chronic condition or disability, including people with learning disabilities, were the third most frequently discussed vulnerable group. They were considered to need help around the house to carry out essential activities of daily living, from reaching and getting objects, to using everyday appliances such as washing machines or TVs.

To address these issues, participants suggested some dedicated robotic solutions: from robotic arms to help patients reach objects, to walking aid robots and automatic hoists to lift users. Table 3 presents the summary of activities that participants considered that robots could support to help those in need to have more independent lives.

For instance, they mentioned the possibility of using robotic animals for helping vulnerable users move around their homes, giving them directions while leading the way. Furthermore, participants discussed robots that could prompt a person to do a task such as switch off the tap or take medication. They could also help vulnerable groups use current technology, for example, an oven or a microwave, by providing visual cues for the user while monitoring their progress. They further considered robots that could identify objects for sight-impaired people. These systems would not only support independent living, but it was mentioned they would also help vulnerable group in "*addressing independence reassurance seeking".*

Participants also acknowledged the potential of robots' computer vision features like motion detection and behaviour analysis, by mentioning they would trust robots monitoring patients. For example, they suggested a system to measure the therapeutic levels of epilepsy medication. By analyzing the patient behaviour using a non-intrusive video system, autonomous systems could identify daily changes and produce a risk-level assessment of seizure each night; *"this will allow high or low alert support, and for medication tweaking if needed"*. Other examples, such as unwitnessed falls detection, wandering or even physical abuse detection were mentioned. Mood and emotion monitoring were also suggested as one useful tool to identify triggers, provide helpful prompts, and early de-escalation of abnormal activities. The examples suggested by participants show the willingness of our health care stakeholders to consider using autonomous systems monitoring patients.

Besides supporting activities of daily living, participants also considered the importance of robots encouraging users to exercise, for example, by following the lead of the robot in a different range of physical activities while the system makes an assessment of various parameters such as the patient's gait and balance, or even stroke rehabilitation assessment of movement. They also considered this technology could play a role in persuading families to eat healthier. Such activities would benefit health and self-management.

Finally, participants agreed that the mentioned robotic solutions would reduce burden and worry for caregivers and families. By using telepresence robots, participants declared that doctors could monitor the living conditions of vulnerable people. This technology was considered useful to assess patients living alone, while not disturbing their independence or deploying health professionals unnecessarily; *"one member of staff could then oversee and support a number of houses"*.

4.2. Social Isolation

Social isolation is the absence of contact between an individual and society. Isolation not only occurs because of geographic remoteness but also within care homes as recorded by our focus group participants. The new environment can be daunting for old people, leaving them feeling excluded from the outside world and alone, despite being surrounded by other residents.

Moreover, it was identified as an effect of experiencing a long-term condition causing slow cognitive decline. Health deterioration, as the progression of dementia, can cause a disconnection from reality. This causes confused residents to withdraw from their healthy hobbies and social events, reducing their quality of life. Also, isolation can increase the workload on health and social care services and affect their working environment.

Participants suggested solutions involving the use of social and therapeutic robots. Paro and Miro were discussed for their perceived ability to entertain the user. Participants mentioned that these robots not only bring reassurance and 'connection' but also could help calm people in distress, reducing agitation and anxiety in patients, and could motivate people and cheer them up.

Other applications discussed included voice recognition of robots to engage in conversation with isolated patients. Participants agreed that human-robot conversations might be a useful feature to reduce patients' loneliness. For example, patients with different level of dementia could benefit from humanoid robots, engaging in conversations. Participants did not view this as an ethical predicament. It was also considered an opportunity to integrate people. For example, participants thought that care home residents would interact more with each other and the caregivers because of the robots. Furthermore, some thought this involvement of robots would help raise the esteem of care home staff.

Human-robot conversations can also benefit people with learning difficulties. Regarding Pepper's tablet and voice recognition system, for example, a participant mentioned that *"people on the autistic spectrum could struggle with this screen so that they would rely on voice commands".* This exemplifies the importance of developing platforms with multiple options of user interface. This was also supported by numerous comments about old people struggling to hear Pepper, but finding the communication proposed by the robot through its tablet adequate. Several people further mentioned the importance of the robot being able to talk in the same accent.

Additional opportunities were discussed. Therapy sessions were considered a useful way of employing robots. The entertainment element that these robots can provide was also regarded as beneficial. The live streaming of physical activity classes, music performance, storytelling or the possibility of retrieving memories using these technologies was deemed to be advantageous. They added that robots might engage the community i.e. motivating family members such as young children to visit residents. Therefore, it was considered useful that robots should have dynamic applications for patients and family members to interact as well, for example, a different range of interactive games.

Finally, this problem also brings an opportunity for telepresence robots. The ability to remotely control these robots, plus features like auto answering and collision detection were thought useful by participants. They considered the telepresence robot as a useful tool for families to keep in touch and avoid social isolation. Furthermore, participants mentioned that robots could have a significant role connecting society in the future (Table 3).

4.3. Rurality

Distance to services, in particular, specialist services, lack of access to care, and the sparse population served was raised in nearly every focus group.

For example, nurses in care homes find it challenging to get hold of a GP when residents are unwell. Participants discussed how healthcare professionals and caregivers' burnout contribute to this problem. Furthermore, rurality is not only a problem of access to care but also to medications or emergency treatment. The example of a cardiac arrest on a beach was cited with the problems of being located on the moors or coastal paths.

The first robotic solution suggested was the use of telepresence robots. Using video calls, participants identified a viable link between GPs, paramedics, care homes, and patients. Doctors or paramedics could carry out a digital consultation being able to see the patient and assess their condition. For all of these, participants discussed including systems in these devices that allow physical readings such as blood pressure. Furthermore, these devices should enable GPs to move around freely, give them reliable images of the patients, and the option to physically interact with patients for a complete inspection. Finally, RAS could run, during the calls, visual health screening of the patients to identify any visible symptom of a disease or condition, to support the health assessment of the caller.

To address the challenges of access to medicine and emergency treatment, some healthcare professionals thought the use of drones useful. Participants suggested drones carrying medical equipment to first responders. Medication delivery could also benefit from this technology (Table 3).

RAS could also offer first aid to some unpredictable events. For instance, if the user suffers a minor injury, such as a broken arm, the robotic platform could immobilize the user limb to prevent further damage, until the user could get professional support. It could also be used to stop bleeding or give medications, such as those that are delivered through intravascular infusion. Besides, RAS active sensing systems could help users understand what their medical symptoms could mean.

Table 3. Summary of user-led challenges and desiderata for RAS.

Maintaining independence at home	**Social Isolation**	**Rurality**
Accessing the bath	Starting and keeping conversations	Platform for GPs video call and teleoperation
Sitting on the toilet	Creating emotional links with the user	Interactive symptom checker
Self-care assistant	Reducing agitation and anxiety	Automatic GP schedule appointment
Eating	Motivating users	Delivering information of the healthcare system
Assisting with white goods.	Bringing patients together	On-call health monitoring systems
Switching off/on devices	Raising esteem of caregivers	First aid response
Reaching things	Developing user socialization skills	Minor injuries response
Lifting heavy things	Entertaining patients and families together	Medication delivery and administration
Cleaning	Video calls services	
Reminder of medication		
Dressing		
Waking-night support		
Indoor guidance support		
Moving around		
Promoting healthy habits		
Health screening		
Mood and emotion monitoring		

Entertainment

5. Discussion

The desiderata identified by the participants of the focus groups were classified in three main groups (Table 3), which, in line with the key findings of [1,2], have demonstrated the main opportunities for RAS to support daily life activities and reduce social isolation. By accomplishing this; participants felt that robots could empower people to stay in their homes, improving user quality of life (see also [54]). RAS were also seen as a way of addressing independence reassurance seeking, having a further impact on care.

5.1. Maintaining independence at home

In line with [32,46], most challenges we identified around maintaining independence at home referred to activities such as reaching and manipulating things or assisting user mobility and self-care. While Table 1 shows different effort for addressing these challenges, there remain non-addressed implications. For instance, participants of our focus groups were concerned about safety parameters [37,55]: declining hand-eye coordination, tremors, or loss of hand dexterity might affect control of robotic arms. Participants discussed that this could not only harm the patients but also the people around them.

Similarly, most challenges involve close physical interaction between robots and users, as dressing or bathroom aids. Current robots often are not sufficiently safe to operate physically with people [2]. Therefore, advances are required in high-performance actuators, tactile sensors, grippers, and manipulation.

Research is also needed in cognitive robotics: to deploy robots that will help people remain in their homes requires them to be able to operate in that environment. This requires advances in locomotion abilities, active sensing systems, and, more generally, artificial intelligence. For example. RAS must be capable of mapping and understanding dynamic human environments, various and varying light conditions, and the full range of designs, shapes, and colours of everyday objects.

Applications promoting healthy habits were also mentioned (as in, for example, [14]). Furthermore, per [34], we found that healthcare professionals were interested in employing robots that could reduce their workload, not only in bureaucratic activities, but in directly engaging with the patients (in contrast with more sceptical findings from [56] where practitioners were questioned about robots replacing them). Participants also saw RAS as tools for raising the self-esteem of caregivers, in line with [44].

Moreover, in contrast with [57,58], our participants showed a predisposition towards autonomous systems for monitoring patients, including the use of non-intrusive cameras for patient surveillance not only improve patient safety and reduce carer's workload, but also as a way to improve response time. For instance, they were not concerned with Pepper's cameras and said that they did not perceive their privacy to be affected. This may be the result of the physical interaction participants had with robots during the technology showcase. First-hand interactions have been found to improve people attitudes towards and preconceptions of RAS [59]. It also highlights the importance of ensuring that cameras and their respective memory systems operate transparently, respecting user rights, and providing options to manage when and what is stored [60].

5.2. Social Isolation

Moving to the desiderata collected around social isolation, most of the applications identified by the participants were also in accordance with the findings of previous research [35]. For instance, previous research identified RAS to reduce agitation and anxiety [17] and to develop social skills [33] as participants suggested (Table 3).

The most interesting finding was participants' acceptance of using robots as a way to create emotional links with users. In contrast with other studies [61], participants were not concerned with ethical predicaments in using humanoid robots like Pepper or fake pets such as Paro to comfort and provide company for care home residents. Again, this could be a result of the participants actually interacting with the RAS at the beginning of the focus groups.

However meeting some of the social isolation challenges that were raised requires improvements in automatic speech recognition. For example, noisy environments, places with echo, or even big rooms, affect Pepper's automatic speech recognition, and this is seen as a limitation by the study participants. Automatic speech recognition must also support a broader range of voices, accents, intonation, dialects, and non-verbal communication. Finally, studies have shown that despite the improvement in adult speech recognition, children's speech recognition does not work reliably, and more research is needed [62].

5.3. Rurality

Finally, desiderata on rurality can be related to previous work [35,63,64], for example, telepresence robots for telemedicine applications, such as video call GP consultation and scheduling appointments [65]. The challenges of delivering medicines, identified in our focus groups, have been studied by others [66] exploring the positive effect in the downstream healthcare supply chain, and on the direct treatment, promoting positive emotions during medicine intake [67]. Emergency response has also been identified by [68] as a future directions for RAS.

Nevertheless, despite some commercial solutions in the market (Table 1), most of these robotic platforms are currently unavailable for most countries. For instance, Zipline or Lucas are only being used in Rwanda and US respectively.

While robotic consultations are suggested as a solution for some challenges around rurality (Table 3), participants mentioned challenges in fitting these into existing working practices, the skills needed to run the equipment, the bandwidth in rural areas, and key technologies for the domain of the application of robotics in healthcare such as motion control or collision avoidance.

Overall, the biggest concerns by the participants for RAS around the three main applications was cost. As other studies have found [37], current robots are not affordable for most end users, even considering that healthcare systems around the world have different budgets for financial incentives to adopt new technologies. For example, the cost of Paro, at around £5000 to £6000, was considered unaffordable, and had a negative impact on participants' acceptance of RAS. Therefore there is a need to make technology financially more accessible.

6. Conclusion

We presented desiderata and challenges for RAS in health and social care settings, identified by all key stakeholders. We collected these using a participatory research strategy through workshops including a technology showcase followed by focus groups.

