Towards designing society 5.0 solutions: The new Quintuple Helix - Design Thinking approach to technology

Technovation

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--Manuscript Draft--

Manuscript Number:	TECHNOVATION-D-20-00871R3
Article Type:	Research Paper
Keywords:	Society 5.0, Industry 4.0, Quintuple Helix Innovation Ecosystem, Design Thinking, Healthcare, Social Entrepreneurship
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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abstract

The integration of Industry 4.0 (I4.0) technologies within society is pivotal for resolving many challenges that the world and its population are facing presently—global pandemics, ageing populations, and climate change. However, academics and practitioners still struggle to fully understand I4.0 outcomes outside of the manufacturing domain, thereby unravelling their potential for society at large. In this scenario, Society 5.0 (S5.0) is arising as a new paradigm that places humans at the centre of innovation. To foster the effective integration of technology into society and to better understand how to design S5.0 configurations and solutions, the authors developed a conceptual model applying the Design Thinking (DT) approach to the Quintuple Helix (QH) innovation framework. The proposed QH–DT model was found to be suitable for allowing the knowledge flow among the actors involved in the design and implementation of the S5.0 solution. The model was then explained through its application in a healthcare project—the SMARTAGE. By adopting an action research methodology, the results explain how it becomes possible to build complex human-centric healthcare solutions.

Keywords: Society 5.0, Industry 4.0, Quintuple Helix Innovation Ecosystem, Design Thinking, Healthcare, Social Entrepreneurship

1. Introduction

The rise of digital technologies and applications, such as cyberphysical systems (CPSs), robotics, augmented reality, artificial intelligence (AI), the Internet of Things (IoT), big data, and the cloud, is bringing dramatic changes to society and industries. Industries are providing with new opportunities to shape and renovate their ways of doing business (Kiel et al., 2017b; Müller et al., 2018b), thereby inducing the advent of the fourth industrial revolution, better known as "Industry 4.0" (I4.0). However, I4.0 technological potential goes beyond its impact on companies and business sectors and benefits the environment and society at large (Bai et al., 2020; Ghobakhloo, 2020; Müller and Voigt, 2018). In the current scenario in which the world is increasingly facing challenges of global scale, such as natural disasters, ageing populations, resource depletion, growing economic disparity, and ultimately the ongoing global pandemic, it is crucial to fully exploit digital technologies to effectively and efficiently resolve these issues to benefit the society at large. Consequently, integrating technology within society will be crucial in the future.

Despite the recent growing interest in the social impact of I4.0 technologies (Beier et al., 2020, Jabbour et al., 2018a; Stock et al., 2018;), the academic literature presents some shortages that could lead practitioners and academics to develop a new paradigm called Society 5.0 (S5.0), in which humans are at the centre of innovation, thus taking advantage of the impact of technology and the results of I4.0. Presented in January 2016 as a growth strategy for Japan, the S5.0 (paradigm) aims at creating a human-centric society in which economic growth and technological development can actually be within everyone's reach. Specifically, it is the society in which I4.0 technologies are actively used in people's everyday lives, industry, healthcare, and other spheres of activity not only to seek progress and technological advancement but also to reach the wellbeing of each person (Fukuyama, 2018). Such interest in a more humanised vision of I4.0 technologies has also recently been confirmed by the European Commission, which openly expresses, in its Horizon Europe research and innovation programme, a need to incorporate more human and societal factors into the idea of a desirable digital future. Notably, while in I4.0 literature the importance of human–machine interactions is mainly restricted to manufacturing processes (Brozzi et al., 2020; Frank et al., 2019), thereby focusing on social issues related to workers (Pinzone et al., 2020), S5.0 considers the role of technology and the results of I4.0 in improving people's quality of life, social responsibility, and sustainability (Onday, 2019).

Indeed, applying new human-centric approaches and methods when developing and introducing new digital technologies is required, along with designing I4.0-enabled works (Kadir et al., 2019). If a beneficial-for-all digital transformation is built, innovative holistic approaches must be implemented. However, despite this assumption, studies addressing the problem of how to create solutions and products that can exploit the I4.0 technological potentials for the benefits of the entire society, thus embracing a Society 5.0 perspective, are lacking.

Therefore, this study aims to bridge this gap by proposing a novel approach to create and design more human–centric solutions, namely Society 5.0 solutions, capable of better integrating I4.0 technologies and human needs. Specifically, we want to understand how S5.0 solutions can be designed and implemented to benefit different publics, such as users, citizens, governments, nations, regions, industries, and organisations.

To study and design S5.0 solutions that integrate I4.0 technologies, we decided to apply a Design Thinking (DT) approach to the Quadruple and Quintuple Helix innovation framework that has been previously applied to theory, policy, and practice in the innovation and knowledge-economy literature. Because this framework assumes that innovation results from the interplay among five subsystems of knowledge, named 'helices' (University, Government, Civil Society, Industry, and Environment), it appears suitable for our purpose. Notably, by developing projects and solutions that integrate these five elements within the DT approach, we can transition towards S5.0 solutions. The proposed QH–DT framework is then explained through the narrative of a case study, the "SMARTAGE" project, which represents an application of the very same framework in the field of healthcare services. Considering that the SMARTAGE's aim is to improve socio-health and social welfare services by integrating physical and virtual spaces and deploying the opportunities created by I4.0 technologies, the case perfectly fits the Society 5.0 domain. Consequently, it allows us to show and explain how involving different actors (QH) during the entire DT process can create interactions and favour knowledge flows that can contribute to the design of S5.0 solutions.

The paper is structured as follows. We first review the literature about I4.0 and its impact on society, thus highlighting the shortages that lead to the definition of the S5.0 paradigm. Second, in the theoretical framework section, we describe the reasoning behind the development of the QH–DT model—a comprehensive framework for designing S5.0 solutions. Third, after describing the action research methodology followed for building the case study, we present the "SMARTAGE project" and its main findings. Finally, theoretical and managerial implications are discussed as well as study limitations and future research directions.

2. Literature Review

2.1. Industry 4.0: Technological dimensions

The term "I4.0" first appeared in a German strategic initiative in 2011 as part of its high-tech programme, the "High-Tech Strategy 2020". Within this document, I4.0 represents the action plan to develop cutting-edge technologies in the German manufacturing sector. Defined by Kagermann et al. (2013, p. 5) as "a new type of industrialisation," I4.0 is considered the fourth industrial revolution. If the first three industrial revolutions were the result of mechanisation, electricity, and IT, the fourth emerged with the introduction of the IoT and IoS into the manufacturing environment. Therefore, the I4.0 paradigm entails synergising interconnected physical and digital technologies able to communicate with one another throughout the entire production system, connecting resources, services, and humans in real time (Stock et al., 2018). By equipping manufacturing with sensors, actuators, and autonomous systems, I4.0 will help factories become more intelligent, flexible, and dynamic (Kamble et al., 2018). Also, operational effectiveness (Müller et al., 2018a), high-quality and customised products and services (Baber et al., 2019), increased sustainability (Müller et al., 2018b; Stock and Seliger, 2016;), open innovation (Obradović et al., 2021) developing entirely new business models (Kiel et al., 2017a; Paiola and Gebauer, 2020), are some benefits that I4.0 can bring to manufacturing companies. Different studies (Frank et al., 2019; Ghobakhloo, 2018) highlighted the design principles and defining characteristics of I4.0, such as supply chain vertical and horizontal integration, interoperability, decentralisation, modularity, customer personalisation, automation, and traceability.

However, although this new paradigm has drawn the interest of both academics and practitioners during the last eight years, consensus on the emerging technologies that fall under the I4.0 domain or its underlying principles is still lacking (Beier et al., 2020). For example, Hermann et al. (2016) identified four components of I4.0: CPSs, IoT, IoS, and the smart factory. More recent studies (Bag et al., 2018; Ghobakhloo, 2018; Tian et al., 2021) further include new technological trends that fall under the I4.0 paradigm, such as cloud computing, blockchain, big data, additive manufacturing, AI, wireless network, augmented and virtual reality, industrial robots, and smart cities. Overall, these advanced digital technological innovations collectively enable the rise of the new digital industrial technology—I4.0 (Liao et al., 2017). However, CPS, IoT, and Cloud computing seem to be the most cited technological pillars of I4.0 and also the ones that we apply in the SMARTAGE project (see Table 1).

Table 1: I4.0 technologies

I4.0 Component	Definition	Source
CPS	CPS is a collection of transformative technologies that integrate the operations of physical assets and computational capabilities, de facto bringing the physical and virtual worlds together. It encompasses different artefacts, which can perform different tasks: measuring and monitoring physical data from the system environment via sensors and actuators; processing, evaluating, and storing the acquired data to interact with the system environment; and providing various human–machine interfaces for different control options.	*Akanmu and Anumba 2015; Hoffman and Rusch, 2017, Stock et al., 2018.*

IoT	The IoT is the addition of new technologies, such as RFID (Radio-Frequency IDentification) to everyday objects, which could communicate and exchange information about their environment, context, and location. Every physical object, thanks to the IoT, may become a "smart" object whose retrieved data can benefit companies in developing new market and consumer insights, thereby improving their strategic planning and implementation. Starting from the general IoT, the terminology became varied, including the Industrial Internet of Things, Internet of Services and, Internet of People. A general IoT system can be represented by a five-layer architecture: a) sensors and actuators, b) a device, which often integrates the former layer, c) a gateway, which is sometimes referred to as a hub or hardware platform, d) a software platform, which is also called integration middleware, and e) an application.	*Ashton, 2009; Ng and Wakenshw, 2017; Sestino et al., 2020; Muller and Voigt, 2018; Conti et al., 2018, Basaure et al. 2020,*
Cloud Computing	Cloud computing is the technology that provides more reliable data management and storage processes, thus allowing full exploitation of the potential of CPS and IoT regarding data volume. Emphatically, although most computer systems lack the necessary storage capacity to manage the great amount of data generated in the newly interconnected world, cloud computing offers flexible provisioning of IT resources to solve this problem Using cloud-based software applications, web-based management dashboards, and cloud-based collaboration software, users and companies can easily receive, analyse, and interpret data from ubiquitous sensors. [B1]	*Stock et al., 2018; Hermann et al., 2016*

Source: Authors elaboration

2.2 The concept of Society 5.0

"*The design principles and technology trends of I4.0, such as horizontal and vertical integration, IIOT, IoD, CPS, interoperability, simulation, and blockchain, indicate that the fourth industrial revolution is all about IT*" (Ghobakhloo, 2018, p. 928). This sentence hides the true nature of the studies that have addressed the I4.0 domain in the last years. By focusing on production systems and their integration with increasingly sophisticated and intelligent devices, technology has always been at the centre of the I4.0 paradigm shift. However, recent studies have acknowledged the major impact of I4.0 not only on companies and business sectors but also on the environment and society at large (Bai et al., 2020; Beier et al., 2020; Jabbour et al., 2018; Müller and Voigt, 2018). For example, Ghobakhloo (2020) provided an interpretative model of how I4.0-related techno-industrial revolutions can contribute to the achievement of economic, social, and environmental sustainability. Waste reduction, increased production and productivity, manufacturing agility and flexibility, circular business model innovation, energy and resource sustainability, and social welfare enhancement are among the most cited benefits that I4.0 can bring to the Triple Bottom Line of sustainability (Khan et al., 2021; Birkel and Müller, 2021). In addition, other studies defined I4.0 as a socio-technical system in which technological, social, and organisational aspects interact (Beier et al., 2020; Davies et al., 2017), thus revealing the importance of human–machine interactions within the new manufacturing processes (Yadal et al., 2020). In these studies, the crucial social aspect of I4.0 is related to human resources and the impact that I4.0 disruptive technologies have on the labour market. While new technology could increase labour shortages, reduce human work, and allow firms and organisations to allocate human resources to higher value-added areas, the digital revolution has defined new disruptive paradigms, requiring dynamic capabilities and the acquisition of knowledge and technology from outside the organisation (Alavi and Leidner, 2001; Carayannis et al., 2018a; Cegarra-Navarro et al., 2016; Vermesan et al., 2011). Therefore, it is argued that the journey towards I4.0 and the increasing implementation of CPSs are evoking changes in human work and work organisations (Kadir et al., 2019). Indeed, I4.0 technologies may induce a progressive replacement of blue-collar workers, which will tremendously impact the societal level (Kiel et al., 2017b; Müller et al., 2018b).

Summarising, the literature on the role of I4.0 technologies in society shows the following limitations:

- The most recent literature (see Khan et al., 2021; Birkel and Müller, 2021; Yadav et al., 2020) about the impact of I4.0 on sustainability issues mostly studied the sustainable supply chain and the role of manufacturing companies in achieving the Triple Bottom Line of economic, social and environmental dimensions of sustainable development. They mainly stressed the enablers (Yadav et al., 2020) and potentials (Sharma et al., 2020) of firms' adoption of I4.0 for creating sustainable industrial value, circular economy solutions, sustainable business models, and smart cities. Consequently, although they acknowledge a broader impact (social, economic and environmental) of I4.0, they still focus on the role of companies and manufacturing firms in pursuing it. Additionally, the majority of sustainability research is conceptual in nature (Khan et al., 2021).
- Many of the studies consider social sustainability in manufacturing and production processes, thus focusing more on workplace safety and human–centric factories (Pinzone et al., 2020) rather than embracing a much broader meaning of human–centric technology issues. For instance, acknowledging the socio-technical nature of I4.0, Neumann et al. (2021) highlighted the strong focus on technology in current I4.0, which lacks attention to human factors and human–system interaction. However, when they described the importance of considering people's needs in the early stage of I4.0 technology development and systems' design, they mostly referred to workers.