Our main findings are in agreement with previous research. A noteworthy exception was that participants were not as concerned with ethics or privacy issues for the applications they proposed. Nevertheless, several implications were also identified. Our goal is to raise awareness of these desiderata, and the resulting potential applications, opportunities and implication for RAS.

Although we presented a comprehensive evaluation of user needs, further research is needed, in particular in other types of regions. Large cities, for example, represent 17.8% of the total EU population [69] and may present different challenges to the rural areas considered here.

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Annexe C – Interviews Paper

The barriers of the assistive robotics market - What inhibits health innovation?

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The barriers of the assistive robotics market - What inhibits health innovation?

Abstract. Demographic changes are putting the healthcare industry under pressure. However, while other industries have been able to automate their operation through robotic and autonomous systems, the healthcare sector is still reluctant to change. What makes robotic innovation in healthcare so difficult? Despite offering more efficient, and consumer-friendly care, the assistive robotics market has lacked penetration. To answer this question, we have broken down the development process, taking a market transformation perspective. By interviewing assistive robotics companies at different business stages, this paper identifies new insight into the main barriers of the assistive robotics market that are inhibiting the sector. Their impact is analysed during the different stages of the development, exploring how these barriers affect the planning, conceptualisation and adoption of these solutions. This research presents a foundation for understanding innovation barriers that high-tech ventures face in the healthcare industry, and the need for public-policy measures to support these technology-based firms.

Keywords: Barriers to innovation, assistive robotics, market barriers, policy innovation, healthcare innovation.

1 Introduction

Technology has always been a vital ally for healthcare (Wang et al., 2006). From the invention of new diagnostic capabilities and therapies to practices that improve the overall quality and cost-effectiveness of the care delivery system. This has changed healthcare and the perception of healthcare. More generally, technology is considered the ‘holy grail’ of public policy, achieving outcomes at a lower cost (Quilter-Pinner and

Muir, 2015). Nevertheless, the healthcare sector and its suppliers are not as productive as they could be at adopting new technologies.

This disparity is generally attributed to the market barriers present in the sector that are impeding the adoption of innovations and therefore their spread. Innovations in medicine do not follow a linear pathway even though there is still an inclination to see these as such (Nelson et al., 2011). Indeed, the innovation process in medicine has been described as long, incremental and path-dependent (Gulbrandsen et al., 2016), reflecting (Garud et al., 2013) recognition of the co-evolutionary and path-dependent nature of innovation processes more generally.

Innovations today are desperately needed. Healthcare systems worldwide are under increasing pressure. Life expectancy has increased, from 52.6 in 1960 to 72.0 in 2016 (World Bank, 2017), and the last two decades have witnessed continued growth in the global population (ONU, 2015). In the European Union, despite fertility levels being below what is generally regarded as the level necessary for a population to maintain it sizes (1.6 against 2.1 respectively (Cocco, 2018). It is estimated that population levels will remain relatively static (falling approximately 0.35% by 2050) due to net migration (Worldometers, 2018), while life expectancy has increased by 2.9 years, from 77.7 in 2002 to 80.6 in 2015 (EUROSTAT, 2015).

For the social care sector, the ageing of the population translates into many more individuals with one or more long-term conditions, and more complex patterns of diseases (Workforce Intelligence, 2013). While shortages of qualified carers are continuously increasing (All-Party Parliamentary Group on Global Health, 2016), because of increased constraints on the funding and resources available governments are urged to find alternatives to help close these gaps. To provide a more tangible example, more than 9 million people in the EU need help getting out of bed (EUrobotics, 2017), and this figure is likely to increase. A new wave of innovations is needed if we want to provide people with affordable and effective healthcare (European Commission, 2012).

Based on these previously introduced challenges, the assistive robotics (AR) market is surging, providing support to patients and care workers, in the globalisation of healthcare (UK-AR, 2017). Assistive robots are shifting the model of healthcare from one focused on hospital treatment to one that supports independent life (EUrobotics, 2017). However, despite the developments of the last two decades, the AR market is not having the impact expected due to the current market barriers (EURobotics, 2014).

Identifying obstacles to innovation has clear policy relevance, since addressing these barriers could increase the population of innovators and boost the performance of current ones (D'Este et al., 2012; Hölzl and Janger, 2013; Pellegrino and Savona, 2017). Consoli and Mina call for more research on problems and challenges surrounding innovation processes in health and care settings (Consoli and Mina, 2009).

By offering insights into current barriers of the AR market, we seek to assist this process for a market we have not seen before. The development of assistive robots for the healthcare sector is not only an issue of technology or societal acceptance. We need to work on the broader market barriers and ways to overcome them. Only then entrepreneurs and firms will be aware of the venture challenges, and governments could take measures to supports these inventions that are highly needed (Marrocu et al., 2013).

Consequently, this paper starts by giving an overview of the current state of this market. Section 3 presents the theoretical background. Then, drawing on the experience of 17 firms engaged in the AR market, Section 4 explores the primary market barriers relating to the product development process, from conceptualisation to commercialisation. Next, we discuss the barriers and its combined effect while providing implications for policy measures to support technology-based firms. Finally, concluding remarks and implications for research are provided in Section 5.

2 Background

The AR market relates to robotics and autonomous systems with the primary role of providing assistive help to carers or directly to patients, in hospital, specialist care facility or domestic healthcare settings (EUrobotics, 2017). This market excludes clinical robots (e.g. surgical robots, (Ballantyne and Moll, 2003; Sackier and Wang, 1994); robots for diagnosis (Anantham et al., 2007) or training purposes (Taehan Sanbuinkwa Hakhoe. et al., 2008)) rehabilitation robots (e.g. prosthesis and exoskeletons (Bogue, 2009) and rehabilitation systems (Díaz et al., 2011)). It also excludes the sector known as service robots or robots for domestic tasks (e.g. vacuum or window cleaning, lawn mowing) (International Federation of Robotics, 2017).

The AR market features robots that organise and deliver medication (Butter et al., 2008), support activities of daily living such as eating (OBI, 2019) or putting clothes on (I-DRESS, 2018), that can improve hygiene (I-SUPPORT, 2018) or the recovery process (Butter et al., 2008). It also includes lifting and displacing aids, from helping nurses moving the patient from bed to wheelchair, or helping the elderly move around their homes (CHIRON, 2016). Socially assistive robots are also part of this sector, offering patient aid in therapy rehabilitation (Feil-Seifer and Mataric, 2011). For instance, the best-known example, Paro, is a therapeutic seal for people with dementia (PARO Robots, U.S., 2014). Finally, AR also includes robots for the transportation of drugs, food or other resources (Bloss, 2011), and communication purposes (Tsui et al., 2011) (Figure 1). It is recognized that this list covers just a fraction of the various applications and opportunities for which assistive robots are being developed in universities, research labs, and start-up companies (Wang et al., 2006).

Figure 1. Assistive robots available in the market. 1 Care-O-bot; domestic robot assistant, 2 Cutii; telepresence robot for older people, 3 Leka; a therapeutic robot for children with developmental disorders, 4 Obi; robotic feeding device, 5 AV1; robotic avatar for users with long-term conditions, 6 Paro; therapeutic robot.

The assistive robotic market is different from any software or hardware application, or even other AR technologies. Manufacturing or agricultural robots have required a focus on the design of the mechatronic structure. Aerial, marine and transportation robots have focused on autonomous navigation and object detection. On the other hand, assistive robots build around the nascent human-robot interaction field (UK-RAS, 2017). They are robots that interact physically with their user, continuously and autonomously monitoring their condition, while supporting them in different activities. The design involves different stakeholders, different structural systems abilities and technologies, different design processes, different testing methodologies, and as a result, it produces different market barriers for the suppliers of this emerging industry.

The size of the global AR market in 2015 was over USD 200 million, with 18.9% Compound Annual Growth Rate estimation from 2016 to 2024 (GMI, 2017). It is characterised as a highly fragmented sector, driven by some small players (Figure 2). The industry is in a nascent state, where start-ups are pushing with an increasing number of robotic products that perform a wide variety of tasks (Wang et al., 2006).

However, despite the potential for the technology, there is limited evidence of AR projects that transform into new products and services for the user (UK-RAS, 2017). The International Federation of Robotics registered only around 5,305 robotics solutions for supporting elderly and handicapped sold in 2016 in the world (International Federation of Robotics, 2017).

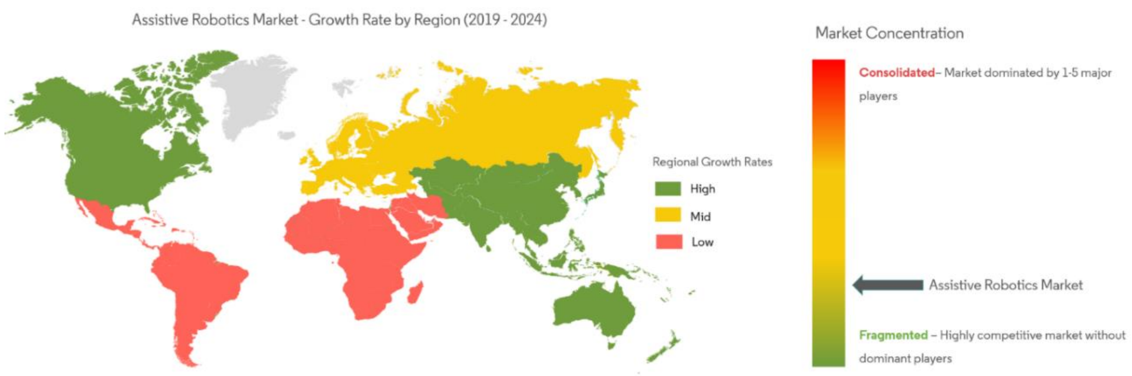

Figure 2. Market Growth rate and concentration. Source; (Mordor Intelligence, 2020)

Furthermore, from February 2019 to March 2019, we contacted 11 robotic companies in the field, inquiring their trending activities (Table 1). Only one was currently supplying to the European market, and three are trading outside the EU. One of these 11 businesses, the American company Jibo Inc. who raised nearly $72.7 M with his social assistive robot (Crunchbase, 2019), was forced to sell its assets on December 2018 and has been out of business since then.

Table 1. Trading activities of assistive robotic companies contacted from February 2019 to March 2019. (Note: -- indicates that the company did not share the information, * year that the relevant robotics division was created. Table last updated the 06 of June of 2018).

Company	Year Founded	Total Funding Amount (*M$)	Product	Currently trading
SONY	*1990	--	AIBO	Worldwide
Intuition Robotics	2015	22	ElliQ	Pre-sale US
Blue Frog Robotics	2014	0.18	Buddy	No
Emotech LTD	2014	10	Olly	No
Jibo	2012	72.7	Jibo	No
Temi	2015	21	Temi	No
ASUS	--	--	Zenbo	No
Groove X	2015	52.7	Lovot	Japan
UBTech Robotics	2012	940	Lynx	US
Zoetic AI	2017	--	Kiki	No
Yukai Engineering	2011	--	BOCCO emo	Japan

2.1 Innovation through barrier identification

Innovation research may be divided into two general areas of analysis an economic-oriented tradition and an organization-oriented tradition (Brown and Eisenhardt, 1995). The first studies innovation across countries and industrial sectors; for instance, through sourcing of knowledge for innovation (West et al., 2014). While the latter focuses on how specific new products are developed; the structure and process by which organisations create products. This study focuses on the latter since by analysing the product development process and identifying the innovation inhibitors or barriers, it is possible to take action to eliminate them and restore the 'natural flow of innovation' (Hadjimanolis, 1999). This approach is particularly useful for cutting-edge technologies and new markets (Hadjimanolis, 2003), such as the AR sector.

Market barriers to new technologies can be perceived in different ways (Hadjimanolis, 1999). For instance, through research, development and deployment perspective, we emphasise the nature of the technology, its manufacture and user adoption (Ehrenhard et al., 2014; Owen, 2006). Since this represents the first line of the development process, much of the literature available around case studies of AR focuses only on these elements of innovations. For instance, (Yusif et al., 2016), (Greco et al., 2009), or (BenMessaoud et al., 2011) studied user needs, acceptability and usability of innovations in technology with end-users. Numerous studies outline the critical technology targets for AR, drawing roadmaps for the development of this sector and main research challenges (e.g. (Butter et al., 2008; EUrobotics, 2017; UK-RAS, 2017)).

None of these studies considers the development of assistive robots as a market-orientated process; the obstacles of producing the technology from concept design to the commercialisation of the AR. We argue, therefore, that since the application of robotics in healthcare is not only an issue of technology or societal acceptance, special attention has also to be paid to broader market barriers and ways to overcome them. Entrepreneurs and businesses find it challenging to navigate in this market due to challenges that have not been studied and addressed.

To thoroughly understand the barriers, we have explored them from a market transformation perspective. Here, we do not focus on the nature of the technology or typical operating characteristics of conventional markets, but rather on the development of technology as part of a market process and what needs to be done in practical terms to create markets for new technologies (Owen, 2006). To date, most of the relevant literature centres on market transformation studied in the eHealth sector, i.e. the use of information and communication technologies in healthcare (i.e.; (Alkhaldi et al., 2014; Mieczkowska et al., 2004; Wang and Hajli, 2017)).

There is, therefore, a predominant focus only on software products. A distinction exists between the development of a hardware product and its commercialisation. Consequently, market barriers may also be different (Cairo, 2019; Thompson, 2019).

This study seeks to apply the Painuly (2001) framework, which builds upon the barriers approach to innovation, focusing on a market transformation perspective. Painuly developed a framework for analysing the barriers to renewable energy penetration when this was an emerging sector. The study analysed the obstacles to creating a new and innovative market. The framework provides a methodology for identifying barriers by reviewing case studies, including criteria for selection and measures to overcome the barriers identified.

Different models describe product development processes for different industries. Ulrich and Eppinger's (2016) six phases of product development balance hardware and software development in the product development process (Figure 3). The process includes the tasks and responsibilities of the critical functions; marketing, design, and manufacture. This model, along with Painuly's (2001) framework will serve as a basis of our exploration of inefficiencies in the AR market.

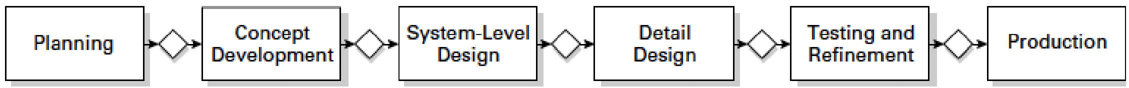

Figure 33. Eppinger, S. D. & Ulrich Product Development Process. Source; (Ulrich and Eppinger, 2016)

To summarise, using a market transformation perspective, this paper explores and identifies market barriers as perceived by companies engaged or trying to engage in the AR market. We argue the study is particularly pertinent at a time of growing care needs, coupled with a minimal understanding of the AR market and the implications for health innovation policy. The current literature focuses on soft elements of AR innovation and not on the implications of the market deployment of these technologies.

Moreover, the current literature around market barriers for healthcare focuses only on digital technologies. The AR market is fundamentally different from the digital or any other robotics sector. Therefore, only by exploring market barriers policymakers and entrepreneurs will be aware of the venture challenges and take measures to supports these inventions that are highly needed for the healthcare sector.

3 Methodology

Semi-structured interviews were conducted with 17 people from different assistive robotic companies. Companies were based either in the UK or France (Table 2). The interviews involved the owners of the company, wherever possible. Where this was not possible, interviews were conducted with senior managers.

The study explored their perspectives relating to the challenges they perceived and were facing during the product development and commercialisation process. Apart from having to be involved in AR, the other criterion used to select businesses was the age of the business. We aimed to get companies covering different business stages: seed and development, start-up, expansion, and maturity.

Table 2. Assistive robotic companies interviewed. (Note: -- indicates that the company did not share the information. Table last updated the 28 of September of 2018).

No. of employees	Registration	Age (date reported, year)	Assets (last reported, *1000 Eur)	Currently trading	Country	Product description
1-10	Jul-18	0.24	5.6	No	UK	Wheelchair robotic arm
1-10	Jan-18	0.74	5.6	No	UK	Therapeutic robot
1-10	Nov-17	0.91	--	No	UK	Emergency drone
1-10	Sep-17	1.07	75	No	France	Medication reminder robot
1-10	Aug-17	1.16	--	No	UK	Care support robot
1-10	Aug-17	1.16	28.5	No	UK	Medication delivery robot
1-10	May-17	1.41	11.2	No	France	Smart wheelchair
11-20	Sep-16	2.07	155	Yes	France	Care support robot
1-10	Sep-16	2.07	5	No	France	Assistive robotic arm
1-10	Jul-16	2.24	192.5	Yes	France	Care support robot
1-10	Apr-16	2.49	143.7	Yes	France	Telepresence robot
--	Jan-16	2.74	--	No	France	Medication delivery robot
1-10	Jul-15	3.25	50	Yes	France	Patient monitoring solution
1-10	Nov-14	3.91	7.2	Yes	France	Therapeutic robot
30-50	Nov-12	5.91	50.3	Yes	France	Indoor projector robot
11-50	Nov-11	6.91	162.5	No	France	Care support robot
41-50	2007	11.00	15,400	Yes	France	Robotic air quality purification

We interviewed start-ups and companies working from at least six months to up to 11 years. This was intended in order to map the different obstacles assistive robotic companies face during the market process/product development and life-cycle. Sampling comprised a mixture of purposive and convenience, given that companies had to meet our selection criteria (Patton, 2014). Participants were briefed about the nature of the study, participation was entirely voluntary, and it was agreed that companies would not be mentioned by name.

To design and structure the questions for the interview, we drew on Ulrich and Eppinger's (2015) six phases of product development. The process includes the tasks and responsibilities of the critical functions of the company for each phase, including marketing, design, and manufacture. The linearity of the process allowed us to structure the interview, but it did not unduly restrain or influence the conversation. In this sense, interviews were semi-structured (Ghauri and Gronhaug, 2002) and akin to Kvale's notion of conversations with a purpose (Kvale, 1997). For each of these stages, several questions were elaborated.

The questions were designed following the study objectives; explore AR market barriers from the perspective of the companies, the critical functions of the development process and an initial literature review from AR projects (Thomas, 2006). Examples of questions include 'What was the most difficult part during the phase of product planning?', 'What was the biggest challenge in assessing customer needs?', 'Tell me about the problems you faced during your prototype testing phase'. Follow up questions were asked to explore the participants' answers in more depth.

Interviews lasted between 20 to 50 minutes and were audio-recorded. They started with an introduction of the objectives of the study and by the participant's overview of their business.

Then, interviews were transcribed using IBM Watson Speech to text. The transcripts were cleaned and put into a standardised format. The general inductive approach was used to analyse the transcripts to identify themes in the text that were related to the study evaluation objectives (Thomas, 2006). The analysis started with a close reading of the text, the themes were developed, which in the view of the investigators captures core messages reported by participants, particularly around barriers and market inefficiencies. Overlap and redundant themes were reduced through a search of subtopics, including different points of view and new insight. To show when companies perceived the effects of the barriers; we also classified themes according to their appearance in the product development process. Nineteen significant themes were identified, hereafter referred to as barriers, and are described in the next section.

4 Results and Discussion

The present paper follows (Painuly, 2001) for classifying the nineteen themes identified. Following Painuly categorisation system, we organise the themes into five distinct sets of market barriers, shown in Table 3. Besides, by his classification scheme, Table 4 shows the elements or the leading examples of the barrier impact in the AR market. Figure 4 displays barrier emergence during the product development process.

Barrier Category	Barrier	Remarks
Market Failure	Access to the healthcare sector	*'without contacts, there is not really a way into it'*
	Highly fragmented healthcare sector	*'there are many different people involved', 'you can't get to the people that make the choices', 'is quite hard to reach the client'*
	Poor market infrastructure	*'you have to manufacture where the skills are'*
	Distrust in entrepreneurs	*'people see us as buyers, instead of people trying to help others doing what we love', 'doors are not open to entrepreneurs with good ideas'*
	High investment requirements	*'is not cheap, is an expensive journey', 'this stop people for doing, the cost puts an extra weight'*
Economic and Financial	High cost of capital	*'bring a project together and fund that project is really really difficult'*
	Lack of/inadequate access to capital	*'there are not investment opportunities for hardware'*
	High up-front capital costs for investors	*'there is great risk involved in funding hardware companies'*
	Lack of access to credit for the consumer	'[the product] *might be too expensive for the final user', 'you need to work on B2B'*
	Small market size	*'we don't know how the UK* [healthcare] *systems work', 'we will need someone to help us get to that market'*
Institutional	Lack of institutions and mechanisms	*'there is a lack of directives', 'government support is minimal'*
	Lack of a legal/regulatory framework	*'AI should be transparent',* '[healthcare segment] *they are reluctant'*
	Lack of stakeholders' involvement in decision making	*'this is a problem, we got the solution, and no one listen* [to entrepreneurs]*'*
	Lack of universities' participation	*'you can't put a price* [university support] *but, unfortunately, they are not interested in product development'*
	Lack of a clear certification process	*'we cannot pursue a medical certification'*
Technical	Lack of skilled care personnel	*'they haven't seen a robot, so they don't know how to use it'*
	Systems constraints	'[challenge] *to know what technology to use', 'integrate all the technology is the main problem'*
Social, Cultural and Behavioural	Lack of consumer acceptance	*'is quite hard to reach the client', 'is not here to take people jobs'*
	Unfounded moral and ethical concerns of AR	'[invest time] *to convince people to have the robot', 'is not going to spy you'*

Table 3. Barriers for AR companies.

Barriers	Barrier elements
1. Market Failure	
Access to the healthcare sector	Access to patients for product co-creation. Disrupts the whole development process.
Highly fragmented healthcare sector	Different stakeholders and organisations. Slows down technology acquisition.
Poor market infrastructure	Lack of manufacture opportunities in Europe. Increases final product cost and slow technology acquisition.
Distrust in entrepreneurs	Disrupts development process and technology adoption.
High investment requirements	High seed funding needed to develop prototypes. Builds an entry barrier for entrepreneurs. Discourage entrepreneurs.
2. Economic and Financial	
High cost of capital	Fundamental differences between software and hardware investment requirements. Creates a lack of capital, high-interest rates, and risk perception by financial organisations. Impacts on economic viability.
Lack of/inadequate access to capital	No awareness of hardware development implications. Impacts market competition and market efficiency.
High up-front capital costs for investors	High seed funding need increases risk perception. Lack of understanding of AR investments needs.
Lack of access to credit for the consumer	High product cost. Under-developed credit market. Reduces market size.
Market size small	Fragment healthcare system between regions and countries. Prevents product scale and potential gains, reducing the appeal for entry of newcomers.
3. Institutional	
Lack of institutions and mechanisms	Missing agencies at the planning level to support AR development. Inhibits information dissemination between producers and consumers, creating extra costs for companies.
Lack of a legal/regulatory framework	Generates liability and concerns in the adoption of new technology.
Lack of stakeholders' involvement in decision making	No involvement seek of developers. Creates misplaced priorities, making policymaker bodies unaware of the market barriers.
Lack of universities' participation	Impacts on recruitment and R&D opportunities.
Lack of a transparent certification process	Not clear the path for certification of AR devices. Disrupts market entry of new products.
4. Technical	
Lack of skilled care personnel	Slows down technology adoption, creates extra expenses.
Systems constraints	Integration problems with healthcare IT infrastructure. Producers cannot realise the market.
5. Social, Cultural and Behavioural	
Lack of consumer acceptance	Fears surrounding the broader impact of AR, for example, fear of robots taking jobs. Reduces the market size.

Unfounded moral and ethical concerns of AR	Affects market size and technology adoption.

Table 4. Elements of identified barriers.