- Sustainability and social aspects are not considered an integral part of the I4.0 concept, rather they are an "add-on-features" (Beier et al., 2020), a desirable outcome that is not incorporated from the beginning into the technological development process.
- Industry manufacturing digitisation can either positively or negatively impact people's quality of life (Ghobakhloo, 2020). Consequently, more holistic studies that focus on synergies between different actors, such as governments, academics, industrialists, and civil society, that can unlock the I4.0 potentials, required further consideration (Khan et al., 2021). According to Benitez et al. (2020), managing the complexity of I4.0 solutions requires an approach oriented towards the co-creation of value among a plurality of actors which constitute an innovation ecosystem. Therefore, innovation ecosystems emerged as a more suitable configuration for technology development. In this scenario, the Quintuple Helix Model (industry, government, university, environment and society) should be applied considering the necessary interplay of a well-planned I4.0 implementation strategy with innovation policies in a diffused social and institutional environment (Khan et al., 2021).

Starting from these limitations, the new model of S5.0 has emerged. Presented in the Fifth Science and Technology Basic Plan and further adopted by the Japanese Cabinet in January 2016 (Ferreira and Serpa, 2018; Salgues, 2018), S5.0 represents the growth strategy for Japan and its attempt to provide a common societal infrastructure for prosperity based on an advanced service platform. S5.0 is the response to overcome societal challenges Japan is facing nowadays, such as the rapid and increasing ageing of society, the consequent shrinking of the labour force, the depopulation of rural areas and their associated deterioration of the city's infrastructures, and depletion of natural resources (Fukuyama, 2018). However, this innovative perspective is not restricted to Japan because it shares common ground with those of the UNDP SDGs (United Nations Development Programme Sustainable Development Goals, www.undp.org). Certainly, S5.0 applies I4.0 technologies and innovation to solve human problems that affect all countries, thus enabling them to meet sustainable development goals.

These societal challenges have induced the development of the S5.0 paradigm to create a human–centric society in which economic growth and technological development can actually be within everyone's reach. Certainly, while I4.0 is mainly restricted to the manufacturing sector (Brozzi et al., 2020; Frank et al., 2019) thus focusing on production effectiveness, S5.0 considers the role of technology and the results of I4.0 in improving people's quality of life, social responsibility, and sustainability (Onday, 2019). By benefiting society at large (Ferreira and Serpa 2018), S5.0 solves social problems by integrating physical and virtual spaces. Specifically, it is the society in which the aforementioned I4.0 technologies (IoT, CPS, Cloud Computing, AI, augmented reality) are actively used in people's everyday lives, industry, healthcare, and other spheres of activity to seek progress and technological advancement, and concurrently reach the wellbeing of each person (Fukuyama, 2018). These new technologies enable the generation of accurate data, such as personal real-time physiological information, healthcare site information, treatment/infection and environmental information, which are analysable in real time by participants of the system and/or automatically solved by automatised or robotised equipment (Japan Business Federation, 2019; Potočan et al., 2020; Savaget et al., 2019; Shiroishi et al., 2018). Consequently, social care issues (promotion of social care, prevention programmes, and healthcare assistance) can be solved mostly by integrating I4.0 technology into a S5.0 paradigm.

The application of S5.0 logic is based on placing the human at the centre of innovation, thus allowing the creation of adoptable products and services for diverse individual and latent needs. Human centeredness in S5.0 translates into resolving the threat that humans can be crushed by machines and technology, since they control the progress of science and design these complex technological systems that can benefit all. However, to achieve and ensure that S5.0 implementation is not just a political-ideological concept, it is necessary to integrate several dimensions, such as innovation policy (from the government side), entrepreneurial spirit (from society's side), and entrepreneurial skills (from civil society and institutions) (Yousefikhah, 2017). Also, solving societal problems by applying new technologies can benefit from a regional orientation that can enable more applicable solutions and also increase the interests of individuals and organisations (Potočan et al., 2020).

Thus, what emerged from the literature is that integrating technology within society will be crucial in the next future. The need to broaden the understanding of I4.0 outcomes and their multiple and future potential in society (Ozdemir and Hekim, 2018; Pashek et al., 2019; Pereira et al., 2020) can be solved by integrating them into a S5.0 paradigm. However, despite this assumption, studies addressing the problem of how to effectively create solutions and products that can use the I4.0 potential for the benefits of the entire society, namely Society 5.0 solutions, are lacking. The literature about S 5.0 is still in its early stage, with most of the works addressing definitional aspects of the concept and scarce empirical studies. Also, as Beier et al. (2020) specified, the analysed literature misses complex scenarios and an in-depth analysis of what these solutions might imply for the environment when the humans remain at the centre of the innovation process.

Starting from that, the aim of this paper is to describe how to design and develop S5.0 solutions - meaning solutions that solve social problems and benefit the entire society by applying I4.0 technologies - thus highlighting the processes and the interactions behind the implementation of these complex solutions.

3. Theoretical Framework

Based on the aforementioned literature studies, to foster effective integration of technology into society from such an S5.0 perspective, we decided to adopt the theoretical framework of the QH innovation ecosystem, since we believe it represents a suitable model for our purposes and has been previously applied to theory, policy, and practice in the innovation and knowledge-economy literature. Additionally, QH has been addressed as a possible suitable model for developing innovative policies able to achieve sustainable value – economic, social, environmental, technological, organizational (Khan et al., 2021). As a matter of fact, the literature (Benitez et al., 2020) acknowledged the important role of innovation ecosystems - such as the QH- in facing the challenge of creating complex technological solutions; they indeed allow value co-creation processes among the actors involved. In doing so, new wider possibilities that go beyond technology as a product can be developed.

Moreover, by emphasising the importance of user needs and their involvement in the decision-making processes, DT has also been considered apt to guide the development of human–centred solutions, including the healthcare and digital solutions (Przybilla et al., 2020) required nowadays. Finally, we proposed combining QH with DT (QH–DT) as a new theoretical lens for the S5.0 context.

3.1 The role of the QH innovation ecosystem

The QH model (Carayannis et al., 2012; Carayannis and Campbell, 2010) was theorised as a further development of the Quadruple (Carayannis and Campbell, 2009) and Triple Helix (Etzkowitz and Leydesdorff, 2000) because it was considered necessary to add further elements to fully comprehend the complex processes of innovation in the unfolding twenty-first century. Therefore, the three helices (Academia/University, Industry, and State/Government), which were originally intertwined to develop innovation systems, were updated with two other dimensions.

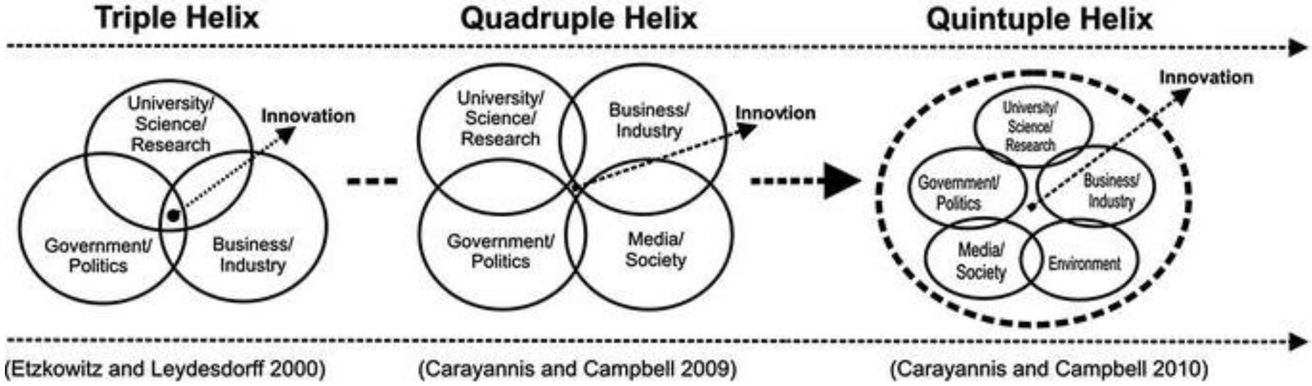
The fourth helix, “Civil Society,” was added to describe a new and more extensive way of creating and sharing knowledge and innovation. Because civil society comprises communities of stakeholders and end users, it has become a key actor in innovation processes, strongly influencing knowledge generation and technological development via its demand and user function (Carayannis and Grigoroudis, 2016).

Later, considering the need for sustainability lying in human intervention, a fifth helix, “Environment,” was introduced (Galvao et al., 2019). Consequently, the new adjusted model allows for a more effective depiction of the strong connection and interdependence characterising an innovative ecosystem by exploiting their juxtapositions.

In an S5.0 context in which it has become increasingly important to develop sustainable and human-centred (rather than technocentric) services and technologies, the QH model seems the perfect fit. Further, if the goal is to develop salient innovation for the user, the user (civil society, humans, people, and citizens) should be at the heart of the innovation process. Here, users and citizens own and drive the innovation processes, and the degree of user involvement could be defined as inclusive of "design by users" (Arnkil *et al.,* 2010). Following this perspective, by involving users and citizens early in the innovation process, innovative products, services, and solutions are developed, thereby making government, industry, and university policies and practices more effective. This can occur thanks to the bottom-up and mid-level activities of civil-society grass-roots initiatives, which make top-down university, industry, and government (UIG) policies and practices more humanised and end-user-focused. Also, for a long-term sustainable development vision for society at large, attention to specific environmental issues ensures that the aforementioned top-down, bottom-up, and mid-level policies, practices, and initiatives become readily smart, sustainable, and inclusive (Park, 2014).

In this latest version of the model, University, Industry, Government, Society, and the Environment become the subsystems of a greater and more inclusive innovation ecosystem capable of guaranteeing socially and environmentally responsible growth (Ketikidis *et al.*, 2016). Hence, the QH represents a suitable model in theory and practice for recognising the link between knowledge and innovation (Carayannis et al., 2012; Dewangan and Godse, 2014; Dziallas and Blind, 2019). In its framework, innovation is created through knowledge sharing and circulation, and this reiterated interaction generates and fuels innovation itself (Figure 1).

Figure 1: The evolution of Triple, Quadruple, and Quintuple Helix innovation ecosystem models



3.2. The DT process model

DT is an approach aimed at addressing complex innovation processes that were developed at Stanford University and then further implemented by both practitioners (Brown, 2008) and scholars (Brenner and Uebermickel, 2016). Given its capability to respond to the complexity of the current business scenario (Kolko, 2015; Waidelich, et al., 2018), interest in this method is growing in multiple fields. The founding principle of DT entails examining and solving a particular problem using an interdisciplinary team whose members are characterised by different backgrounds and types of expertise (Taratukhin et al., 2018). With DT, the concept of design, previously strictly related to physical products, has been extended to a new collaborative and iterative problem-solving approach. According to Kolko (2015), DT models are "tools for understanding" and provide "alternative ways of analysing a problem." Thus, design thinkers address a problem by adopting the end-user perspective; this user-centric approach allows team members to brainstorm and then design and develop effective and innovative solutions (Brown, 2009). Scholars agree that DT can be applied in numerous fields and sectors (Uebernickel et al., 2015). Also, according to Ferreira Martins et al. (2019), DT allows the creation of products and services that can improve people's quality of life. Therefore, adopting DT into innovative technological solutions implies that design thinkers focus more on human-centred aspects (Lockwood, 2010), such as end-users' needs and approaches to technology usage, thus not limiting them to technological ones.

Today, consensus on a standardised model is lacking despite the growing interest of DT in different fields. However, Waidelich et al. (2018), in their extensive literature review, found some commonalities in the terminology and in the model's stages. Given the nature of our case study, we adopted the process model proposed by Brown (2008), Chair of IDEO, one of the first companies that introduced DT. According to Brown, "Design thinking is a human-centred approach to innovation that draws from the designer's toolkit to integrate the people's need, the possibilities of technology, and the requirements for business success" (www.ideo.com). Then, this definition has been further suggested by Chou (2018) as suitable for innovative social entrepreneurship projects. Certainly, he identified a strong coherence between these principles and the creation of social entrepreneurship projects since these initiatives centred on introducing innovative ways of supporting disadvantaged communities. With this in mind, the actors involved in the project must be aware of the needs and problems faced by the people they intend to help. Additionally, a deep understanding of the cultural aspects and socio-economic conditions of the context appears to be necessary. Therefore, we adopted the model proposed by Chou (2018) since SMARTAGE is led by three social cooperatives whose characteristics and objectives fully reflect his description.

This specific approach comprises three macro-spaces—*inspiration, ideation,* and *implementation*: social problems and business opportunities emerge in the inspiration space; the ideation space comprises mainly the definition of the ideas that will be validated through tests or simulations; and the ideation space comprises mainly the definition of the ideas that will be validated through tests or simulations; and the implementation space put the designed concept into practice. It is important to highlight that the DT workflow implies a loop between spaces, particularly between the first two (Chou, 2018). Each space will be extensively described in Section 5.