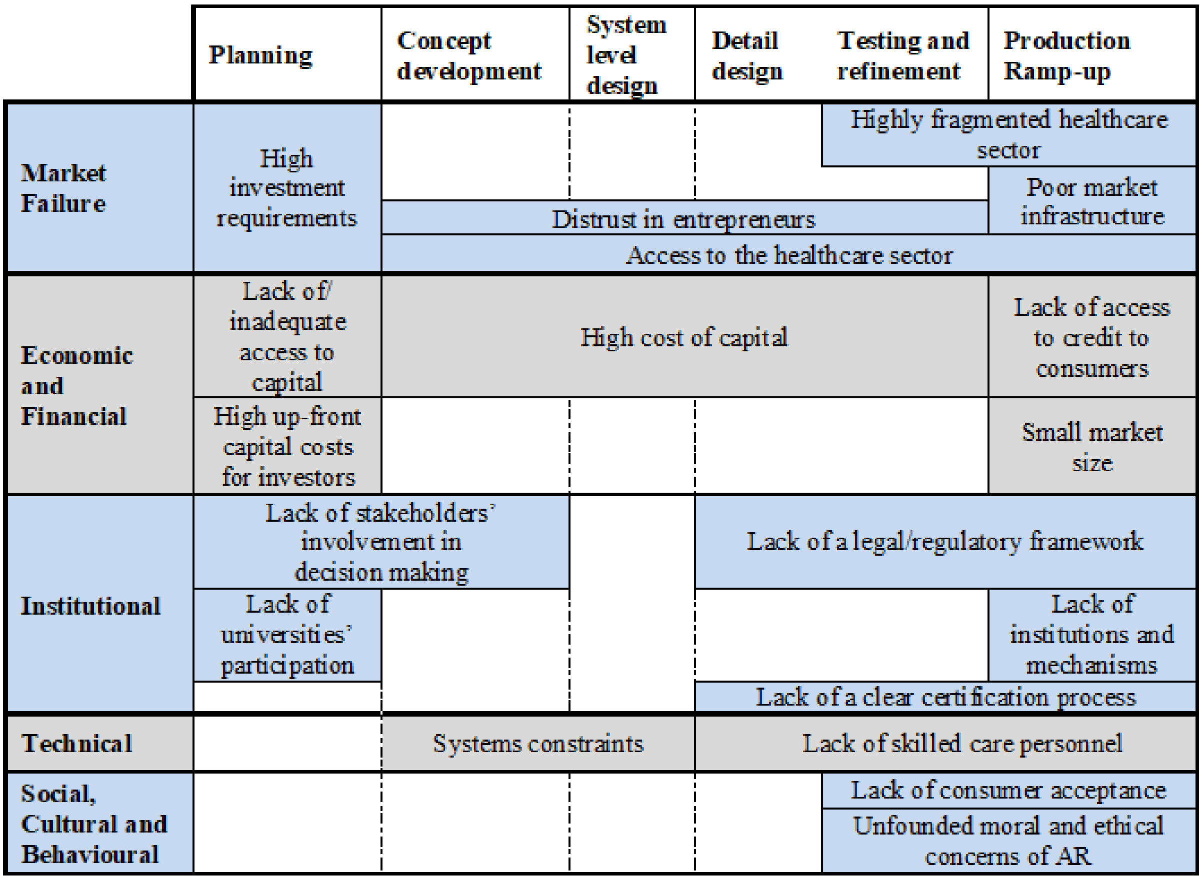

Figure 4. Barriers over the development process of AR for healthcare.

These tables present a useful heuristic device as a means of understanding the nature and scope of critical barriers in the AR market, as evidenced in the interviews. However, we recognise that the classification of barriers shown in Table 3 is not rigid, that some of the barriers are interrelated, and that some barriers can, arguably, belong in more than one category and share a similar impact. That is why the remaining section discusses and analyses these findings not as individual and independent elements, but as members of each barrier category.

4.1 Market Failure

This refers to the lack of conditions needed for perfect competition in the market, most notable access to information. The impact of hereof can be seen through the whole development process.

4.1.1 Access to highly fragmented healthcare sectors

The most frequent barrier identified was access to the healthcare industry. Specifically, for innovation to take place, entrepreneurs need access to patients, families and carers' needs, to know and understand their problems. Only with this knowledge is it possible to generate and implement ideas for new improvements. User-centred design is seen as a vital tool when it comes to AR innovation for healthcare, and its input could overcome further barriers of adaptability and implementation. The interdisciplinary field of the innovation process demands specialised knowledge in methods of care, presenting new challenges for innovators who ask themselves whom they should involve in the process. Being able to define and then access an ideally representative sample of early adopters for the market is the initial challenge that AR companies face.

'without contacts, there is not a really a way into it […] you are not exactly going to be able to walk into any care home ask them; do you want a robot? Can we now work with you?'

The fragmented structure of healthcare systems was seen as the primary reason for this barrier since there is not a clear go-to point. Take for instance the National Health Service (NHS) in the UK. Commonly seen as one entity, it is, in fact, a group of many individual organisations; NHS England, NHS Scotland, NHS Wales, and the affiliated Health and Social Care in Northern Ireland, Public Health England, 195 Clinical

Commissioning Groups (CCGs), 245 hospital or acute trusts, around 7,454 general practices only in England, and thousands of community providers. Each often includes clinicians, financial managers, commissioners and Information Technology managers.

Respondents mentioned that some health organisations charge for preliminary assistance, even up to *'£1,500 for a 3-hour consultation'*. Besides being an elevated price for new ventures, 3 hours is unrealistic about the actual time needed to gain sufficient understanding of consumer needs. Every decision taken during the innovation process should count with the feedback of lead-users and stakeholders involved. Some companies mentioned that for conceptualisation, development and testing of their prototype product, consultation time ranged between 10 to 15 hours.

The alternative is to look to family and friends to become involved in the process. This is a reason why so many entrepreneurs innovate around the needs of their relatives. Participants also mentioned the extreme option of having to '*look in the streets*' for potential lead-users.

Distrust towards entrepreneurs was also mentioned as a barrier. Participants mentioned there was an expectation for eHealth entrepreneurs to have an extended portfolio of developing robots as if they were app developers. Therefore, many mentioned that *'doors are not open to entrepreneurs with good ideas'*.

'We don't have a reputation, or much more, products to our names, so that we can go and say, this is a current problem, look what we have done, we got the solution … no one listens'

In particular, this last quotation illustrates the credibility problem these new entrepreneurs have in gaining acceptance in the eHealth market place.

What makes the mentioned lack of access different for AR companies compared to digital companies is its combination with social, cultural and behavioural barriers. Where digital technologies also suffer from negative attitudes and beliefs from the healthcare members, individuals have been widely exposed to apps and programs in their daily lives, greatly improving the user perception of the innovation and adoption of these solutions (Goldzweig et al., 2009; Police et al., 2011). Robots, on the other hand, have not yet had the same visibility. Combined with this distrust towards entrepreneurs, we have a market that closes its doors to technology and innovation-driven in part by ignorance including uninformed ethical concerns as well as cultural barriers. This restriction not only impacts the development process but also businesses' access to funding opportunities since cost-saving studies cannot be done without healthcare support.

4.1.2 Complex market infrastructure

The complex structure of the healthcare system has a direct impact on our target market infrastructure. According to interviewers, multiple people influence the procurement process, making it challenging to identify and locate who is, ultimately, responsible for making the final decision on a purchase or commission. Interviewers also mentioned that the spread of AR technologies within healthcare systems is slow and fails to achieve widespread use.

The number of individuals involved in the adoption process, not only defines the demand of the market but also slows down the diffusion of a product. It also raises a fundamental problem; transparency regarding the structures and purchasing processes within each organisation. This barrier has further impacts that discourage private funding from supporting AR ventures.

'[regarding the purchasing processes] for someone that is new to the market it is exceptionally difficult to get to the right people, to go to the people that make the choices'

Lack of a technological appraisal tool or method for AR that could benefit companies as a route to widespread use was also mentioned. There is currently a market search friction problem; purchasing and supply agencies do not know what technologies are currently available. There is no standard platform for AR to prove their benefits to healthcare stakeholders and look for potential buyers. Moreover, there are no distribution channels for AR technologies.

'it is quite hard to reach the client, and distributors ask for a lot of money, raising prices'

Currently, initiatives such as Innovation, Health and Wealth introducing a legal obligation on all UK's CCGs to offer National Institute for Health and Care Excellence (NICE) approved technologies to patients, had a positive impact on new medicine use, but it does not cover non-medicines (Quilter-Pinner and Muir, 2015). Therefore, initiatives like those should be designed to overcome search friction.

4.2. Economic and Financial

This category describes those barriers which had an impact on the access to finance and the conditions attached to obtaining financial backing. From the interviews, it was clear that the main barriers focused on the lack of seed funding with implications for scalability of the market. These issues have a significant impact during the first stages of the development process (Figure 4).

4.2.1 Capital and Investment

According to interviewees, on average, three to four prototypes are required before getting a minimum viable product. This could translate into four years' of work and at least three rounds of funding. This demonstrates that it is not only the technical challenges that discourage AR innovation but also economic viability considerations. Fear of financial failure appears to be thwarting most projects before they properly have the chance to flourish.

As in other markets, robotics companies frequently start with entrepreneurs working part-time on their projects. However, while app developers can find solutions to avoid incurring initial costs, for robotics start-ups, the scope here is more limited. The high initial investment is needed for buying off-the-shelf devices, as well as fast prototyping tools.

'finance, is so difficult, is not cheap, is an expensive journey, and this stops people from doing it'

Several participants explained that there is an underdeveloped capital market; scarcity of capital, restricted entry, unavowed regulations and lack of access to affordable capital for AR ventures. Others mentioned that there were few investors and venture capital providers who understood hardware development and therefore, the seed capital needed. Those who are willing to invest perceive this as a high-risk involvement, demanding high-interest rates to offset the risks they take.

There is poor creditworthiness for AR and inadequate recovery regulations. Without a repayment history, credit score or available assets, financial institutes perceive early-stage AR companies as a high-risk investment. This translates into high-interest rates and low credit limits. This has a direct impact in particular on indebted businesses. AR companies are often forced to recover through the sale of the collaterals, which in this market is the manufacturing equipment or the technology inside the robot, not allowing a real recovery for start-ups.

The lack of openness from the healthcare sector makes it difficult for start-ups to prove cost-savings of their products; how they affect the right treatment and the downstream healthcare system. Besides, assistive robots have an impact on the quality of life of patients (i.e. therapeutic robots for reducing isolation, stress, anxiety), making it difficult to define the real value of innovation without standard technological appraisal tools. Also, participants' views were that health commissioning bodies take their investment decisions motivated more on cost and risk concerns than the healthcare outcomes for patients.

4.2.2 Customer credit facilities and market size

The cost of acquisition and use of assistive robots was reported as a significant barrier. Business to Consumer schemes are not viable for most companies since final AR products are commonly too expensive for their end-users due to the costs associated with manufacturing and the technology behind the product. Even if consumers want to purchase AR products, because of under-developed credit facilities, this could present a barrier. Thus, currently, there are no government policies, strategies and incentives for encouraging the adoption of AR technologies that extend to offering either credit facilities or other elements of financial support.

On the other hand, due to the complex structure of healthcare systems, the end-user generally has no input on pricing considerations, only purchasing and supply agencies.

Therefore, if the product has not been prescribed, the final user will have to pay the full price for a product, irrespective of affordability. All of this has an impact on the current market size for AR companies.

Healthcare systems around the world not only vary in their structures and entry channels but also in terms of their regulations and economic context, different leadership styles and environments. Product or service development strategies may need to be tailored to each unique system. This makes access to new markets, i.e. ones with which the eHealth entrepreneur is not familiar, difficult. Interview responses indicated that companies from France and the UK did not have any knowledge about the other's healthcare market, and both mentioned that they could not enter a new market without support. Some companies mentioned difficulties expanding to other regions within the same country due to the fragmented structure of the healthcare sector.

4.3 Institutional

Since AR in the healthcare sector represents an emerging market, policies and governments are still playing a catch-up game concerning regulation and support. We refer here to the notion of institutional burdens, that is underdeveloped or absent institutional structures which can hinder aspiring entrepreneurs from exploiting opportunities fully (De Clercq et al., 2010).

4.3.1 Poor legislation, poor policies

The AR market lacks specialised agencies at a planning level that can develop and ensure a safety adoption framework for AR innovations. As mentioned in section 5.1.2, there is lack of transparency in the purchasing and adoption procedure of new technologies for the healthcare sector, starting with initial go-to points for entrepreneurs. The absence of adequate appraisal tools makes it difficult for start-ups to assess the economic evaluation of their products, which generally have an impact on the quality of life of patients (i.e. therapeutic robots for reducing isolation, stress, anxiety).

In the same way, there is no education for health stakeholders of the technology available and opportunities this new market presents. Besides, liability concerns interrupt the development process and AR adoption. All of this is compounded by a missing regulatory body that supports early-stage companies, regulates the development process, and promotes the adoption of assistive robots.

A lack of planning and the absence of policies to foster the development of innovations in the eHealth sector was also mentioned. Barriers such as access to health experts and lead users could be overcome with the right regulatory body. It could also address the absence of legislation surrounding liability while testing or adopting new AR products at the organisational and health professional levels. This includes critical appraisal tools for testing AR, approved by the relevant bodies.

These barriers are the result of the reduced involvement that the supply side has in decision making. Different from traditional markets, the healthcare stakeholders counterpart do not involve engineers, developers, entrepreneurs in the development of policies for innovations. There is currently a consultation culture missing, driven by a tension surrounding change alongside social, cultural and behavioural barriers described in section 4.5.

Another essential subject mentioned was the lack of support for entrepreneurs to protect the Intellectual Property (IP) of their products. The current process takes around five years to complete and requires a substantial investment in applications for patents and design rights. In the UK, only one in twenty applications get a patent without professional support. Subsequently, this might need to be renewed on an annual basis. This problem prevents companies from accessing quality manufacturers recognised by the healthcare industry, which often required IP before getting involved in the process.

4.3.2 Lack of university participation

Most companies that took part in this study mentioned the vital role that universities played in this market. From access to technical and medical knowledge to the recruitment of new talent. Nevertheless, it was acknowledged that doors are not open to entrepreneurs and businesses.

'you can't put a price [university support] but, unfortunately, they are not interested in product development'

Moreover, current policies from some of the universities mentioned during the interviews highlighted the regulations against university spinout. Companies believe that some universities currently retain intellectual property over any technological development. Therefore if an entrepreneur wants to apply the research carried out, they will have to address the corresponding payback to the university.

4.3.3 Lack of a transparent certification process

Navigating the tricky channels to obtain medical certification was regarded by the businesses interviewed as burdensome and costly. None of the companies younger than five years considered it worth the effort. Most companies mentioned that understanding, meeting and measuring the regulation requirements translate into a cost AR companies cannot afford. For the companies, there is no transparent process to get their products certificated.

Therefore, instead of looking for medical certification, most companies only seek and achieve conformity with the CE marking standards that rule the use of products sold within the European Economic Area. To put this in perspective, this means most of these AR companies follow the same procedure as toy manufacturers. The practical implication of this choice is that doctors cannot prescribe toys and medical insurance do not recognise toys either. Therefore, the patient should have to cover the full cost of the product.

We mentioned in previous sections the lack of an appraisal tool. Existing legal and regulatory systems, initially designed for medicine, have not been adapted to the characteristics of AR. However, most importantly, they do not allow entrepreneurs and start-ups to enter and meet requirements without creating significant expenses.

4.4 Technical

This category discusses technological viability for AR in the healthcare market, not state of the art challenges. It includes barriers for the adoption due to the nature of these technologies.

4.4.1 Skilled health personnel and system constraints

There appears to be a gap in the provision of education and training of healthcare professionals regarding AR as all the companies interviewed currently trading said they had to spend time and money training healthcare professionals and carers on how to use their products. It seemed that this could be addressed by improving the curriculum of healthcare staff.

This acts as one constraint for the adoption of new technologies. Integration problems, such as obsolete data records, or other current software being used as per regulatory requirements in health settings also slows down the development process of RAS. The lack of infrastructure was also a concern; availability of resources such as connectivity to the internet in remote healthcare organisations or directly with the final user, limit the market further.

4.5 Social, Cultural and Behavioural

This category described the opposition from the healthcare professionals to AR, the willingness of the healthcare stakeholders to incorporate AR into their work environment and care of patients.

4.5.1 Consumers' acceptance and ethical concerns

Attitudes and beliefs were seen as a crucial barrier for the market, slowing the introduction of assistive robots in healthy environments. There is currently a distrust in AR companies, enhanced by a lack of understanding of how the final product works. This impacts on stakeholders' understanding of the benefits and opportunities from AR.

The current distrust is also driven by concerns over patient safety, but also strong resistance from staff to change their current practices, considering AR will disorder the delivery of care. Some concerns were also raised about the belief among healthcare professionals that robots will take their jobs.

Furthermore, ethical concerns were mentioned concerning AR and its underpinning technology, to include robots' levels of autonomy, and more general concerns around automation. This fear of automation and AR is leading to an industry that is technology lagging and consequently, the sector and crucially patients are missing out on these advances. The consequences for eHealth start-ups is that they have to commit their resources, to face the market misconceptions of AR.

Education is a critical aspect. Like many other implementation evaluation studies (Orwat et al., 2008), better education has been seen as a facilitator for the eHealth market. Skills-related barriers, such as healthcare professionals' and end-users technological abilities and experience, influence also the implementation and acceptance of AR.

5. Conclusion

Given the potential of assistive robotics (AR) to improve lives, and upon a backdrop of concerns around growing costs in health services, research on the adoption of AR in a health care setting is still minimal. There is a clear need for research into improving the efficiency of the AR market place (EURobotics, 2014). The need to identify persisting innovation barriers in the health industry has also been recognised by the European Innovation Partnership (EIP on AHA, 2011). Thus, while the entry of AR into the mainstream healthcare sector has been constrained by a range of obstacles slowing down the adoption of the technology, to our knowledge no research explores this issue specifically for this high-tech market.

The presented work presented new insight into and addressed the source and nature of the barriers that are inhibiting a more rapid and widespread adoption of advances in AR in the healthcare.

Identifying market barriers has clear policy relevance. Addressing these barriers, policymakers could increase the entrepreneurship and boost the performance of the sector. Our goal is to raise awareness of these barriers, that further research may be conducted and that policymakers may develop a sustainable framework that ensures AR and associated technologies are realised in the healthcare sector.

Some of the main findings are in agreement with previous research that identifies barriers in the adoption of digital technologies in eHealth and the co-evolutionary and path-dependent nature of innovation process more generally (Garud et al., 2013). However, the impact of our identified barriers in the AR market, and, crucially their interaction is more far-reaching than for digital companies in eHealth. Since this represents a new market for the healthcare sector, there are several policy gaps impacting the development process and the procurement and adoption of assistive robots.

There is a need to strengthen bonds to sources of specific and codified knowledge in more traditional industries (Jensen et al., 2007). Fostering a culture of collaboration, involvement, education, and communication have been seen as ways of overcoming healthcare stakeholders' opposition to digital innovations (Broens et al., 2007; Castillo et al., 2010). The concerns about liability, patient privacy, and security, also mentioned in studies regarding digital technologies (Archer et al., 2011; Boonstra and Broekhuis, 2010), could be addressed through the introduction of institutes and legislation, designed solely for AR development. This also involves making a transparent, affordable, and accessible certification process for assistive technologies.

All of these show, that to address the significant barrier of access to the healthcare sector, governments have to take a more proactive role. To overcome market failure or inefficiencies that result from these barriers government intervention is vital (Dean and McMullen, 2011). From the creation of legislation and policies to the establishment of open standards for the development of AR, governments could sustainably facilitate the implementation of assistive robots in different healthcare environments. Governments can also subsidise AR and provide seed funding with positive externalities (Ludwick and Doucette, 2009).

However, this governmental effort should be a joint effort among different countries. Supportive legislation to ease the adoption of innovation among healthcare systems from different countries should be encouraged. Only then can the real potential of AR be realised, providing the companies with new opportunities, expanding the size of their market. As a result, venture capital firms, angel investors, crowdfunding providers and other financial backers will start reducing their risk perception.

Although we presented a comprehensive evaluation of market barriers, further research is needed, in particular in other types of regions, including less developed economies.

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Annexe D – EPIC Start manual

EPIC START

We know that is always daunting starting your own business. The road is long, and there are many things to consider beforehand. However, if you ever wanted to develop eHealth devices such as wearables, sensors, assistive technology and services, or robots to improve the life of others and grow a successful business, our project, called EPIC, could provide some valuable support on your journey.

The Ehealth Productivity and Innovation in Cornwall and the Isles of Scilly (EPIC) project, is a collaborative project part funded by the European Regional Development Fund that aims to improve health and wellbeing of people in Cornwall and grow the economy in this sector.

We have established a network of healthcare professionals, medical centres, local authorities and patients and patient organisations. We have identified the needs and challenges of the Cornish health and wellbeing sector that might be addressed by technology solutions. Now we are looking for entrepreneurs that want to develop a different range of devices and robots to tackle these problems. With the help of our team of leading specialist and collaborative partners, we are here to try to help your businesses succeed.

I. BEFORE YOU START

A good beginning makes a good ending.

Let's meet

We will talk about:

- EPIC's and our partners support for eHealth businesses
- Cornwall's main healthcare challenges
- Our Challenge Fund
- Your business idea
- People and projects that could provide you with valuable help as you start to cultivate a business idea.

It will also be the perfect opportunity for you to ask all the questions and concerns that you might have.

To meet with us and talk through your initial idea you should contact Gabriel Aguiar who is helping to support potential start-ups within our project. You should email gabriel.aguiar@plymouth.ac.uk with the email subject: "EPIC Start"

2. DEVELOP AND PLAN

Time to develop a strategy

After we have had an initial discussion around your business concept you may wish to take your idea forward. That is the time to develop a strategy and approach for your start-up. Having a clear plan will make life easier and give your business a fighting chance of success.

Step 1: Develop a Proposal

You will need to develop a document where you describe

- Your business idea
- Your competitors and what is available on the market
- Your goals
- Potential problems and opportunities

There are lots of useful resources and projects, highlighted in section three, that can provide valuable general business advice for developing your business plan; EPIC can provide expertise in the areas related to eHealth. For example, we can provide some initial assessment of the technical feasibility of your product, and discuss potential strategies for the initial stages of your product development. This could include concept design and/or testing plans as well as putting you in contact with the right members of our healthcare network who can help you assess the viability of your idea.

Step 2: Design with your stakeholders

If these initial activities indicate your concept has potential then you may wish to further develop your product concepts, and for this, you will need the feedback of the right health or social care professionals and patients, families, and carers. Grow sustainably by designing with the user. By an inclusive design strategy, you can improve the chances of success for your product.

You can join our online working groups where you will have the opportunity to discuss your product idea with your stakeholders. We may be able to arrange for you to visit care homes or general practices to improve your concepts. This also gives you the opportunity to develop links with small and medium-sized enterpris es (SMEs), care homes, or others who may than collaborate with you in the devel opment of your new product or service.

3. REGISTER YOUR BUSINESS

Together we can do so much.

Once you have selected the best concept for your product or service it might be a good time to set up a company to help secure finance, this could be useful for example to develop your first prototype or a pilot. Many schemes and their funding opportunities, for example the EPIC Challenge fund, require you to be a registered business in order to qualify for funding.

Get support

You legally have to register your business with the Government (HMRC and Companies House), but first, you must consider several things as the type of business structure. You could do this on your own, but we encourage you to get the expert help, which is available in a number of projects currently providing support for start-ups. Examples of some of the areas to consider and support available is provided below and you may wish to look at all of them.

- Here you will find useful information you need to set up a business: https://www.gov.uk/set-up-business
- If you are looking for one-to-one business start-up support, we collaborate with a number of projects that can offer this to entrepreneurs. Services they offer include:

  1. Business review
  2. Deciding the best business type for you
  3. Understanding your obligations
  4. Help through the HMRC and Companies House registration process.
  5. Developing and delivering your business plan

Unlocking Potential / Breakthrough for Start-ups

https://www.breakthroughcornwall.co.uk/

Cost: Free

Outset Cornwall

http://www.outsetcornwall.co.uk/

Cost: Free

SPARK

https://www.truro-penwith.ac.uk/working-with-business/how-we-support-you/spark-business-start-up

Cost: Free

Plymouth University and Cornwall Council

http://www.formationzone.co.uk/our-network/health-wellbeing/
Cost: £60, one-off fee

Here are other organizations that could offer you one-to-one business assistance and support, but only if you have already register your business with the relevant authorities:

Acceleration Through Innovation

https://www.plymouth.ac.uk/research/acceleration-through-innovation-ati
Cost: Free

The Growth Hub

http://www.ciosgrowthhub.com
Cost: Free

4. BECOME OPERATIONAL

Enjoy the journey

Now could be the time to think about developing your business structure. This will not only improve your company's image, but it will also help you access funding sources like the EPIC challenge fund.