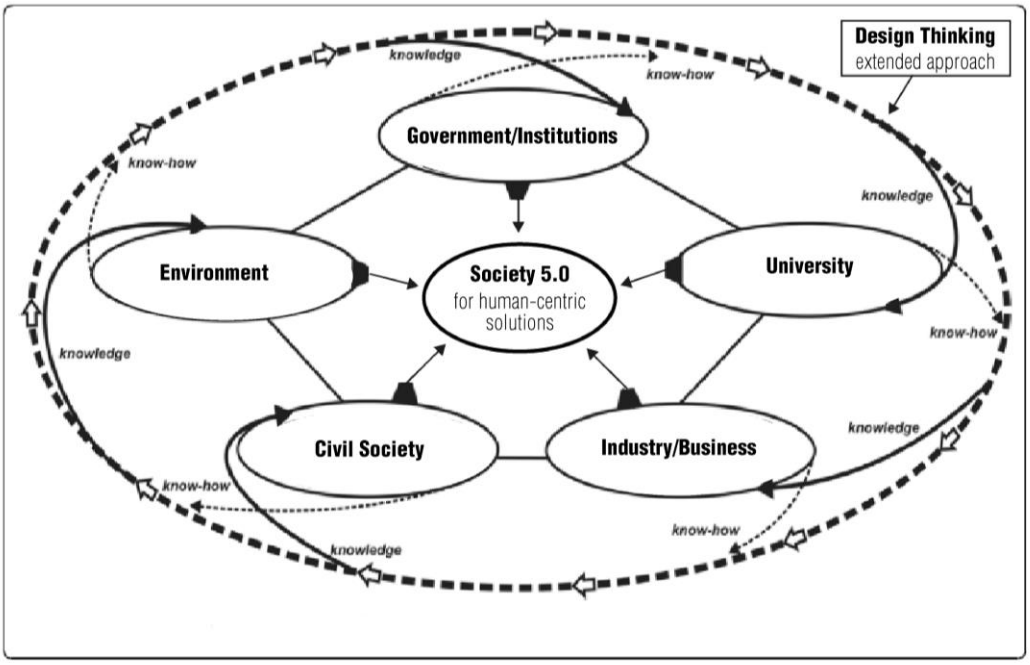
3.3 Addressing S5.0 projects through the QH framework and a DT approach

By integrating the QH framework and the DT approach, we conceived the following conceptual model (Figure 2) aimed at designing and developing new S5.0 human-centred solutions. The model can be seen as an innovative theoretical and operational toolkit capable of effectively implementing products and services from an S5.0 perspective.

Specifically, the model combines the rules of open innovation derived from a participatory and synergic DT process with the five helices involved, both individually and jointly, regarding their (eco)systemic nature. The S5.0 perspective is central to the model to benefit from the interactive propulsive thrust of the QH subsystems—Industry, Government, University, Civil Society, and the Environment (Carayannis et al. 2017; 2018b). Then, the DT approach is considered a frame, a constant superset that regulates the interaction and knowledge flow among the individual subsystems and ensures stakeholders' collective participation (Nieto and Santamaría, 2007; Oh et al., 2016; Walch and Karagiannis, 2019; Zuh et al., 2019).

Therefore, if the entire innovation process benefits from the participation and joint feedback with the five subsystems considered (as we conceived using a new QH–DT approach), then it is expected that the implemented solutions strongly impact the same five dimensions within a circular, multilateral S5.0 logic. For this purpose, the new solutions must not only be ethical, efficient, and effective but also *environmentally, socially,* and *economically* sustainable, that is, to be consistent with the triple bottom line (TBL) of sustainability (Müller et al., 2018b; Jabbour et al., 2018b; Kamble *et al.*, 2018; Khan et al., 2021) pursued by both the I4.0 and S5.0 paradigms.

Figure 2: The proposed QH–DT conceptual model



4. Methodology

As argued in the previous sections, how to design Society 5.0 solutions that, by adopting a human-centric perspective, integrate Industry 4.0 technologies and benefit the society at large, has yet to be studied. Hence, our research is exploratory in nature and requires qualitative methods to conduct an in-depth analysis and get a richer and thicker understanding of this complex phenomenon in its real-life context (Eisenhardt, 1989; Yin, 2009). As a consequence, a single case study of an Italian Smart-health project – SMARTAGE- has been purposefully (Patton, 1990) chosen to shed light on how the aforementioned QH-DT framework can be applied in the designing process of Society 5.0 solutions. As a matter of fact, this project was chosen for its revelatory potential as it offers a distinctive setting to explore the phenomenon under investigation and to gain insights that other cases would not be able to provide (Coviello and Joseph, 2012; Siggelkow, 2007). Firstly, as described in the following section, the SMARTAGE case perfectly fits the Society 5.0 depiction, since it aims to improve socio-health and social-welfare services by integrating physical and virtual spaces, thereby deploying the opportunities created by I4.0 technologies. Secondly, different actors - representing the different helices of the QH model - were involved during the entire DT process, thus providing us the opportunity for gathering insights about the innovative theoretical and operational potential of the proposed QH-DT model in implementing S5.0 solutions. Consequently, since the goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory (Eisenhardt, 1989), SMARTAGE appears a suitable representative case for a single case study (Yin, 2009), that was then built on the action research methodology (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009).

Case description

The SMARTAGE project is part of a 2018 funding programme (the POR FESR 2014–2020: Regional Operational Programme POR, European Regional Development Fund *FESR*) of Le Marche Region in Italy, which supported the development and the enhancement of social enterprises in the areas affected by the earthquake that hit Central Italy in 2016 and significantly damaged people, homes, and infrastructure. The funded programme must pursue the following objectives: new opportunity creation for social enterprises in the citizen services market, relationship and synergy development between social enterprises and structures operating in the health and wellbeing domain, and innovative solution testing to create products and services with performance requirements that best meet the needs of users.

Accordingly, the SMARTAGE project was conceived to solve the social issues that emerged from the combination of two important phenomena: the earthquake and the rise of the elderly population. Notably, analysing the rapid growth of the world population, the over-60 segment is experiencing the greatest increase. According to Global AgeWatch Insights, this phenomenon is mainly due to the achievable progress in the fields of healthcare and, concurrently, overall economic development. The number of people aged 60 or over is expected to reach two billion by 2050 (United Nation, 2017). Also, the phenomenon is becoming increasingly considered in Italy—the most aged country in Europe with an 18.6% seniority rate. As a matter of fact, the earthquake greatly complexified the elderly population's access to health and social services, especially because they mostly lived far away from the main urban centres, sometimes even in isolated areas. Consequently, social-assistance interventions require longer shifts, thereby affecting the frequency and effectiveness of the intervention. Also, with the COVID-19 pandemic emergence, the situation has dramatically worsened.

To solve these problems and improve the way social enterprises may deliver health assistance and services to older adults living in isolation, introducing technological innovation in the field of homecare, social inclusion, and active ageing seemed to be the right solution. From a cooperative viewpoint, new technology-driven services could have brought both benefits and challenges. While they may contribute to improving competitiveness by reducing costs and creating new market opportunities, they probably would have to acquire new skills and competences regarding the virtual spaces and the technologies adopted. Consequently, a partnership among various actors (see Table 2) that constantly intertwined and collaborated during the entire DT process was formed. However, the "environment" helix is not represented as an actor but rather as an element that needs to be taken under consideration during the entire DT process. Regarding the role of the University, the collaboration between different departments has been divided into two macro-areas: the first area concerns the design, testing, and relative release of the technological solutions; the second area, closely related to the previous one, and is focused on management, organisational, and business-related aspects. Here, the team members supported the social cooperatives in defining new business models aimed at introducing new services into their portfolio.

Table 2: Actors involved

Corresponding Helices	**SMARTAGE Actors**	**Description**
Government/ Institutions	Le Marche Region (IT)	2018 funding program (within the POR FESR 2014–2020) for supporting the development and the enhancement of social enterprises in the areas affected by the 2016 earthquake
Government/ Institutions	Municipal administrations*	Six urban centres belonging to the "crater area" of the 2016 earthquake, Italy: - Ascoli Piceno (49.209 inhabitants) - Acquasanta Terme (2.855 inhabitants) - Venarotta (2.051 inhabitants) - Force (1.212 inhabitants) - Montegallo (462 inhabitants) - Palmiano (171 inhabitants)
Industry/Business	Social Cooperative #1	As project leader, it promotes social inclusion through activities and workshops relating to vegetable garden management and the creation of handcraft products. In this perspective, the cooperatives' ideas of involving elderly volunteers is particularly relevant
Industry/Business	Social Cooperative #2	Founded in 2012, its mission is to contribute to the prevention of discomfort, the promotion of wellbeing, and social integration through the design and implementation of psychosocial, health, and educational services. The cooperative participated in the project to extend its range of services, which are already present in the region
Industry/Business	Social Cooperative #3	Since 2003, it has offered numerous social services. The cooperative collaborates with numerous professional figures. It is also embedded within an articulated institutional network

Industry/Business	Technology Provider #1	Company A
Industry/Business	Technology Provider #2	Company B
University	University Department #1	Department of Information Engineering—Faculty of Engineering—Marche Polytechnic University
University	University Department #2	Department of Industrial Engineering and Mathematical Science —Faculty of Engineering—Marche Polytechnic University
University	University Department #3	Department of Management—Faculty of Economics—Marche Polytechnic University
Civil Society	End Users	15 elderlies
Environment	–	The environment was considered a *passive actor*. If a precise interlocutor, representing the interests of the environmental system in an active DT perspective, was not referable, then the attention to the specific environmental prerogatives (2016 earthquake and COVID-19) was paid by all the actors involved.

* To complete the picture, it is appropriate to include the administrations of the municipalities of the areas involved. Their role was particularly relevant, especially in the first stages of the process for raising awareness in the local communities.
Source: Authors' elaboration

Data collection and analysis: the action research methodology

The case study was built and analysed relying on the action research methodology (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009), which involves observations, document analysis, and the direct participation of researchers. Specifically, three researchers among the authors were directly involved during the entire project, starting from the kick-off stage. Since the project under study was developed through the DT approach and witnessed the participation of numerous actors, action research represents the most suitable methodology. In fact, during action research, researchers not only observe phenomena, by overviewing the entire system of interactions among the actors involved, but they can also intervene and participate in the subject under study (Baskerville et al., 1999). In doing so, the direct participation of researchers enhances knowledge acquisition through active involvement (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009).

The entire period of observation and direct participation lasted 14 months, from June 2019 to August 2020. Additional data—in-depth semi-structured interviews, email correspondence, and documents—were collected, codified, and analysed to better understand the entire process that induced the S5.0 solution design and triangulate the findings (Eisenhardt, 1989; Yin, 2009) (Table 3). The interviews were conducted in Italian, audio-recorded and transcribed verbatim and were based on open-ended questions within a semi-standardised protocol to ensure both guidance and consistency in the interviewing style and an adequate level of freedom in answering. The interviews primarily aimed to determine the final individual and organisational viewpoints from which the contributions of the present case could be derived.

The study development followed an iterative approach (Lofland et al., 2005) and covered the three macro-phases of the DT process implementation (Brown, 2008; Chou, 2018) that are used to develop the narrative. The direct observation of each phase allowed us to identify the context in which the SMARTAGE solutions occurred, the needs and social/technological issues to be solved, and the role of each actor involved, thus revealing the knowledge flow and the QH–DT interactive dynamics generated during the entire process.

Table 3: Summary of data source

Source	Volume
Direct participation at meeting (offline/online)	11 meetings; approximately 25 hours
Meeting reports	11 documents; 24 pages
SMARTAGE project documents	6 documents; 103 pages
Email correspondence	43 email with 11 different people
Face-to-face interviews	19 interviews, ranging from 30 to 90 minutes; approximately 15 hours
Other documents	two documents; 80 pages

Source: Authors elaboration

5. Designing Society 5.0 solutions: The Case of SMARTAGE Project

5.1 Inspiration: Three scenarios to solve the problems

The "inspiration" phase of the DT process witnessed the participation of all the actors involved in the project since the very beginning, when the kick-off meeting mostly dealt with understanding the guidelines provided by Le Marche Region and how to put them into practice for supporting the territories affected by the earthquake. Then, the social cooperatives, with the help of the University began to investigate the most perceived obstacles and challenges in delivering their services to the elderly population living in those areas. Specifically, the University researchers interviewed different members of social cooperatives, the elderly, and their caregivers as a sample of potential users. From this first analysis, some critical issues emerged. For instance, the need to remotely monitor the health state of cooperatives' patients, giving the cooperatives' operators the possibility to reduce the number of direct interventions in a territory where the earthquake's damages made mobility and direct intervention a critical problem. Moreover, since the cooperatives' mission goes beyond solving health-related issues to embrace a much broader role in ensuring the elderly's social inclusion, it emerged that the monitoring activity should have been applied not only in their homes but also in other environments that foster the elderly's social relationship and participation. At this point, it was clear that technology would have played a key role in resolving these issues. However, the cooperatives still had no idea how this was going to happen.

Therefore, in this stage, the University helped in shedding light on how disruptive technologies could effectively help cooperatives in designing innovative services based on totally new needs of the elderly, such as psychological and physical protection, social inclusion, and service flexibility.