Some practical areas you may wish to consider include:

- Think about your team
  - o The people in your project can be a decisive factor, especially for early-stage companies, in securing support. Your team its scalability, and profitability.
- Name and logo of your product
  - o This is critical for your product success. Look for a distinctive and easy to remember name and logo that will set your product apart from the rest.
- Set up a business bank account
  - o Separate your business finances from your day-to-day living to help you stay on track.
- Start working on your pitch
  - o Keep it simple. Investors mainly look for 3 main points:
    - What you need
    - Where it will go
    - When they'll get it back

5. EPIC CHALLENGE FUND

We are your support

If you have set up a company to develop a product or service in EHealth you will be able to apply for EPIC's Challenge fund which offers two grants:

- Feasibility grant
  - Up to £5K
  - To test the viability of your product
- Product development grant
  - From £5k to £100k
  - To develop your product

There are two ways of applying to the challenge fund:

Option 1. Solo application

If you have the initial capital, you can make the application on your own. Remember that you will receive the money from the grant once you have completed an individual activity and it is possible that only 80% of your costs will be reimbursed. For some of the smaller grants the Challenge Fund may reimburse 100%. This will be decided on a case-by-case basis.

Step 1: *Review the guidelines*
Step 2: *Complete the application*

The times for your application to be assessed will vary between 4 to 8 weeks according to the type of grant that you apply.

Option 2. Collaborate with someone

If your concept is of interest to an SME, medical centre, care home, or third person, you could collaborate with them. With this:

- They could apply to the challenge fund and work with you as a member of their project team.
    - As a freelancer, you could be paid for your working fees, travel, equipment.
    - You will have to agree on cost and intellectual property.
- If you would like to promote your concept to find potential collaborators then tell us. We can share the idea with a range of stakeholders in the health, social care and business communities that may be interested in collaborating.

OTHER SOURCES OF FUNDING

There are many other sources of funding available for start-ups and some of the projects highlighted in Section Three can provide you with information and guidance about those which may be most appropriate for you based on the stage of your development and opportunity.

Do you have any questions?

Please review the Q&A section below. If you can't find your answer, send an email to our research assistant Gabriel Aguiar at gabriel.aguiar@plymouth.ac.uk.

- Is this opportunity for me?
  - If you have in mind a device or a tech-based service that could improve the lives of those in need and while boosting the healthcare sector of Cornwall this is for you. It doesn't matter if you don't have the technical background. We could put you in contact with the right persons so you can start developing your idea.
- What do you mean by eHealth devices?
  - We are looking for startups that are planning to develop a device that has a hardware and a software component. For example, if you might want to create a robotic arm for reaching things, or a wearable to measure a particular condition, you can be supported. In addition, if you are going to set up a tech-based service such as supporting communications with telepresence robots, this opportunity is even for you. If you are not sure, send as an email.
- What does EPIC offer?
  - EPIC can provide access to specialised business support expertise from the digital and eHealth sector to Small/Medium Sized Enterprises based in Cornwall. We can also provide support from experts in research areas critical for development of eHealth products and services. Finally, you could apply to our £600,000 EPIC Challenge Fund.


CHANGE THE LIVES OF YOUR COMMUNITY,
CHANGE THE WORLD THROUGH YOUR
PASSION.
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creative england
SUCCEED WITH PLYMOUTH UNIVERSITY
South West Academic Health Science Network
the patients association

Annexe E – HCO questionnaire example for roadshows

This short questionnaire aims to explore HCO's perception of AR devices in a roadshow context.

During greeting

- What is your profession/background?
- Are you a healthcare professional or a carer?

After the presentation of each of the robots to be display

- What do you think about the robot? Do you like it?

  If the answer is positive

  - What do you like most about him? / What is the feature you liked the most?

  If the answer is negative

  - Why? / What do you not like?
- What other application the robot could have?
- How do you think it could help you?
- How would you mainly use it?
- What would you like to add to the robot? What feature will you include?
- What are the barriers to the adoption of these technologies?
- Would you like to buy/have one?

Follow-up questions. For example:

- Why do you not like [feature] of the robot?
- How will you use [robot] with [patient]?

Annexe F – EPIC Start invitation


pepper
UAS
For more information or to register your interest please follow this link:
MORE INFO
CHANGE THE LIVES OF YOUR COMMUNITY, CHANGE THE WORLD THROUGH YOUR PASSION.
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Annexe G – EPIC Start registration form

EPIC Start

Please, complete the form to receive the EPIC Start booklet.

*Required

My name is *

Your answer

My email is *

Your answer

I'm a *

- ◯ Student
- ◯ Recent Graduate
- ◯ Professional
- ◯ Other:

What is your academic background?

Your answer

If you are a student, what year are you currently in?

- First year
- Second year
- Third year
- Fourth year
- Postgraduate
- Other:

If you are a professional, what is your job occupation?

Your answer

Are you interested in creating your own eHealth startup with the support of the EPIC project? *

- Yes
- No
- Maybe

Are you interested in collaborating with a Cornish business that has an EPIC idea?

- Yes
- No
- Maybe

Submit

Annexe H – Example of AR proposal

Proposal for [illegible]

[illegible]

Business Idea

- [illegible]

Goals

- Enable [illegible]
  - "Simple" bio-inspired design, able to navigate challenging environments
  - Safe for unsupervised end-user usage
  - Affordable (3D printed) < $5,000
  - Modular segments & EE (ease of interchangeability to suite application)
  - Lightweight & discreet
  - [illegible]

Competitors

- **Keeping the product inexpensive and unobtrusive will make it accessible** [illegible] **users who cannot afford a > $5,000** [illegible] **cost > $15,000** (as can be seen on the table below, taken from this research paper).
  - The cheapest [illegible] are not commercially available: the former is a research platform, and the latter is a non-profit.
  - [illegible] market appear to be "rigid" robots which are more susceptible to being damaged due to lack of back-drivability.

[illegible]

Problems/ Opportunities

- Mounting the (modular) robot to [illegible]
- Difficult to achieve [illegible] whilst keeping the segments both long and thin..
- Variable-link curvature (serpentine maneuvering around obstacles)
- Interfacing teleoperation platform (e.g. gaming controllers) and other components (MCU, etc) with ROS for ease of development/ use.
- [illegible] **(Method A)**:
    - Easier to define individual segment curvatures.
    - Increases mass of each segment => CoM moves away from user => less stable compared to **(B)**.
    - Smaller (hence less powerful) [illegible] segment volume and mass.
    - Difficult to implement co-contraction.
- [illegible] **(Method B)**:
    - Multiple cable channels needed (two per DOF), as opposed to 4 in each segment as with **(A)**.
    - Heavier, more powerful motors can be used at the base; [illegible] and overall width of segment can be minimised with longer lengths compared to **(A).**
    - [illegible]
- [illegible]
    - [illegible]
    - [illegible]
- [illegible]
- [illegible]

Annexe I – Questionnaire guide for AR evaluation

This questionnaire aims to show some practical examples of how to integrate UX/UI tools and clinical assessments insight into the evaluations.

Objectives Exploration

- Who are our users?
- What is the product used for?
- When is it used?
- What situations is it used in?
- What will be the most crucial functionality?
- What are the benefits for the user?
- What is the most significant risk to product delivery?
- What can we improve in the product?

Questionnaire Categories and Examples

- Perceived Usefulness Questions
  Example;

Strongly Disagree	Moderately Disagree	Slightly Disagree	Neutral Slightly	Agree	Moderately Agree	Strongly Agree

  - The [function] enables me to manage my [aspect] more quickly.
  - The [function] improves my performance in managing [aspect].
  - I want to use this [feature] frequently.
  - Overall, I find the [feature] useful in [aspect].

- Perceived Ease Of Use Questions
  Example;

Strongly Disagree	Moderately Disagree	Slightly Disagree	Neutral Slightly	Agree	Moderately Agree	Strongly Agree

  - Learning to operate [feature] would be easy for me.
  - I would find it easy to get [feature] to do what I want it to do.
  - I found this [feature] unnecessarily complicated.
  - Overall, I find the [feature] easy to use.

- List of negative and positive aspects
- Overall Satisfaction
- System usability scale
    - I think I want to use this robot/app frequently.
    - I found this tool/feature unnecessarily complicated.
    - I thought this feature was easy to use.
    - I felt very confident in using this website.
- Features Rating
- Net Promoter Score
    - How likely are to your recommend (product) to a friend or colleague?

Further examples and recommendations for Usability and Desirability testing

Usability

- Is the product consistent?
- Are the products' features well organised?
- Is the product understandable?
- Is the product simple?
- Is the product efficient?
- Useful to the user? Does it have a purpose that the user accepts?
- Does the product meet the needs of the user?
- Is the product easy and intuitive to use?

Desirability

- Will the product be self-fulfilment for the user?
    - make the user feel good
    - look good
    - empower the user
    - not interfere with the user style
- Will the product provide satisfaction to the user?
    - the device is easy to control
    - makes things easier for the user
    - understand the user needs
    - the device fits the general life of the user
    - do I want it
    - will it annoy me
- Do you like the design of the product?
- Give a list of adjectives that you consider relevant in the Desirability category and ask them to choose some.
    - For instance; mundane amusing appealing boring eye-catchy exciting fresh friendly encouraging meaningful

- You can also ask people to complete the sentence;
  - This app makes me feel[….]
  - If I used this all day, I would [….]
- Use product reaction dyads
  - Rate on a 5-point scale;
    - Attractive _ _ _ _ _ _ Unattractive
    - Calm _ _ _ _ _ _ Busy
    - Clean _ _ _ _ _ _ Clutter

Long-term interventions

- Collect user activity
  - DAU/WAU/MAU; Daily, Weekly, and Monthly Active User
  - Activity history
- Task retention
- Device Performance
  - Battery life
  - Wi-Fi coverage
  - The time it required assistance/device support
- Ask participants to keep diaries

UX/UI Lab evaluations

Task success

- Successful completion of tasks
- Time spent on a task
- Critical errors
- Non-critical errors

Participant attention

- Did the participant have difficulty focusing attention?
- What areas attract the most attention?
- Key elements they look at.
- How do participants distribute their attention over a stimulus?

  Tool:

  - Eye-tracking system; Label mapping or time focus on object/KPI

Self-completion of the task

- No Assistance
  - Means that the participants can complete the task by their own means.
- Occasional Assistance
  - Means that most of the time participants can complete the task by their own means, but that on occasion (perhaps once or twice per experiment) they require minor assistance. Verbal assistance.
- Considerable Assistance

- Means that regularly the participant needs help to complete the tasks. Continues verbal support.
- Mainly Assistance
  - A further extension of ‘considerable.’ The participant now needs help but also needs assistance. Verbal and physical intervention.
- Total Assistance
  - Means that the patient is entirely unable to experiment.

Tool

- Time researcher talks during the experiment.
  - Experiment audio analysis
  - The researcher starts stopwatch every time he will intervene
  - An external observer takes the time
- The number of times researcher physically interact with the device.
  - Experiment video analysis
  - Researcher keeps count
  - External observer keeps count

Emotion and behavioural patterns

- How do participants react over a stimulus?
  - Happiness, Sadness, Anger, Surprise, Hostility, Friendliness, Surprise, Sadness, Fear
- Metrics around
  - Confusion, Stupor, Coma
    - Asses level of consciousness. It may be mild, moderate or severe with multiple possible aetiologies.
- Valence and Arousal scale
  - Valence
    - 1 = very unpleasant,
    - 2 = unpleasant,
    - 3 = neutral,
    - 4 = pleasant,
    - 5 = very pleasant
  - Arousal
    - 1 = very inactive,
    - 2 = inactive,
    - 3 = moderately active,
    - 4 = active,
    - 5 = very active
- Activity impact on participants.
  - Affect Grid
  - PANAS
  - Geneva Emotional Wheel

Annexe J – Evaluation criteria for AR proposals

To evaluate AR proposals for an entrepreneurship program, this thesis recommends assessing the proposals under three categories: regional needs, economic and technical viability, and AR start-up success. The following questions will assist Ecosystem Developers in the decision-making process. The aim is not to score or predict overall venture success, but rather assess whether the ED has the resources to support the AR proposal being evaluated and the potential benefits to the region. Since this will vary according to the ED and its region, these criteria should be used only as a guide.