After various meetings among the University representatives and social cooperatives, in which the need and the competences of the different actors converged, the team eventually ended up proposing the radical transformation of various environments, such as homes, workplaces, and public spaces, by embedding them with I4.0 technological solutions aimed at improving the life quality of the elderly. With this in mind, three scenarios of intervention were proposed and subsequently validated by the cooperatives.

—Scenario no 1: "Social Garden"

Supervised by Social Cooperative #1, it comprises monitoring the elderly while they are gardening in a shared space. Socialisation, activity level, and physiological values are the main parameters to be measured.

—Scenario no. 2: "Diurnal Centre"

Supervised by Social Cooperative #2, this scenario allows the cooperative's employees to monitor the elderly’s activities into a recreation centre in which they can interact and socialise with children. Activity and socialisation levels and physiological parameters will be monitored.

—Scenario no 3: “Home Assistance”

Supervised by Social Cooperative #3, this scenario comprises non-invasive monitoring of the elderly users’ behaviours in their home environment through non-contact and physiological sensors. Elderly people, living alone with an age above 65, are the target users of this solution. The monitoring will be focused on physiological, environmental, and behavioural parameters.

5.2.2 Ideation: The use cases definition

To better contextualise the aforementioned three scenarios, in the ideation phase, the team members guided by the university researchers developed three use cases identifying the potential users, the problems they might face in each scenario, and the possible solutions the cooperatives can provide through implementing the SMARTAGE platform. By considering the users’ issues and needs emerged in the previous stage, the use case definition allowed the university researchers to better identify how to approach each scenario and how to design the technological setting and to select the right components. As a matter of fact, in this stage, the social cooperatives’ knowledge regarding patients’ needs and characteristics played a key role in defining the recurring problems they faced in everyday life. Certainly, these hypothetical use cases exemplify how social cooperatives can exploit the potential of the SMARTAGE platform to better plan and schedule its intervention, but also to introduce innovative services for local communities.

The Use Case 1—related to the first scenario—identifies Users A and B as a close-knit and dynamic couple in their seventies, who loved going out with their friends and family. Unfortunately, after the 2016 earthquakemost of their friends moved to other cities because of fear and home damage, thereby leaving Users A and B alone in the countryside. Consequently, they were eager to participate in the new social garden initiative proposed by the mayor and Social Cooperative #1, wishing to make new acquaintances while engaging in manual work. In this supposed scenario, the cooperative offers elderly people a space just outside the city, where it is possible to garden without jeopardising their health and by making them feel less lonely and isolated. Therefore, the garden is terraced at one metre of height to prevent the elderly from bending over and allowing them to converse easily while standing up and gardening. Additionally, the entire area is covered by a network of sensors to monitor the level of activity during gardening (Pietroni et al., 2016). In this use case, the SMARTAGE platform analysis helps the social cooperative’s employees to constantly monitor the elderly’s levels of physical activity and eventually intervene if they do something that endangers them considering their health condition. Few weeks after the opening, the User A and B couple are enthusiastic about the initiative which improves their physical and mental condition.

The Use Case 2—referring to the second scenario—has been designed for User C, who is a 73-year-old man living alone since his wife died. Seeing him alone and inactive, his son decides to enrol him in the Diurnal Centre managed by Social Cooperative #2. The goal of the Centre is to make the elderly socialise through organised activities with children. The entire Centre space is equipped with sensors and vision systems that allow the cooperative to monitor the elderly activity level to understand how they interact with children and to evaluate which of the Centre activities is the most engaging for them. Additionally, to monitor physiological parameters, the Centre provides User C with a smartwatch that he needs to wear for the entire visit time. In this use case, the SMARTAGE platform analysis allows Social Cooperative #2 to detect an increase in User C body weight—a symptom of better health—due to some specific activities with children inside the Centre. This allows the cooperative to better define the Diurnal Centre activities by selecting those that relate more to higher levels of health. Finally, after a month of his father attending the Diurnal Centre, User C's son is pleased to see his father happier and more willing to go out, thus making him grateful and satisfied with the cooperative's service.

In Use Case 3—related to the third scenario—the research team identifies User D, a 75-year-old who lives alone in his apartment a few metres away from his sons, who cannot actively take care of him all day long. Due to a stroke he had when he was 59 years old, User D had trouble walking despite the rehabilitation sessions made. Since his wife died, User D has dramatically reduced his outdoor activity, thus making his sons worried about his health. Consequently, they call Social Cooperative #3 to look after their father. In this hypothetical scenario, a network of sensors remotely controlled by Cooperatives #3 are placed in User D's home to monitor his daily activities, environmental and home salubrity parameters, and some physiological parameters (e.g., blood pressure and body weight) (Casaccia et al., 2019; 2020a). Particularly, three passive infrared (PIR) sensors are installed in the kitchen, in the bathroom, and at the entrance, plus two door sensors, one on the entrance door and one in the kitchens' cabinet medicines. After a few weeks, the social cooperative can detect some interesting insights about User D's home activity. For example, they discovered that he had never opened the door for three days straight since nobody visited him, and he lost weight and the house's comfort level decreased. By collecting and analysing this data, the SMARTAGE platform in this use case allows the cooperative to plan a new schedule to look after the User D. They decide to visit him twice a week, to call him every morning, and thus invite his sons to visit him more often. After two months of following the scheduled activities, User D starts to go out more frequently and gain weight, thereby improving his comfort at home.

Alongside the definition of the use case, a technology scouting process was performed by the University team members and two different technology providers. The interface between them occurred in two aspects: the use cases' technical and financial feasibility; the definition of the most suitable technological configuration of each use case, considering different users' and environments' characteristics.

5.2.*3 Implementation: The human-centric integrated platform*

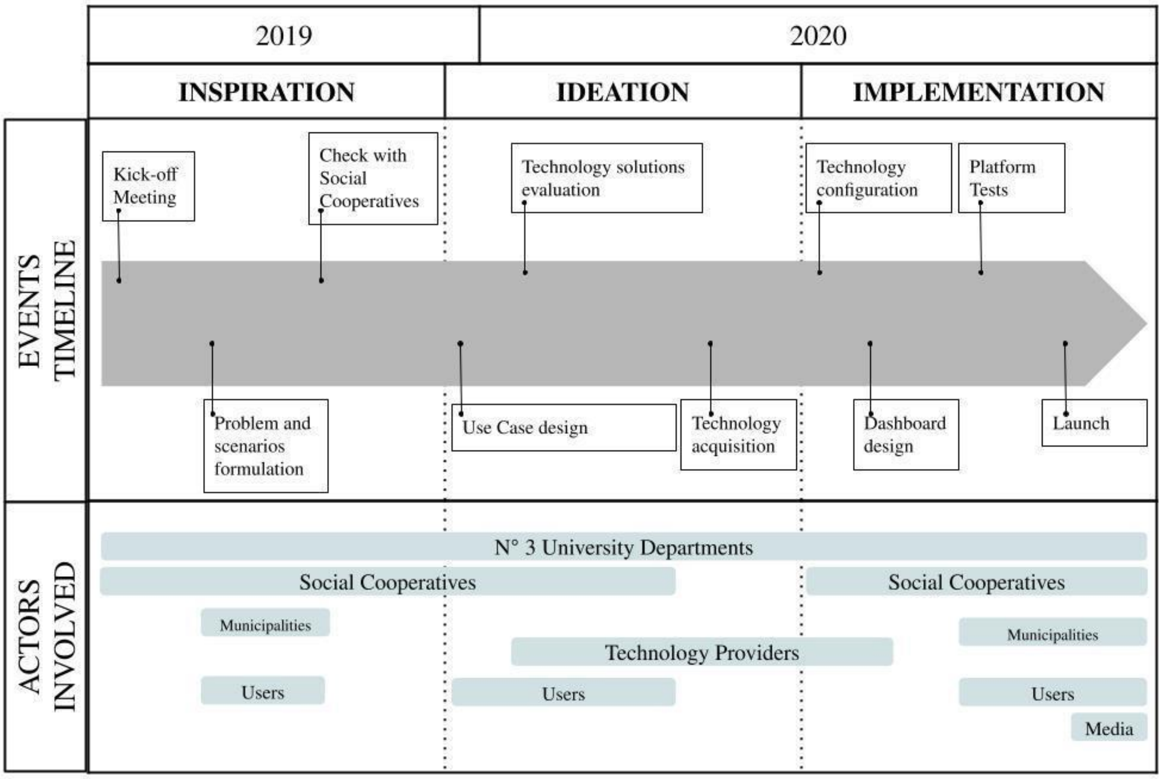
In this last phase, guided by the designed scenario and the layout of each use case, the team members started to effectively implement the SMARTAGE platform, thus focusing on integrated and interconnected solutions. Certainly, the research team, guided in this phase by the researchers of the engineering department, agreed to develop an open Cloud Infrastructure that can easily communicate with third party actors. Consequently, in selecting the applicable devices in each scenario, the research team considered their functionalities and technical features and concurrently another important manufacturer's capability—the possibility of acquiring and then integrating remote sensor data within a cloud infrastructure by providing, for example, APIs that third-party developers can use to extend programmes, applications, and platforms. Indeed, the ability to read data from interconnected devices allows the SMARTAGE Cloud to better analyse and then display the results. Furthermore, the interconnection level was designed in a modular way so that multiple devices and data analysis algorithms can be added to make the Cloud architecture readily adaptable to the environment and user needs. For the multi-source data analysis from both wearable and non-wearable sensors, the team members chose to implement machine learning (ML) to identify and extract features within the database of the generated data (Casaccia et al., 2018; Casaccia et al., 2020b; Monteriù et al., 2018; Scalise et al., 2016). Unlike traditional algorithms, ML allows for managing sparse data metrics, avoiding deleting data, and imputing median values.

At the same time, a research was conducted on the target users who, as early adopters, would be the first to test the implemented solutions. Furthermore, their direct involvement was also necessary to test the usability level of the user interface. The early adopters engaged in this phase were identified through an open call delivered through the official communication channels of the local government (municipalities).

Today, the SMARTAGE Cloud platform and the ad-hoc developed dashboard allow both parties (the cooperatives and the elderly's families) to easily access and manage useful medical information about the patient, previously acquired through the sensors. Consequently, it becomes easier not only for the cooperatives but also for the families to decide whether and how to intervene in the elderly's activities.

Finally, it is important to highlight that the entire DT process concerning the SMARTAGE project has been profoundly marked by the advent of COVID-19. However, thanks to the iterative nature of the DT process, it was possible to add new features to the project (such as body temperature, blood saturation, and social distancing sensors), which allowed us to tackle new and urgent needs faced by both cooperatives and elderly people due to the pandemic. As regards the environment aiming at fostering elderly social inclusion and interactions the anti-Covid-19 regulations were introduced, therefore, accesses were limited, and social distance maintained. From this point of view, the use case that presented the most critical issues was the scenario of "Diurnal Center" (no.2) in which users would interact in a closed place. Consequently, in the implementation phase, the team initially focused on developing the other two use cases - the no. 1 scenario of "Social Garden") and the no. 3 of "Home Assistance", thus postponing the implementation phase of the Diurnal Center.
To better display the results, the entire project flow timeline and the related involvement of the actors are illustrated in Figure 3.

Figure 3: the SMARTAGE project workflow



6. Discussion

Despite the nature of the single case study generates findings that may not be generalizable to all kinds of settings, the use of the SMARTAGE case provides in-depth and rich data about the phenomenon investigated.

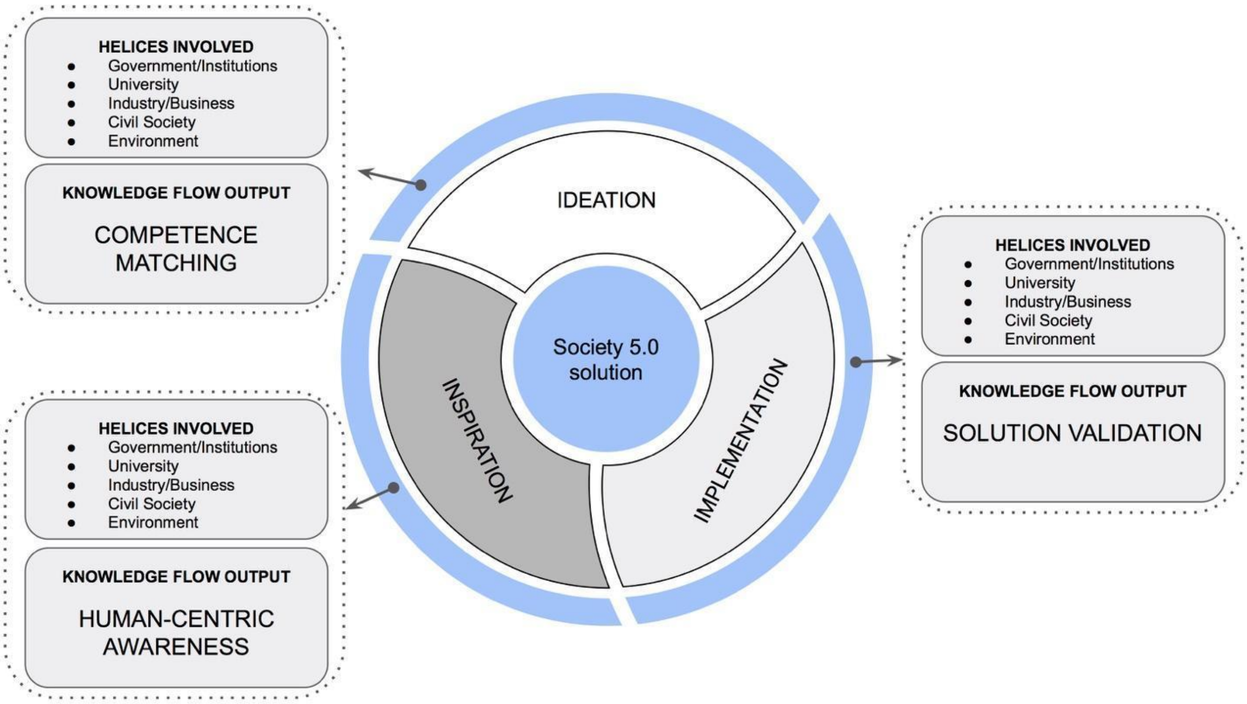
As emerged from the findings, the SMARTAGE project was conducted from the beginning through interactions, cooperation, and knowledge flow among different helices (Carayannis et al. 2017; 2018b) (Figure 4). Consequently, it appears that by following the proposed QH-DT approach it is possible to design and implement S.5.0 solutions which are human-centric.