Regional Needs

First, we evaluate the proposal against the region's healthcare challenges that should have been explored first by EDs as described in Chapter 6. In addition, Chapter 7 also presents ideal market segments for the technology to guide EDs in this assessment. If there is no documented need for the devices, the proposal should not be rejected, but instead, the other two criteria should be considered carefully.

- Does the solution address a healthcare challenge for a specific patient group?
- Does the solution address a healthcare challenge of health professionals or informal carers?
- Has been the challenge documented as a need for the people in the region?

Economic viability

The economic evaluation should focus on the seed funding available for the start-up to produce the project's proof of concept. Other factors, such as final product cost, business marketing and selling strategies, could also be considered according to the resources of the ED. They were not analysed here since they are out of the scope of the presented AR Technology Strategy (*Chapter 6*).

- How much funding is needed to build the prototype including ensuring system operability and integration?
- How much funding is needed to buy the essential equipment to establish the business?
- What funding opportunities are available and what are their requirements?
- Could the proposed AR technology be in the future developed and priced at an affordable cost for its final user?

Technical viability

The technical evaluation should focus on key research challenges, taking special consideration to the interaction with the user.

- What new components should be built (hardware and software)?
- If there is an ML element, do we have access to the training dataset/data?
- How scalable is the business idea?
- Is it viable to downsize the product offer to reduce technical complexity?
- What are the key research areas that the project is addressing?
- Will the technology interact physically with the user?

- What are the risks involved for the user and the technology in its final environment?
- What is the main technological challenge in the interaction with the user?
- How we could evaluate the benefits of the technology?

AR start-up success

AR start-up success is measured upon the start-up composition (section 6.2.3.4) and if the region has an HCO capable of supporting the AR development.

- Does the team have the right balance between engineering and business development?
- Does the team have enough prototyping experience (hardware and software)?
- Does the team have the skills to put together a business plan and a project pitch?
- What HCOs does the region has to support the development of the venture?
- Will the team need support preparing for the initial meetings with their respective co-creation partners?

Annexe K - Results of Innovate UK 2016 RAS competition

Innovate UK

Results of Competition: Robotics & Autonomous Systems Application over £100k and Over 12 months

Competition Code: 1607_MM_RAS_LO

Total available funding is £4m across 2 streams

Note: These proposals have succeeded in the assessment stage of this competition. All are subject to grant offer and conditions being met.

Participant organisation names	Project title	Proposed project costs	Proposed project grant
HAL Robotics Ltd Innovative Technology and Science Limited ABB Limited Skanska Technology Ltd	CAMERA: Construction and Manufacturing Enabled by a mobile Robotic Arm	£499,922	£322,716

Project description - provided by applicants
Construction accounts for 9% of UK GDP, employing 3M people. Whilst the size of the construction industry suggests that there should be many opportunities for the use of robotics, uptake has been slow. Projects are often bespoke, with complex supply chains. Demand also fluctuates, leading to a risk-averse approach to investment. Previous work has shown that individual construction tasks can be efficiently and effectively automated. However, to achieve the overall efficiency improvements needed to justify investment it is essential that robotics and autonomous system (RAS) solutions can move between different activities (either on-site or in a temporary construction component assembly factory) and to be easily reconfigured by non-expert staff. Mobility and positioning is a key component of this but existing mobile solutions are not suitable for use in harsh, dynamic environments that typify construction. The project will therefore build on recent innovation in the development of construction RAS. It will develop, demonstrate and assess a proof of concept version of a robust mobile 'platform' and supporting visioning and positioning capabilities that can support, place and control a robotic arm in a 'flying factory' or small product manufacturing factory.

Note: you can see all Innovate UK-funded projects here
https://www.gov.uk/government/publications/innovate-uk-funded-projects Use the Competition Code given above to search for this competition's results

Innovate UK

Results of Competition: Robotics & Autonomous Systems Application over £100k and Over 12 months

Competition Code: 1607_MM_RAS_LO

Total available funding is £4m across 2 streams

Note: These proposals have succeeded in the assessment stage of this competition. All are subject to grant offer and conditions being met.

Participant organisation names	Project title	Proposed project costs	Proposed project grant
Dogtooth Technologies Limited NIAB Hugh Lowe Farms Limited	VESCA	£467,561	£353,251

Project description - provided by applicants

Strawberry harvesting is a labour intensive task that depends critically on the availability of a large amount of low-cost labour. Growers are increasingly vulnerable to labour market price fluctuations and burdened by high employment overheads. Building on Dogtooth's proof of concept strawberry picking robot (developed during Innovate UK project Ananassa), project Vesca will deliver commercially viable picking performance using cutting edge machine learning and computer vision techniques to facilitate more efficient localization of target fruit (by more nearly optimal control of robot motion) and more accurate determination of suitability for picking. The project will also provide ancillary benefits such as yield mapping and prediction that are of significant importance to growers.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
RPPtv Ltd Queen Mary University of London Mixed Immersion Ltd	Autonomous Systems for Sound Integration and GenerationN (ASSIGN)	£386,823	£305,368

Project description - provided by applicants

In immersive media and game sound design, the biggest challenge is the effort required to source the sounds and integrate them with the timeline and visual content. We propose an intelligent decision-making system in a system that generates sounds (with their immersive context) from other sensor data. The Autonomous Systems for Sound Integration and GenerationN (ASSIGN) project exploits innovative vision-based object recognition technologies to control sound synthesis techniques, so that captured video information can drive sound generation, placement and perspective. This parallels visual effects and computer games, where rendering is driven by high level information, e.g., if a man drops a glass, we see it falling in the virtual world of the game, film or augmented reality. The animation is a property of the object, and sound effects should follow this same paradigm. The business potential is compelling, since ASSIGN could revolutionise the sound design process. Outputs will include a prototype for autonomous sound effect generation, with market analysis, business models and road map to launch a commercial service.

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Innovate UK

Results of Competition: **Robotics & Autonomous Systems Application over £100k and Over 12 months**

Competition Code: **1607_MM_RAS_LO**

Total available funding is £4m across 2 streams

Note: These proposals have succeeded in the assessment stage of this competition. All are subject to grant offer and conditions being met.

Participant organisation names	Project title	Proposed project costs	Proposed project grant
Computerised Information Technology Ltd Innovative Technology and Science Limited London South Bank University TWI Limited	Robotic Inspection of Mooring Chains in Air and Water (RIMCAW)	£499,312	£394,518

Project description - provided by applicants
Failure of mooring chains that secure floating structures in off-shore production of oil and gas results in oil leaks due to the rupture of flexible pipes that bring product to the surface. The clean-up costs of environmental pollution run into hundreds of millions of pounds. It is therefore important to inspect the mooring chain links to assess the extent of corrosion, fatigue cracking and developing weld faults before they result in failure of a chain. It is very expensive to remove a chain weighing many tons and bring it to shore to inspect it. Savings can be made by perfoming non-destructive testing (NDT) of a chain in-situ while it is in operation. The heavy chains generate large dynamic forces so that inspection using divers is extremely hazardous. The project aims to develop a small, compact mobile robot that can climb on mooring chains both underwater and in air to scan chain links with advanced ultrasound sensors. The robotic NDT system will provide a tool to assess the condition of mooring chains to enable asset managers to make decisions on repair and remaining lifetime of a chain. It will reduce inspection costs by speeding up coverage of a mooring chain and remove the need for diver inspection which costs £40,000 per floating structure and puts their lives at risk.

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Note: These proposals have succeeded in the assessment stage of this competition. All are subject to grant offer and conditions being met.

Participant organisation names	Project title	Proposed project costs	Proposed project grant
N.D.T. Consultants Ltd Innovative Technology and Science Limited London South Bank University	Autonomous phased array ultrasound robotic NDT of long weld lines (AWI)	£465,324	£360,621

Project description - provided by applicants
Failure of ship-hull welds can result in loss of vessels, loss of life and pollution of the environment. This is prevented by inspecting all welds with ultrasound (as required by Classification Society rules) which is labour-intensive, expensive and hazardous to operators. The aim of this project is to develop a new, automated robotic inspection system that will climb ship surfaces, autonomously tracking the weld lines, ultrasonically scanning the weld. AWI will dramatically reduce inspection and maintenance times by 32%, reduce shipbuilding and ship operating costs by 4%, and upskill the UK shipbuilding workforce, bringing a competitive edge to the UK shipbuilding and non-destructive testing / inspection industry. AWI benefits include: fast reproducible and accurate weld testing, reduced labour costs, safer working and lower insurance costs, higher overall equipment effectiveness due to high availability™ (uptime), performance and quality. The project is led by NDT Consultants Ltd., a UK SME inspection services provider who will develop new robotic inspection services for the UK and global shipping industries. The supply-chain consortium also includes InnotecUK Ltd., an SME robotics manufacturer who will commercialise the AWI robot.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
All Street Research Limited University of Cambridge	Virtual Investment Reseacher	£411,073	£312,954

Project description - provided by applicants

All Street is recognised by the UK Cabinet Office as a market maker in alternative finance. The company provides investment research on SMEs. Both individual and institutional investors are demanding more investment research on SMEs, but the level of coverage is actually falling. There are over 5 million SMEs in the UK with an estimated funding gap of £30bn and only a technology solution can scale investment research coverage to a meaningful level. In partnership with the University of Cambridge, All Street has developed the specification for a virtual investment research system using machine learning and artificial intelligence. This technology will enable All Street to significantly expand its SME research coverage, providing investors with the information they need to invest in this key economic segment. The project has significant economic and social impact, in helping to bridge the SME funding gap and enhancing financial literacy.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Olympus Automation Ltd University of Lincoln	Automated Robotic Food Manufacturing System	£488,580	£348,523

Project description - provided by applicants
Traditional soup, sauces and other liquid based product manufacturing utilises large fixed cooking kettles (500 to 3000Kg) requiring pumped and manual handling transfer systems for moving ingredients and finished product from process to process. Consequently, this leads to prolonged manufacturing times, variable product quality, considerable waste and high energy usage. Olympus Automation Ltd (OAL) intends to address these issues through developing a fully integrated automated robotic food manufacturing system. With the help of an Innovate UK grant, OAL and the University of Lincoln (UoL) will design and develop the technically difficult and innovative robotics control and materials handling systems. It will incorporate the development of a semi-automonous system that combines state of the art cooking and materials handling technologies with automated robotic ingredient loading, utilising vessels up to 1000Kgs. The integrated system will produce higher quality food with unprecedented flexibility, more consistently and faster with greatly reduced ingredient wastage and energy costs, whilst taking up to 50% less factory space. The system will be located and tested in a dedicated food processing hall at UoL's National Centre for Food Manufacturing at Holbeach.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Shadow Robot Company Limited Cambrian Intelligence Ltd Oliver Crispin Robotics Ltd University College London	SAT - Semi Autonomous Teleoperation	£506,224	£399,225

Project description - provided by applicants
We aim to create a novel semi-autonomous teleoperation experience using modern virtual reality tools. We will build on Shadow Robot's autonomous dexterous grasping capabilities, Cambrian's teleoperation control platform and OC Robotics flexible snake arm robots, to take advantage of significant RAS, teleoperation research and equipment at UCL to build a new capability. Our model of teleoperation control will use augmented reality and gesture recognition to drive robots, with autonomous grasping technologies used to hold objects and automatic path planning to manage motion in complex workspaces.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Pabugi Limited Cranfield University Adroit Economics Ltd	Pothole Identification and Management Autonomous System	£499,584	£394,358

Project description - provided by applicants
The Pothole Identification and Management Autonomous System project is a feasibility study into systems for improving the way local authorities identify and manage potholes. Its aim is to improve the current system using autonomous systems and artificial intelligence and enable local authority highways departments to improve the quality of roads and reduce costs.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
BeTomorrow UK Limited Foster + Partners Ltd	Simultaneous Localisation and Aerial Mapping in the Built Environment (SLAMBE)	£458,876	£292,684