Specifically, the findings revealed the important role of DT as a frame, a constant superset that regulates the interaction among the individual subsystems, ensures stakeholders' collective participation in various capacities, and contributes to feeding the circuit of knowledge creation and sharing (Nieto and Santamaría, 2007; Oh et al., 2016; Walch and Karagiannis, 2019; Zuh et al., 2019). For example, if the *government-institution* subsystem provides the lines of regulatory intervention concerning the *environmental context* (administration of the territories affected by the earthquake and regulations for security measures regarding the COVID-19 pandemic), the *social cooperatives* contribute to the knowledge flow by sharing their long experience and the related competencies in the field of healthcare and social services for the elderly. Nonetheless, the social cooperatives lack the professional background to fully understand the potential impact that I4.0 technologies can bring to their business. In this sense, a crucial role was played by the *university* whose team acted as a bridge between the cooperatives and the *technology providers*, thus allowing the design of a solution that considers both perspectives—social cooperatives' needs and issues from one side and technological constraints from the other (Bai et al. 2020; Jabbour et al., 2018).

Additionally, the findings also confirm the fact that in a S5.0 context in which sustainable and human-centric (rather than technocentric) services and technologies are becoming more and more important, the user (civil society, humans, people, and citizens) should be at the heart of the entire innovation process. Consistent with Arnkil et al., 2010, the users' involvement, especially during the design of the user interface, was pivotal for the success of the entire QH–DT process. For example, only by considering the needs of the elderly and the knowledge and experience of the social cooperatives, the development team could define the three use cases and design the right solutions for them. This is in line with DT's founding principle, which entails the process of examining and solving a specific problem by an interdisciplinary team, whose members are characterised by their various backgrounds and types of expertise (Taratukhin et al., 2018). Furthermore, to promote the launch of the SMARTAGE project and highlight the importance of the new services implemented the *media* were involved, thus supporting the dissemination of the first results, and increasing the reach of the initiative among potential users.

Figure 4 summarizes what we have just discussed by highlighting the process, the main stages, and most relevant knowledge flow outputs that occur in applying a QH-DT model for the design of S.5.0 solutions. As illustrated in the diagram, the DT allowed the actors involved (QH) to contribute both directly and indirectly to the project by ensuring a continuous flow of knowledge made by know-how and experience spillovers among the parties involved.

Figure 4: The QH-DT model in action for Society 5.0 solutions



In particular, in the first DT phase (Inspiration), the knowledge flow contributes to increase the awareness of all actors about the research context and the issues faced by the elderly, cooperatives and municipalities, thus aligning all the subjects regarding the need to adopt a human-centric perspective. Afterwards, the second phase (Ideation) entails the competence matching between the actors involved. As stated before, the continuous knowledge flow among actors allowed the integration of different skills and competences. For example, during this phase the technological and managerial expertise brought by the different University departments matches with the cooperatives' knowledge and expertise in the social field. Finally, in the third and last phase (Implementation), the flow was translated into a feedback system between the parties aimed at validating the solution in terms of technical feasibility, market opportunities, and usability by both operators and end users.

7. Theoretical implication

Analysing the SMARTAGE project case allows us to generate some theoretical implications about the ever-important paradigm of S5.0, thereby highlighting how to design and manage complex Society 5.0 solutions, capable of exploiting the potential of I4.0 technologies to solve important social issues. SMARTAGE was indeed born with the aim of solving social problems faced by cooperatives and municipalities in an area which was struggling with the rise of the elderly population hit by a severe earthquake through the implementation of I4.0 technologies. Theoretically, by identifying an innovative framework suitable for effectively responding to the implementation requirements of new healthcare products and services, this paper contributes to the Society 5.0 literature in different ways.

First of all, this study is one of the first attempts to bring S5.0 research beyond its definitional aspects, thus providing an empirical contribution on how to create solutions that can fit the Society 5.0 domain. As a matter of fact, despite the literature (e.g., Ghobakhloo, 2020; Pinzone et al., 2020; Beier et al., 2020) call for studies regarding the Society 5.0 paradigm to overcome some shortages about the role of I4.0 technologies in society, little has been done so far. Consequently, this study is a first attempt to explain how important social problems can be solved by integrating I4.0 technologies via a practical case analysis (see Beier et al., 2020; Khan et al., 2021). Particularly, by following a step-by-step DT approach (Chou, 2018), the narrative showed how it became possible to define and design more human-centric products and services capable of benefiting various publics, such as users and citizens (the elderly and their related communities), governments and regions (Le Marche Region and the six cities involved), industries and organisations (the social cooperatives, the technology providers and the healthcare industry), universities (Università Politecnica delle Marche), and the environment. This allows us to answer recent calls (Khan et al., 2021; Benitez et al., 2020) on more holistic studies focusing on the synergies between different actors in order to unlock I4.0 potentials in fostering social, economic and environmental value. Additionally, we confirm the importance of the role of innovation ecosystems in addressing the complexity of technological solutions (Benitez et al. 2020). Indeed, the SMARTAGE innovation ecosystem fostered a value co-creation process among the helices involved; process that was able to contextualize I4.0 technologies within wider innovative solutions.

Another noteworthy contribution from a S5.0 perspective, is the importance of a regional orientation (Potočan et al., 2020) in developing these kinds of solutions. As emerged from the narrative, the regional orientation of the entire project helped to build more applicable solutions and support more human-oriented development by increasing the interests of all the actors in participating in the project. Particularly, the local population, the social cooperatives and the municipalities were the utmost invested in contributing to the project, since they experienced first-hand the pressure of the social issues emerging first from the earthquake and then from the pandemic. In line with Keidanren (2016) and Potočan et al. (2020), SMARTAGE confirms how the ability of different actors to solve social problems of individuals in the local environment is one of the most important aspects in developing S 5.0 solutions. Moreover, the SMARTAGE project confirms the need to integrate innovation policy (from the government side), entrepreneurial spirit (from society side), and entrepreneurial skills (from civil society and institutions) in developing S5.0 solutions (Yousefikhah, 2017), ensuring that its implementation is not just a political-ideological concept, but something achievable and effective.

Additionally, the paper contributes to the DT and QH literature by unravelling their importance in the development of human–centric solutions (see Przybilla et al., 2020; Nieto and Santamaría, 2007; Carayannis et al. 2017). Notably, the discussion of the narratives allowed us to identify the knowledge flows that resulted from the interaction among the different actors involved during the entire DT process. In doing so, we confirm the fact that innovation is created through knowledge sharing and circulation, and this reiterated interaction generates and fuels innovation itself (Carayannis et al., 2012; Dewangan and Godse, 2014; Dziallas and Blind, 2019).

Specifically, by framing the conceptual model according to the stages of DT, we extend the theoretical understanding of the QH literature providing a new possible helices configuration suitable for the S5.0 paradigm. This was possible by observing the knowledge flow generated among the actors involved during the entire innovation process. In doing so, the case findings allow us to stress the link between knowledge and innovation (Carayannins and Campbell, 2010), as both *knowledge creation* and *production* and *knowledge application, diffusion and use* took place in the same environment. In this regard, Carayannis and Campbell (2009, p. 225) already highlighted the importance of a "knowledge swing" and of a cross-communication between helices. This study enriches their findings by identifying different forms of knowledge flow output that are crucial for designing S.50 solutions.

Finally, by concentrating on how to create solutions that can fit the S 5.0 domain, the present study may eventually help to overcome some of the emerging key shortages about the social impact of I4.0 technologies (Ghobakhloo, 2020; Neumann et al., 2021; Khan et al., 2021) and confirm once again the need to embrace a S5.0 domain. Firstly, unlike other studies (Brozzi et al., 2020; Frank et al., 2019), by focusing on healthcare services, it takes the social impact that I4.0 technologies may have outside the production and manufacturing domains, thus unravelling its potential in other sectors. In doing so, we enrich the current literature by embracing a much broader meaning of human-centric technology that goes beyond workplace safety and human-centric factories issues (Pinzone et al., 2020). Additionally, the SMARTAGE project is based on the interplay of different actors which are equally important in the design process of human-centric solutions thanks to knowledge flows and spillovers created among them. Consequently, even if the role of Industry (technological providers and social cooperatives) is crucial for the success of the initiative, we highlight the importance of each helix thus overcoming the narrow focus of firms' adoption of I4.0 for creating sustainable value (Yadav et al., 2020; Birkel and Müller, 2021).

Finally, the study findings expand and broaden the meaning and importance of designing human-centric technologies capable of benefiting the society at large by integrating users' needs from the beginning of the entire technological development process and do not consider the social impact as a technology's add-on features (Beier et al., 2020).

8. Managerial implications

From a managerial viewpoint, the SMARTAGE narrative could provide useful implications to different audiences. First of all, the discussed results could provide policymakers with valuable guidance on how to design and implement social care solutions to address important and urgent issues, such as the elderly's isolation caused by natural disasters. Consequently, they should fund projects featuring the active participation and commitment of different actors and their respective subsystems, including those who will be the end users to develop new products and services (or even new production models), which can be considered S5.0. Additionally, this work has implications even for those directly involved in the design and implementation of S5.0 solutions. They should therefore develop these solutions by considering that different forms of knowledge (technological, industry-based, user-based, and market-based) should circulate during the entire workflow, thus creating a spillover effect, which allows each project members to properly assimilate them. Furthermore, creating an inclusive work environment characterised by listening and contamination should be encouraged. Therefore, the study demonstrates that those participating in this type of project should address this issue by combining their viewpoints with an external perspective.

Further, the paper confirms the vital role of technology in designing Society 5.0 solutions; it shows how to use technologies, such as wearable and non-wearable sensors, ML, and cloud architectures, to improve the way cooperatives and governments serve elderly people in their everyday lives, This is possible by monitoring not only their health systems but also their social activities and interactions, thus offering cooperatives huge amounts of data with which to sustainably improve quality of life and social responsibility. Also, these human-centric technology solutions in healthcare seemed to represent a valuable opportunity to solve the problems and issues caused by the global COVID-19 pandemic: sensors could grant the monitoring of elderly people remotely by constantly reporting their health state and preventing them from going out for a medical visit in case of symptoms. In the use cases proposed, these innovative solutions will allow cooperatives to maintain social distancing without creating social alienation.

For the reasons above, the SMARTAGE project allowed us to highlight the potential dynamic nature of a QH–DT approach when developing S5.0 solutions. By integrating and interacting the five helices during the entire design process, the team could adapt the innovative solutions to the actual user needs and develop services that are compliant with the recent health regulations provided by the Italian Government.

9. Conclusion

In a global scenario recently characterised by different challenges, it appears mandatory to understand how I.4.0 technologies could benefit the entire society. Therefore, starting from the need to overcome some I.4.0 shortages, this study recognizes the ever increasing importance of the Society 5.0 paradigm, thus explaining how to design more human–centric solutions, capable of better integrating the I4.0 technologies and human needs. To achieve this, we first defined a new conceptual framework that combined the QH innovation ecosystem model and the DT process. This seems to be a suitable approach because it allowed the actors of the five helices to cooperate in a systematic way, fulfilling the different needs and favouring the circulation of dissimilar knowledge and skills. Then, a practical application of the proposed model in the field of healthcare service was presented. By applying action research, we developed the SMARTAGE case, describing how the QH–DT approach can help all the actors involved to design and develop S5.0 inclusive solutions. The findings showed how it was possible to provide technological solutions that meet the needs and expectations of different actors, perfectly in line with the S5.0 paradigm.

Obviously, the study has certain limitations which suggest various opportunities for future research. First of all, it is an explorative study that relies on a single case – the SMARTAGE project – and on a specific field of application – the healthcare industry and the emergencies deriving from the administration of areas affected by earthquakes and the current pandemic context. Hence, the methodology may limit the generalizability of the observations to other companies and industries. Notably, even though generalizability is not the aim of the study - like the majority of qualitative research (Strauss and Corbin, 1998) - future researches could apply the QH-DT model proposed in this study to prove its effectiveness also in other industries and contexts. In doing so, the validity and representativeness of the QH-DT model proposed will eventually improve.

Besides, the study suffers from the emergence of the COVID-19 pandemic which inevitably implied changes during the entire DT process. Although the proposed model shows a great flexibility and versatility allowing the actors involved to react and adjust their solutions to the new issues faced by the local population during the pandemic, it could be interesting to investigate other situations dealing with the pandemic since the initiation phase.

Furthermore, the feedback provided by the actors of the five helices could be extended even more, involving new social aggregates and communities, along with new businesses, universities, and institutional partnerships, to build new social infrastructures and social innovation ecosystems.

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Table 1: I4.0 technologies

I4.0 Component	Definition	Source
CPS	CPS is a collection of transformative technologies that integrate the operations of physical assets and computational capabilities, de facto bringing the physical and virtual worlds together. It encompasses different artefacts, which can perform different tasks: measuring and monitoring physical data from the system environment via sensors and actuators; processing, evaluating, and storing the acquired data to interact with the system environment; and providing various human–machine interfaces for different control options.	*Akanmu and Anumba 2015; Hoffman and Rusch, 2017, Stock et al., 2018.*
IoT	The IoT is the addition of new technologies, such as RFID (Radio-Frequency IDentification) to everyday objects, which could communicate and exchange information about their environment, context, and location. Every physical object, thanks to the IoT, may become a “smart” object whose retrieved data can benefit companies in developing new market and consumer insights, thereby improving their strategic planning and implementation. Starting from the general IoT, the terminology became varied, including the Industrial Internet of Things, Internet of Services and, Internet of People. A general IoT system can be represented by a five-layer architecture: a) sensors and actuators, b) a device, which often integrates the former layer, c) a gateway, which is sometimes referred to as a hub or hardware platform, d) a software platform, which is also called integration middleware, and e) an application.	*Ashton, 2009; Ng and Wakenshw, 2017; Sestino et al., 2020; Muller and Voigt, 2018, Conti et al., 2018, Basaure et al. 2020,*
Cloud Computing	Cloud computing is the technology that provides more reliable data management and storage processes, thus allowing full exploitation of the potential of CPS and IoT regarding data volume. Emphatically, although most computer systems lack the necessary storage capacity to manage the great amount of data generated in the newly interconnected world, cloud computing offers flexible provisioning of IT resources to solve this problem Using cloud-based software applications, web-based management dashboards, and cloud-based collaboration software, users and companies can easily receive, analyse, and interpret data from ubiquitous sensors. [B1]	*Stock et al., 2018; Hermann et al., 2016*

Source: Authors’ elaboration

Table 2: Actors involved

Corresponding Helices	SMARTAGE Actors	Description
Government/ Institutions	Le Marche Region (IT)	2018 funding program (within the POR FESR 2014–2020) for supporting the development and the enhancement of social enterprises in the areas affected by the 2016 earthquake
Government/ Institutions	Municipal administrations*	Six urban centres belonging to the “crater area” of the 2016 earthquake, Italy: - Ascoli Piceno (49.209 inhabitants) - Acquasanta Terme (2.855 inhabitants) - Venarotta (2.051 inhabitants) - Force (1.212 inhabitants) - Montegallo (462 inhabitants) - Palmiano (171 inhabitants)
Industry/Business	Social Cooperative #1	As project leader, it promotes social inclusion through activities and workshops relating to vegetable garden management and the creation of handcraft products. In this perspective, the cooperatives' ideas of involving elderly volunteers is particularly relevant
Industry/Business	Social Cooperative #2	Founded in 2012, its mission is to contribute to the prevention of discomfort, the promotion of wellbeing, and social integration through the design and implementation of psychosocial, health, and educational services. The cooperative participated in the project to extend its range of services, which are already present in the region
Industry/Business	Social Cooperative #3	Since 2003, it has offered numerous social services. The cooperative collaborates with numerous professional figures. It is also embedded within an articulated institutional network
Industry/Business	Technology Provider #1	Company A
Industry/Business	Technology Provider #2	Company B
University	University Department #1	Department of Information Engineering—Faculty of Engineering—Marche Polytechnic University

University	University Department #2	Department of Industrial Engineering and Mathematical Science—Faculty of Engineering—Marche Polytechnic University
University	University Department #3	Department of Management—Faculty of Economics—Marche Polytechnic University
Civil Society	End Users	15 elderlies
Environment	–	The environment was considered a *passive actor*. If a precise interlocutor, representing the interests of the environmental system in an active DT perspective, was not referable, then the attention to the specific environmental prerogatives (2016 earthquake and COVID-19) was paid by all the actors involved.

* To complete the picture, it is appropriate to include the administrations of the municipalities of the areas involved. Their role was particularly relevant, especially in the first stages of the process forraising awareness in the local communities.
Source: Authors' elaboration

Table 3: Summary of data source

Source	**Volume**
Direct participation at meeting (offline/online)	11 meetings; approximately 25 hours
Meeting reports	11 documents; 24 pages
SMARTAGE project documents	6 documents; 103 pages
Email correspondence	43 email with 11 different people
Face-to-face interviews	19 interviews, ranging from 30 to 90 minutes; approximately 15 hours
Other documents	two documents; 80 pages

Source: Authors elaboration

Dear Editor,

We thank you again for giving us the possibility to revise the paper.
As recommended, we carefully followed the minor revision the reviewer gave us.
Hopefully, with these last improvements, the paper can be suitable for publication.
Given the entity of the minor changes, we uploaded the response letter to reviewer with a specific version of the paper where we highlighted in red the changes.

Sincerely
The authors

Dear reviewer,

We are grateful for the precious advice you gave us to improve the quality of our work. We hope with these last minor changes we will be able to make the paper publishable.

Initially, the paper started with a totally different perspective: we originally based our paper on the Industry 5.0 paradigm, thus missing to understand that our case has little to do with Industry but much more with Society. Consequently, in the previous rounds of review we completely changed our perspective. The proposed QH-DT model, that we draw from the literature, can be used to explain how to design Society 5.0 solutions. In doing so, we dropped the Industry 5.0 domain, thus reconceptualizing the entire paper starting from the shortages about the social impact of the Industry 4.0 paradigm. We did so to introduce the concept of Society 5.0. Then, in order to unravel how to design S5.0 solutions, we highlight the role of each actor in creating and disseminating different types of knowledge thus finally detecting the knowledge flow output in each of the DT phases.

Below you can find the answer to your concerns. Additionally, in order for you to better detect the changes we made, we added a specific manuscript version in which we highlight in red the part that we changed following the minor revisions you required us to do.

1. The theoretical contribution is still not solid enough. There is a lot of "we contribute to calls of XY", but what this manuscript serves as theory-building must still be enhanced.

Thank you for suggesting improving this part of the paper. We tried to enhance the theoretical contribution in two ways:

- We added the papers you suggested about Industry 4.0 literature. This allows us to better frame the I4.0 shortages in the literature paragraphs and eventually have more arguments also for the theoretical discussions. You can find these changes on page 6 (line 2, 5, 17-26) and 7 (line 4-14) of the literature review paragraph and on page 25 (line 16; 22-28), 26 (line 26-34) and 27 (1-9) of the theoretical contributions.

- We better explain the role of the SMARTAGE project in contributing to the QH literature. Specifically, we made clearer how the case allows us to better highlight the link between knowledge and innovation since *knowledge creation* and *production* and *knowledge application, diffusion* and *use* took place in the same environment. Additionally, by identifying different forms of knowledge flow output we were able to provide a new possible helices configuration suitable for the S5.0 paradigm thus taking the QH literature (Carayannis and Campbell, 2010) a little step further. You can find these changes in page 9 (lines 5-11) of the theoretical framework and 26 (lines 16-25) of the theoretical implications.

2. How this case is suitable for theory building, based on an improved theoretical contribution, must be better explained.

As we mentioned in the previous answer, we improve the theoretical contribution, and this allows us to better explain why the case is suitable for theory building.

Additionally, in the methodology section (page 13, lines 17-21) we strengthen the reasons behind SMARTAGE choice, following Eisenhardt (1989) suggestions: *"Consequently, since the goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory), SMARTAGE appears a suitable representative case for a single case study (Yin, 2009), that was then built on the action research methodology (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009)"*.

3. As still a lot of Industry 4.0 literature is cited, this must be updated or at least complemented, as a lot of quite outdated or of doubtful quality literature is cited (e.g., Schmidt et al., 2015, Lee et al., Wan et al., "International Scientific Journal". "International Journal of Recent Technology and Engineering"). Please add literature from 2020 and 2021 and discuss the theoretical contribution in comparison to these references (see under 1.), such as:

   Benitez, G. B., Ayala, N. F., & Frank, A. G. (2020). Industry 4.0 innovation ecosystems: An evolutionary perspective on value cocreation. International Journal of Production Economics, 228, 107735.
   Birkel, H. S., & Müller, J. M. (2021). Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability-A systematic literature review. Journal of Cleaner Production, 125612.
   Khan, I. S., Ahmad, M. O., & Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. Journal of Cleaner Production, 126655.
   Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J. A., Kumar, V., & Batista, L. (2020). A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. Computers in industry, 122, 103280.

Thank you for letting us realize that some literature was not adequate to be cited in the paper. We deleted these references and replaced them with the papers you suggested.

As requested, we used these references to enhance the theoretical contributions as we explained in point 1.

4. As a further remark, I would spell out the abbreviations in the title as those might not be easily understandable for a broader readership.

We spell out the abbreviation in the title as you requested. Consequently, we change the title in “Towards Designing Society 5.0 Solutions: the Quintuple Helix - Design Thinking Approach to Technology”

Towards Designing Society 5.0 Solutions: the new Quintuple Helix - Design Thinking Approach to Technology

Abstract

The integration of Industry 4.0 (I4.0) technologies within society is pivotal for resolving many challenges that the world and its population are facing presently—global pandemics, ageing populations, and climate change. However, academics and practitioners still struggle to fully understand I4.0 outcomes outside of the manufacturing domain, thereby unravelling their potential for society at large. In this scenario, Society 5.0 (S5.0) is arising as a new paradigm that places humans at the centre of innovation. To foster the effective integration of technology into society and to better understand how to design S5.0 configurations and solutions, the authors developed a conceptual model applying the Design Thinking (DT) approach to the Quintuple Helix (QH) innovation framework. The proposed QH–DT model was found to be suitable for allowing the knowledge flow among the actors involved in the design and implementation of the S5.0 solution. The model was then explained through its application in a healthcare project—the SMARTAGE. By adopting an action research methodology, the results explain how it becomes possible to build complex human-centric healthcare solutions.

Keywords: Society 5.0, Industry 4.0, Quintuple Helix Innovation Ecosystem, Design Thinking, Healthcare, Social Entrepreneurship

1. Introduction

The rise of digital technologies and applications, such as cyberphysical systems (CPSs), robotics, augmented reality, artificial intelligence (AI), the Internet of Things (IoT), big data, and the cloud, is bringing dramatic changes to society and industries. Industries are providing with new opportunities to shape and renovate their ways of doing business (Kiel et al., 2017b; Müller et al., 2018b), thereby inducing the advent of the fourth industrial revolution, better known as "Industry 4.0" (I4.0). However, I4.0 technological potential goes beyond its impact on companies and business sectors and benefits the environment and society at large (Bai et al., 2020; Ghobakhloo, 2020; Müller and Voigt, 2018). In the current scenario in which the world is increasingly facing challenges of global scale, such as natural disasters, ageing populations, resource depletion, growing economic disparity, and ultimately the ongoing global pandemic, it is crucial to fully exploit digital technologies to effectively and efficiently resolve these issues to benefit the society at large. Consequently, integrating technology within society will be crucial in the future.

Despite the recent growing interest in the social impact of I4.0 technologies (Beier et al., 2020, Jabbour et al., 2018a; Stock et al., 2018;), the academic literature presents some shortages that could lead practitioners and academics to develop a new paradigm called Society 5.0 (S5.0), in which humans are at the centre of innovation, thus taking advantage of the impact of technology and the results of I4.0. Presented in January 2016 as a growth strategy for Japan, the S5.0 (paradigm) aims at creating a human-centric society in which economic growth and technological development can actually be within everyone's reach. Specifically, it is the society in which I4.0 technologies are actively used in people's everyday lives, industry, healthcare, and other spheres of activity not only to seek progress and technological advancement but also to reach the wellbeing of each person (Fukuyama, 2018). Such interest in a more humanised vision of I4.0 technologies has also recently been confirmed by the European Commission, which openly expresses, in its Horizon Europe research and innovation programme, a need to incorporate more human and societal factors into the idea of a desirable digital future. Notably, while in I4.0 literature the importance of human–machine interactions is mainly restricted to manufacturing processes (Brozzi et al., 2020; Frank et al., 2019), thereby focusing on social issues related to workers (Pinzone et al., 2020), S5.0 considers the role of technology and the results of I4.0 in improving people's quality of life, social responsibility, and sustainability (Onday, 2019).

Indeed, applying new human-centric approaches and methods when developing and introducing new digital technologies is required, along with designing I4.0-enabled works (Kadir et al., 2019). If a beneficial-for-all digital transformation is built, innovative holistic approaches must be implemented. However, despite this assumption, studies addressing the problem of how to create solutions and products that can exploit the I4.0 technological potentials for the benefits of the entire society, thus embracing a Society 5.0 perspective, are lacking.