Project description - provided by applicants
Defects in construction work cost billions globally and >£9bn / year in Great Britain alone. Spotting defects quickly and reliably is key to avoiding or reducing these costs. Current surveying/monitoring techniques are labour-intensive, slow and prone to repeating errors. No solution currently exists to autonomously survey the inside of a construction project, where most problems are hidden (even if drones can do so externally). In this project we propose developing an autonomous drone-based solution that can quickly, cost-effectively and reliably verify accuracy of a recently built internal environment with respect to its proposed design, in order to identify construction defects. Such a service will offer big benefits to the construction industry and building contractors in particular, because, for a relatively small investment, it will help lower overall project costs and risk, while also helping increase quality, client confidence and ultimately sales.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Oliver Crispin Robotics Ltd Airbus Defence and Space Limited	ASRND: Autonomous Scout Rover for Nuclear Decommissioning	£312,013	£195,978

Project description - provided by applicants
This project will develop an autonomous scout rover system, for scanning and mapping of a nuclear environment as a part of decommissioning effort. The scout rover is an intelligent autonomous machine capable of conducting operations without human interaction, with the long term goal of making decommissioning of nuclear sites safer and quicker. The innovative robotic system will map otherwise inaccessible, cluttered nuclear environments providing vital information for subsequent safety-critical operations. It's autonomy will allow it to perform frequent, repeat inspections of a hazardous environment inaccessible to a human operator allowing hazardous areas to be routinely monitored - reducing the risk caused by nuclear plants awaiting decommissioning. This project combines OC Robotics' demonstrated experience in accessing and operating in confined and hazardous environments with Airbus Defence and Space's cutting-edge expertise in autonomous navigation, originally developed for the European Space Agency's ExoMars 2020 Rover Mission.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Shadow Robot Company Limited University of Glasgow	iSee - Intelligent Vision for Grasping	£505,025	£397,923

Project description - provided by applicants
Smart vision for grasping robots (like the Shadow Smart Grasping System) will unlock significant new markets in research and industry. The iSee project is a feasibility investigation to find out if linking state of the art robotics hardware with cutting-edge research in vision and modern deep learning'•methods can transform the way robots can see - and therefore interact with - the world.

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Innovate UK

Results of Competition: **Robotics & Autonomous Systems Application under £100k and under 12 months**

Competition Code: **1607_MM_RAS_SC**

Total available funding is £4m across 2 streams

Note: These proposals have succeeded in the assessment stage of this competition. All are subject to grant offer and conditions being met.

Participant organisation names	Project title	Proposed project costs	Proposed project grant
Oxford Lasers Limited	Robotic Autonomous Laser Processing for agile High volume production (RALPH)	£98,776	£69,143

Project description - provided by applicants

RALPH's objective is to develop an autonomous laser micromachining system with fully auto-mated part handling, but agile and easily reconfigurable, suitable for mass customisation pro-duction of different device formfactors. Despite laser manufacturing being a rapid process (typical laser drill/cut time in sec), long production cycle times of several min/part due to manual part handling, hinder further uptake of advanced photonics-based production technologies in high value microelectronics, powertrain or medical device manufacturing, resulting in uncom-petitively high laser process costs and loss of global market share for the UK. The challenge is to satisfy the stringent part positioning accuracy requirements for laser processing (5 m) using conventional, affordable, but less accurate robotic pick and place technology. We will develop a technical solution integrating the laser, optics, 6-axis robot and machine vision for parts hand-ling of various sample formfactors (wafer, cylinder, disc) based on intelligent part registration and adaptation of laser beam positioning through high precision optical scan axes.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Myrtle Software Limited	Efficient Deep Learning Hardware for Robotics and Autonomous Systems	£98,799	£69,159
Project description - provided by applicants			
There is a wide consensus that deep learning algorithms are key to the future of smart autonomous machines and robots. This project aims to automate the production of low power, lightweight hardware implementing these algorithms so that RAS applications become a reality.			

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
i3d Robotics Limited	IVIRA- Intelligent VIsion for Robot Awareness using multi-sensor data fusion	£90,481	£63,337

Project description - provided by applicants

IVIRA will address the needs of RAS by providing further information to high resolution 3D models of scenes and objects. Data fusion and interface will be used to provide perception for the RAS, enabling the system to make informed decisions on the appropriate task to perform as well as responding to unexpected results. This technology will initially be proved through this project for high value agriculture and will be expended to other RAS application areas beyond the project. IVIRA will provide further functionality to the high resolution 3D vision systems produced by i3D robotics to increase our competitiveness in various markets. Achieving our aims will significantly move the RAS technology from automated systems to become autonomous.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
BECOCO Ltd	BECOCO. Be confident.	£98,003	£68,602

Project description - provided by applicants

Every woman knows this feeling. When you wear something but don't feel quite right in it. You pull, you tuck, you twitch - nothing seems to help. This feeling of discomfort and haunting self-awareness will stay with you the entirety of the day. It will follow you into meeting rooms, school yards and every public space you go. And it will impede you from doing what you have to do that day. Imagine a service that analyses your individual body shape and personal colour complexion and sifts through millions of items of clothing in seconds, to find the ones that will suit and flatter you best. Not some celebrity. You - just the way you are. BECOCO is a virtual styling platform, which does exactly that. For free or for £49, if you would like your customised styling report with it. In addition to helping consumers becoming more confident, BECOCO is determined to support retailers in reducing their return rates for items ordered and to decrease the impact that the handling of those returns have on the environment.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Swarm Systems Ltd Loughborough University	Persistence through Reliable Perching (PEP)	£85,819	£66,073

Project description - provided by applicants

Swarm Systems is developing a product for the growing market need of Flying Binoculars. Multi-rotor, battery SUAS have endurance of around 20 mins. A common request is for SUAS persistence of hours or more. Customers are specifically asking for a perch and stare capability to achieve persistence. However, perching using existing technology is very hit and miss. This PEP proposal has a goal of achieving greater than 99% reliability in perching on unprepared, outdoor locations in challenging weather conditions and taking off again. The SUAS category is sub-200g. The PEP research approach includes: adding new passive and active sensors, creating soft sensors from combinations of existing sensors, researching a novel automatic abort using 'disturbance from internal model' techniques (Loughborough University) and innovating undercarriage design including multi-surface gripping. PEP project management will be led by an analysis of perching ground types and weather conditions. The final 1/3 of the project will be focused on improving where testing proves that reliability is poor. A commercial goal is to add a key new capability to Swarm Systems product, enabling it to win export orders.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Swarm Systems Ltd	Robust and Reduced SWaP Obstacle Sensing	£69,935	£48,955
Project description - provided by applicants			
Small Unmanned Air Systems (SUAS), or "drones", have captured the public imagination. In the military domain SUAS can offer Flying Binoculars™ capability, allowing a user to monitor an area of interest from the air, out of sight and out of danger. In the non-military domain, search & rescue, inspection and remote delivery have all been suggested as the next 'killer' application. To extend the range of SUAS uses, the systems must be capable of operating in the real world without human intervention. The technology required to operate SUAS autonomously in wide open spaces is relatively mature. Operation in complex environments, such as urban, is still challenging. The SUAS has to fly in and around trees, buildings, walls and, in some cases, people. Several critical capabilities are needed to enable this type of operation. Robust sensing of obstacles is one of these. A miniature obstacle avoidance module is proposed incorporating two cameras, a processor and an active rangefinder. The objective is a low cost module capable of sensing obstacle presence and relative position. The module, when incorporated with an SUAS, will enable new applications. It will remove limitations to SUAS use in complex environments and will allow industry growth to proliferate.			

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Rovco Limited	Real Time 3D Modelling for Subsea Asset Management - Feasibility Study	£76,345	£53,441

Project description - provided by applicants

Rovco are developing a system that will improve the way in which subsea assets are managed through the development of a 3D modelling process which will allow inspection personnel to be based onshore. The aim of the system is to make asset management far more cost efficient, while also improving safety for staff and the environment. The final product will allow chartered offshore vessels on inspection campaigns to be smaller, while reducing costs and the number of personnel required at sea. Using visual 3D models of subsea assets will allow onshore assessment by all interested parties meaning decision making can be referred as needed, and onshore communication between all of the parties will be made more effective. This will allow faults to be spotted more efficiently and repairs to be made to damaged assets well before the point of failure, decreasing the chance of environmental pollution by mitigating the chance of corrosion going undetected. Initially a feasibility study will be conducted to ensure that industry is ready for this solution, and that it is viable. Alongside this an example of the final output will be produced to help recruit collaborators and assist in defining the project direction during market analysis.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Motion Robotics Limited	Ultra Safe Ambulation Control System of Systems for a Bipedal Host Robot	£67,517	£47,262

Project description - provided by applicants

SARAH is a bidpedal humanoid silent, agile, robotic, semi-autonomous, host vehicle that can carry a high tech payload. The payload can interface to SARAH and provide further ambulation guidance and environmental context or the payload can just rely totally on SARAH to carry around the payload using remote human guidance or GPS way points. SARAH is semi-autonomous and even though blind and relying only on proprioception and inertial sensors, she can stand and walk safely under a large number of circumstances; zero visibility, unstable ground, pushed, shoved, tripped. The idea is that high tech developers of robotic health care, search and rescue, hazard detection or companionship and domestic services can simply use SARAH as their trusted bipedal locomotion subsystem on sensitive terrain, around children, pets, and frail elderly. SARAH's ultra safe and agile quiet ambulation will be feasibility tested and demonstrated in this project. The control system of systems will make use of state of the art innovations in deep learning, morphed modality pattern generators and these will be integrated with an OPEN API so a developer can quickly interface to SARAH and reach the market sooner and safer. SARAH will be developed and manufactured in the UK for export.

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Participant organisation names	Project title	Proposed project costs	Proposed project grant
Oxford Robotics Ltd Performance Projects Ltd	Autonomous Agricultural Robotics Platform	£98,283	£44,227

Project description - provided by applicants

The aim of this project is to develop a robot that is suited to 21st century farming. Our Robot will be autonomous, efficient, affordable, flexible and powerful. With a standard three-point-hitch and Agricultural PTO, our robot will be compatible with traditional farming tools as well as 3rd party apps and implements developed by others. Technology is hard to predict, but with a standardised platform we hope our product will be prepared to perform a broad range of future tasks such as crop analysis, picking, weeding and spraying. Our project will involve the design, calibration and testing of the robot ready for commercialization and 3rd party collaborator involvement.

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FlyLogix Limited	Tern	£97,017	£67,912
Project description - provided by applicants			
FlyLogix is a developer of low cost, innovative RPAS (remotely piloted aircraft systems). FlyLogix is currently working with the CAA (Civil Aviation Authority) to conduct what will be one of the first beyond visual line of sight (BVLoS) flights of an RPAS. This project addresses the limitations of the current technology by developing a low cost control system that will allow the RPAS to be flown over a range of >100 miles. Once FlyLogix has worked with the CAA to build a safety case for this technology this will enable FlyLogix to become the first commercial provider of BVLoS RPAS flights. The first application of this position will be providing inspection for offshore platforms and wind turbines - removing the expense and risk of mobilising people by helicopter. Once proven the technology will have wider applications in the development of RPAS.			

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Muretex Ltd	Enabling Ubiquitous Control of RAS	£97,184	£68,029

Project description - provided by applicants

Funding from Innovate UK has allowed Muretex to continue developing their prototype system for intuitive control of robotics and autonomous systems (RAS). In the near future RAS will become increasingly necessary to many aspects of human life and work- such as manufacture, construction, healthcare, transport and energy. It is essential therefore that an easy to use and safe "langauge" or method of human/machine interaction (which is applicable to and easily portable across the many different sectors) is developed. The Muretex protoype system consists of a high level RAS, being controlled by the operator using gestures. These form a system of abstracted comands delivered to the the RAS via a data glove. Real-time visual feedback and position information from the RAS is continuously delivered to the operator's smart glasses, allowing the operator to see what, where and how the RAS is performing. This represents a prototype for a genuinely teamed integration of a human and robotic autonomous system.

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