Therefore, this study aims to bridge this gap by proposing a novel approach to create and design more human–centric solutions, namely Society 5.0 solutions, capable of better integrating I4.0 technologies and human needs. Specifically, we want to understand how S5.0 solutions can be designed and implemented to benefit different publics, such as users, citizens, governments, nations, regions, industries, and organisations.

To study and design S5.0 solutions that integrate I4.0 technologies, we decided to apply a Design Thinking (DT) approach to the Quadruple and Quintuple Helix innovation framework that has been previously applied to theory, policy, and practice in the innovation and knowledge-economy literature. Because this framework assumes that innovation results from the interplay among five subsystems of knowledge, named 'helices' (University, Government, Civil Society, Industry, and Environment), it appears suitable for our purpose. Notably, by developing projects and solutions that integrate these five elements within the DT approach, we can transition towards S5.0 solutions. The proposed QH–DT framework is then explained through the narrative of a case study, the "SMARTAGE" project, which represents an application of the very same framework in the field of healthcare services. Considering that the SMARTAGE's aim is to improve socio-health and social welfare services by integrating physical and virtual spaces and deploying the opportunities created by I4.0 technologies, the case perfectly fits the Society 5.0 domain. Consequently, it allows us to show and explain how involving different actors (QH) during the entire DT process can create interactions and favour knowledge flows that can contribute to the design of S5.0 solutions.

The paper is structured as follows. We first review the literature about I4.0 and its impact on society, thus highlighting the shortages that lead to the definition of the S5.0 paradigm. Second, in the theoretical framework section, we describe the reasoning behind the development of the QH–DT model—a comprehensive framework for designing S5.0 solutions. Third, after describing the action research methodology followed for building the case study, we present the "SMARTAGE project" and its main findings. Finally, theoretical and managerial implications are discussed as well as study limitations and future research directions.

2. Literature Review

2.1. Industry 4.0: Technological dimensions

The term "I4.0" first appeared in a German strategic initiative in 2011 as part of its high-tech programme, the "High-Tech Strategy 2020". Within this document, I4.0 represents the action plan to develop cutting-edge technologies in the German manufacturing sector. Defined by Kagermann et al. (2013, p. 5) as "a new type of industrialisation," I4.0 is considered the fourth industrial revolution. If the first three industrial revolutions were the result of mechanisation, electricity, and IT, the fourth emerged with the introduction of the IoT and IoS into the manufacturing environment. Therefore, the I4.0 paradigm entails synergising interconnected physical and digital technologies able to communicate with one another throughout the entire production system, connecting resources, services, and humans in real time (Stock et al., 2018). By equipping manufacturing with sensors, actuators, and autonomous systems, I4.0 will help factories become more intelligent, flexible, and dynamic (Kamble et al., 2018). Also, operational effectiveness (Müller et al., 2018a), high-quality and customised products and services (Baber et al., 2019), increased sustainability (Müller et al., 2018b; Stock and Seliger, 2016;), open innovation (Obradović et al., 2021) developing entirely new business models (Kiel et al., 2017a; Paiola and Gebauer, 2020), are some benefits that I4.0 can bring to manufacturing companies. Different studies (Frank et al., 2019; Ghobakhloo, 2018) highlighted the design principles and defining characteristics of I4.0, such as supply chain vertical and horizontal integration, interoperability, decentralisation, modularity, customer personalisation, automation, and traceability.

However, although this new paradigm has drawn the interest of both academics and practitioners during the last eight years, consensus on the emerging technologies that fall under the I4.0 domain or its underlying principles is still lacking (Beier et al., 2020). For example, Hermann et al. (2016) identified four components of I4.0: CPSs, IoT, IoS, and the smart factory. More recent studies (Bag et al., 2018; Ghobakhloo, 2018; Tian et al., 2021) further include new technological trends that fall under the I4.0 paradigm, such as cloud computing, blockchain, big data, additive manufacturing, AI, wireless network, augmented and virtual reality, industrial robots, and smart cities. Overall, these advanced digital technological innovations collectively enable the rise of the new digital industrial technology—I4.0 (Liao et al., 2017). However, CPS, IoT, and Cloud computing seem to be the most cited technological pillars of I4.0 and also the ones that we apply in the SMARTAGE project (see Table 1).

Table 1: I4.0 technologies

I4.0 Component	Definition	Source
CPS	CPS is a collection of transformative technologies that integrate the operations of physical assets and computational capabilities, de facto bringing the physical and virtual worlds together. It encompasses different artefacts, which can perform different tasks: measuring and monitoring physical data from the system environment via sensors and actuators; processing, evaluating, and storing the acquired data to interact with the system environment; and providing various human–machine interfaces for different control options.	*Akanmu and Anumba 2015; Hoffman and Rusch, 2017, Stock et al., 2018.*

IoT	The IoT is the addition of new technologies, such as RFID (Radio-Frequency IDentification) to everyday objects, which could communicate and exchange information about their environment, context, and location. Every physical object, thanks to the IoT, may become a "smart" object whose retrieved data can benefit companies in developing new market and consumer insights, thereby improving their strategic planning and implementation. Starting from the general IoT, the terminology became varied, including the Industrial Internet of Things, Internet of Services and, Internet of People. A general IoT system can be represented by a five-layer architecture: a) sensors and actuators, b) a device, which often integrates the former layer, c) a gateway, which is sometimes referred to as a hub or hardware platform, d) a software platform, which is also called integration middleware, and e) an application.	*Ashton, 2009; Ng and Wakenshw, 2017; Sestino et al., 2020; Muller and Voigt, 2018; Conti et al., 2018, Basaure et al. 2020,*
Cloud Computing	Cloud computing is the technology that provides more reliable data management and storage processes, thus allowing full exploitation of the potential of CPS and IoT regarding data volume. Emphatically, although most computer systems lack the necessary storage capacity to manage the great amount of data generated in the newly interconnected world, cloud computing offers flexible provisioning of IT resources to solve this problem Using cloud-based software applications, web-based management dashboards, and cloud-based collaboration software, users and companies can easily receive, analyse, and interpret data from ubiquitous sensors. [B1]	*Stock et al., 2018; Hermann et al., 2016*

Source: Authors elaboration

2.2 The concept of Society 5.0

"*The design principles and technology trends of I4.0, such as horizontal and vertical integration, IIOT, IoD, CPS, interoperability, simulation, and blockchain, indicate that the fourth industrial revolution is all about IT*" (Ghobakhloo, 2018, p. 928). This sentence hides the true nature of the studies that have addressed the I4.0 domain in the last years. By focusing on production systems and their integration with increasingly sophisticated and intelligent devices, technology has always been at the centre of the I4.0 paradigm shift. However, recent studies have acknowledged the major impact of I4.0 not only on companies and business sectors but also on the environment and society at large (Bai et al., 2020; Beier et al., 2020; Jabbour et al., 2018; Müller and Voigt, 2018). For example, Ghobakhloo (2020) provided an interpretative model of how I4.0-related techno-industrial revolutions can contribute to the achievement of economic, social, and environmental sustainability. Waste reduction, increased production and productivity, manufacturing agility and flexibility, circular business model innovation, energy and resource sustainability, and social welfare enhancement are among the most cited benefits that I4.0 can bring to the Triple Bottom Line of sustainability (Khan et al., 2021; Birkel and Müller, 2021). In addition, other studies defined I4.0 as a socio-technical system in which technological, social, and organisational aspects interact (Beier et al., 2020; Davies et al., 2017), thus revealing the importance of human–machine interactions within the new manufacturing processes (Yadal et al., 2020). In these studies, the crucial social aspect of I4.0 is related to human resources and the impact that I4.0 disruptive technologies have on the labour market. While new technology could increase labour shortages, reduce human work, and allow firms and organisations to allocate human resources to higher value-added areas, the digital revolution has defined new disruptive paradigms, requiring dynamic capabilities and the acquisition of knowledge and technology from outside the organisation (Alavi and Leidner, 2001; Carayannis et al., 2018a; Cegarra-Navarro et al., 2016; Vermesan et al., 2011). Therefore, it is argued that the journey towards I4.0 and the increasing implementation of CPSs are evoking changes in human work and work organisations (Kadir et al., 2019). Indeed, I4.0 technologies may induce a progressive replacement of blue-collar workers, which will tremendously impact the societal level (Kiel et al., 2017b; Müller et al., 2018b).

Summarising, the literature on the role of I4.0 technologies in society shows the following limitations:

- The most recent literature (see Khan et al., 2021; Birkel and Müller, 2021; Yadav et al., 2020) about the impact of I4.0 on sustainability issues mostly studied the sustainable supply chain and the role of manufacturing companies in achieving the Triple Bottom Line of economic, social and environmental dimensions of sustainable development. They mainly stressed the enablers (Yadav et al., 2020) and potentials (Sharma et al., 2020) of firms' adoption of I4.0 for creating sustainable industrial value, circular economy solutions, sustainable business models, and smart cities. Consequently, although they acknowledge a broader impact (social, economic and environmental) of I4.0, they still focus on the role of companies and manufacturing firms in pursuing it. Additionally, the majority of sustainability research is conceptual in nature (Khan et al., 2021).
- Many of the studies consider social sustainability in manufacturing and production processes, thus focusing more on workplace safety and human–centric factories (Pinzone et al., 2020) rather than embracing a much broader meaning of human–centric technology issues. For instance, acknowledging the socio-technical nature of I4.0, Neumann et al. (2021) highlighted the strong focus on technology in current I4.0, which lacks attention to human factors and human–system interaction. However, when they described the importance of considering people's needs in the early stage of I4.0 technology development and systems' design, they mostly referred to workers.

- Sustainability and social aspects are not considered an integral part of the I4.0 concept, rather they are an "add-on-features" (Beier et al., 2020), a desirable outcome that is not incorporated from the beginning into the technological development process.
- Industry manufacturing digitisation can either positively or negatively impact people's quality of life (Ghobakhloo, 2020). Consequently, more holistic studies that focus on synergies between different actors, such as governments, academics, industrialists, and civil society, that can unlock the I4.0 potentials, required further consideration (Khan et al., 2021). According to Benitez et al. (2020), managing the complexity of I4.0 solutions requires an approach oriented towards the co-creation of value among a plurality of actors which constitute an innovation ecosystem. Therefore, innovation ecosystems emerged as a more suitable configuration for technology development. In this scenario, the Quintuple Helix Model (industry, government, university, environment and society) should be applied considering the necessary interplay of a well-planned I4.0 implementation strategy with innovation policies in a diffused social and institutional environment (Khan et al., 2021).

Starting from these limitations, the new model of S5.0 has emerged. Presented in the Fifth Science and Technology Basic Plan and further adopted by the Japanese Cabinet in January 2016 (Ferreira and Serpa, 2018; Salgues, 2018), S5.0 represents the growth strategy for Japan and its attempt to provide a common societal infrastructure for prosperity based on an advanced service platform. S5.0 is the response to overcome societal challenges Japan is facing nowadays, such as the rapid and increasing ageing of society, the consequent shrinking of the labour force, the depopulation of rural areas and their associated deterioration of the city's infrastructures, and depletion of natural resources (Fukuyama, 2018). However, this innovative perspective is not restricted to Japan because it shares common ground with those of the UNDP SDGs (United Nations Development Programme Sustainable Development Goals, www.undp.org). Certainly, S5.0 applies I4.0 technologies and innovation to solve human problems that affect all countries, thus enabling them to meet sustainable development goals.

These societal challenges have induced the development of the S5.0 paradigm to create a human–centric society in which economic growth and technological development can actually be within everyone's reach. Certainly, while I4.0 is mainly restricted to the manufacturing sector (Brozzi et al., 2020; Frank et al., 2019) thus focusing on production effectiveness, S5.0 considers the role of technology and the results of I4.0 in improving people's quality of life, social responsibility, and sustainability (Onday, 2019). By benefiting society at large (Ferreira and Serpa 2018), S5.0 solves social problems by integrating physical and virtual spaces. Specifically, it is the society in which the aforementioned I4.0 technologies (IoT, CPS, Cloud Computing, AI, augmented reality) are actively used in people's everyday lives, industry, healthcare, and other spheres of activity to seek progress and technological advancement, and concurrently reach the wellbeing of each person (Fukuyama, 2018). These new technologies enable the generation of accurate data, such as personal real-time physiological information, healthcare site information, treatment/infection and environmental information, which are analysable in real time by participants of the system and/or automatically solved by automatised or robotised equipment (Japan Business Federation, 2019; Potočan et al., 2020; Savaget et al., 2019; Shiroishi et al., 2018). Consequently, social care issues (promotion of social care, prevention programmes, and healthcare assistance) can be solved mostly by integrating I4.0 technology into a S5.0 paradigm.

The application of S5.0 logic is based on placing the human at the centre of innovation, thus allowing the creation of adoptable products and services for diverse individual and latent needs. Human centeredness in S5.0 translates into resolving the threat that humans can be crushed by machines and technology, since they control the progress of science and design these complex technological systems that can benefit all. However, to achieve and ensure that S5.0 implementation is not just a political-ideological concept, it is necessary to integrate several dimensions, such as innovation policy (from the government side), entrepreneurial spirit (from society's side), and entrepreneurial skills (from civil society and institutions) (Yousefikhah, 2017). Also, solving societal problems by applying new technologies can benefit from a regional orientation that can enable more applicable solutions and also increase the interests of individuals and organisations (Potočan et al., 2020).

Thus, what emerged from the literature is that integrating technology within society will be crucial in the next future. The need to broaden the understanding of I4.0 outcomes and their multiple and future potential in society (Ozdemir and Hekim, 2018; Pashek et al., 2019; Pereira et al., 2020) can be solved by integrating them into a S5.0 paradigm. However, despite this assumption, studies addressing the problem of how to effectively create solutions and products that can use the I4.0 potential for the benefits of the entire society, namely Society 5.0 solutions, are lacking. The literature about S 5.0 is still in its early stage, with most of the works addressing definitional aspects of the concept and scarce empirical studies. Also, as Beier et al. (2020) specified, the analysed literature misses complex scenarios and an in-depth analysis of what these solutions might imply for the environment when the humans remain at the centre of the innovation process.

Starting from that, the aim of this paper is to describe how to design and develop S5.0 solutions - meaning solutions that solve social problems and benefit the entire society by applying I4.0 technologies - thus highlighting the processes and the interactions behind the implementation of these complex solutions.

3. Theoretical Framework

Based on the aforementioned literature studies, to foster effective integration of technology into society from such an S5.0 perspective, we decided to adopt the theoretical framework of the QH innovation ecosystem, since we believe it represents a suitable model for our purposes and has been previously applied to theory, policy, and practice in the innovation and knowledge-economy literature. Additionally, QH has been addressed as a possible suitable model for developing innovative policies able to achieve sustainable value – economic, social, environmental, technological, organizational (Khan et al., 2021). As a matter of fact, the literature (Benitez et al., 2020) acknowledged the important role of innovation ecosystems - such as the QH- in facing the challenge of creating complex technological solutions; they indeed allow value co-creation processes among the actors involved. In doing so, new wider possibilities that go beyond technology as a product can be developed.

Moreover, by emphasising the importance of user needs and their involvement in the decision-making processes, DT has also been considered apt to guide the development of human–centred solutions, including the healthcare and digital solutions (Przybilla et al., 2020) required nowadays. Finally, we proposed combining QH with DT (QH–DT) as a new theoretical lens for the S5.0 context.

3.1 The role of the QH innovation ecosystem

The QH model (Carayannis et al., 2012; Carayannis and Campbell, 2010) was theorised as a further development of the Quadruple (Carayannis and Campbell, 2009) and Triple Helix (Etzkowitz and Leydesdorff, 2000) because it was considered necessary to add further elements to fully comprehend the complex processes of innovation in the unfolding twenty-first century. Therefore, the three helices (Academia/University, Industry, and State/Government), which were originally intertwined to develop innovation systems, were updated with two other dimensions.

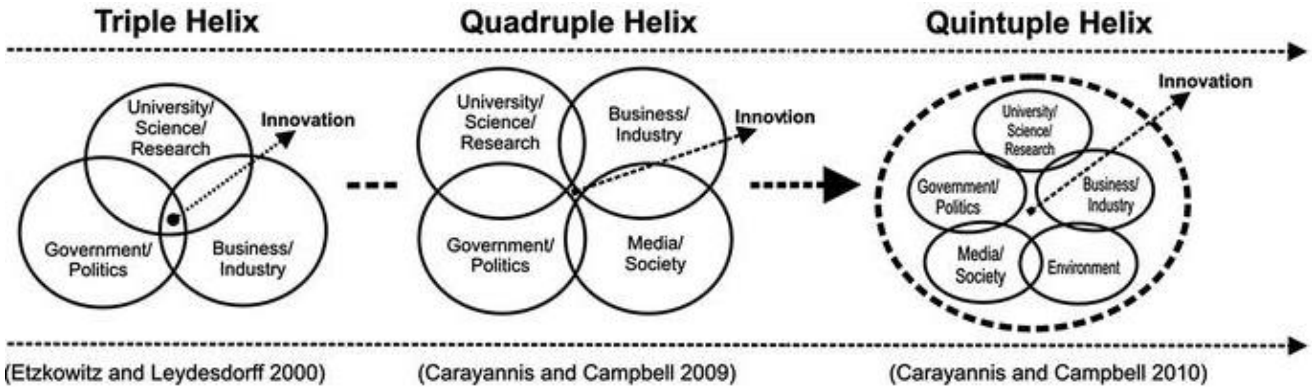
The fourth helix, “Civil Society,” was added to describe a new and more extensive way of creating and sharing knowledge and innovation. Because civil society comprises communities of stakeholders and end users, it has become a key actor in innovation processes, strongly influencing knowledge generation and technological development via its demand and user function (Carayannis and Grigoroudis, 2016).

Later, considering the need for sustainability lying in human intervention, a fifth helix, “Environment,” was introduced (Galvao et al., 2019). Consequently, the new adjusted model allows for a more effective depiction of the strong connection and interdependence characterising an innovative ecosystem by exploiting their juxtapositions.

In an S5.0 context in which it has become increasingly important to develop sustainable and human-centred (rather than technocentric) services and technologies, the QH model seems the perfect fit. Further, if the goal is to develop salient innovation for the user, the user (civil society, humans, people, and citizens) should be at the heart of the innovation process. Here, users and citizens own and drive the innovation processes, and the degree of user involvement could be defined as inclusive of "design by users" (Arnkil *et al.*, 2010). Following this perspective, by involving users and citizens early in the innovation process, innovative products, services, and solutions are developed, thereby making government, industry, and university policies and practices more effective. This can occur thanks to the bottom-up and mid-level activities of civil-society grass-roots initiatives, which make top-down university, industry, and government (UIG) policies and practices more humanised and end-user-focused. Also, for a long-term sustainable development vision for society at large, attention to specific environmental issues ensures that the aforementioned top-down, bottom-up, and mid-level policies, practices, and initiatives become readily smart, sustainable, and inclusive (Park, 2014).

In this latest version of the model, University, Industry, Government, Society, and the Environment become the subsystems of a greater and more inclusive innovation ecosystem capable of guaranteeing socially and environmentally responsible growth (Ketikidis *et al.*, 2016). Hence, the QH represents a suitable model in theory and practice for recognising the link between knowledge and innovation (Carayannis et al., 2012; Dewangan and Godse, 2014; Dziallas and Blind, 2019). In its framework, innovation is created through knowledge sharing and circulation, and this reiterated interaction generates and fuels innovation itself (Figure 1).

Figure 1: The evolution of Triple, Quadruple, and Quintuple Helix innovation ecosystem models



3.2. The DT process model

DT is an approach aimed at addressing complex innovation processes that were developed at Stanford University and then further implemented by both practitioners (Brown, 2008) and scholars (Brenner and Uebermickel, 2016). Given its capability to respond to the complexity of the current business scenario (Kolko, 2015; Waidelich, et al., 2018), interest in this method is growing in multiple fields. The founding principle of DT entails examining and solving a particular problem using an interdisciplinary team whose members are characterised by different backgrounds and types of expertise (Taratukhin et al., 2018). With DT, the concept of design, previously strictly related to physical products, has been extended to a new collaborative and iterative problem-solving approach. According to Kolko (2015), DT models are "tools for understanding" and provide "alternative ways of analysing a problem." Thus, design thinkers address a problem by adopting the end-user perspective; this user-centric approach allows team members to brainstorm and then design and develop effective and innovative solutions (Brown, 2009). Scholars agree that DT can be applied in numerous fields and sectors (Uebernickel et al., 2015). Also, according to Ferreira Martins et al. (2019), DT allows the creation of products and services that can improve people's quality of life. Therefore, adopting DT into innovative technological solutions implies that design thinkers focus more on human-centred aspects (Lockwood, 2010), such as end-users' needs and approaches to technology usage, thus not limiting them to technological ones.

Today, consensus on a standardised model is lacking despite the growing interest of DT in different fields. However, Waidelich et al. (2018), in their extensive literature review, found some commonalities in the terminology and in the model's stages. Given the nature of our case study, we adopted the process model proposed by Brown (2008), Chair of IDEO, one of the first companies that introduced DT. According to Brown, "Design thinking is a human-centred approach to innovation that draws from the designer's toolkit to integrate the people's need, the possibilities of technology, and the requirements for business success" (www.ideo.com). Then, this definition has been further suggested by Chou (2018) as suitable for innovative social entrepreneurship projects. Certainly, he identified a strong coherence between these principles and the creation of social entrepreneurship projects since these initiatives centred on introducing innovative ways of supporting disadvantaged communities. With this in mind, the actors involved in the project must be aware of the needs and problems faced by the people they intend to help. Additionally, a deep understanding of the cultural aspects and socio-economic conditions of the context appears to be necessary. Therefore, we adopted the model proposed by Chou (2018) since SMARTAGE is led by three social cooperatives whose characteristics and objectives fully reflect his description.

This specific approach comprises three macro-spaces—*inspiration*, *ideation,* and *implementation*: social problems and business opportunities emerge in the inspiration space; the ideation space comprises mainly the definition of the ideas that will be validated through tests or simulations; and the ideation space comprises mainly the definition of the ideas that will be validated through tests or simulations; and the implementation space put the designed concept into practice. It is important to highlight that the DT workflow implies a loop between spaces, particularly between the first two (Chou, 2018). Each space will be extensively described in Section 5.

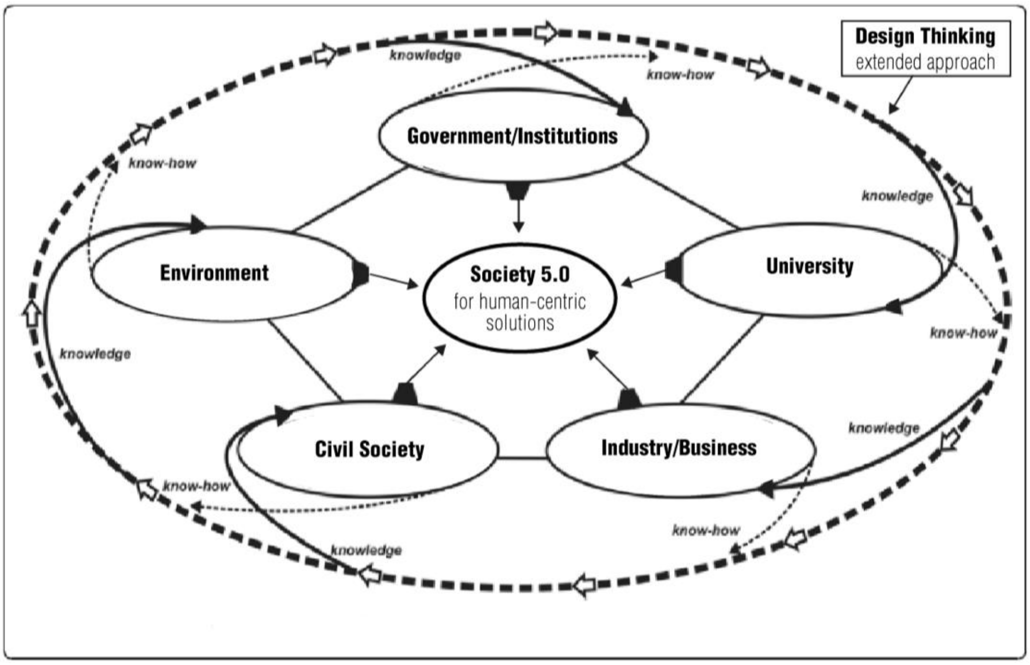
3.3 Addressing S5.0 projects through the QH framework and a DT approach

By integrating the QH framework and the DT approach, we conceived the following conceptual model (Figure 2) aimed at designing and developing new S5.0 human-centred solutions. The model can be seen as an innovative theoretical and operational toolkit capable of effectively implementing products and services from an S5.0 perspective.

Specifically, the model combines the rules of open innovation derived from a participatory and synergic DT process with the five helices involved, both individually and jointly, regarding their (eco)systemic nature. The S5.0 perspective is central to the model to benefit from the interactive propulsive thrust of the QH subsystems—Industry, Government, University, Civil Society, and the Environment (Carayannis et al. 2017; 2018b). Then, the DT approach is considered a frame, a constant superset that regulates the interaction and knowledge flow among the individual subsystems and ensures stakeholders' collective participation (Nieto and Santamaría, 2007; Oh et al., 2016; Walch and Karagiannis, 2019; Zuh et al., 2019).

Therefore, if the entire innovation process benefits from the participation and joint feedback with the five subsystems considered (as we conceived using a new QH–DT approach), then it is expected that the implemented solutions strongly impact the same five dimensions within a circular, multilateral S5.0 logic. For this purpose, the new solutions must not only be ethical, efficient, and effective but also *environmentally, socially,* and *economically* sustainable, that is, to be consistent with the triple bottom line (TBL) of sustainability (Müller et al., 2018b; Jabbour et al., 2018b; Kamble *et al.*, 2018; Khan et al., 2021) pursued by both the I4.0 and S5.0 paradigms.

Figure 2: The proposed QH–DT conceptual model



4. Methodology

As argued in the previous sections, how to design Society 5.0 solutions that, by adopting a human-centric perspective, integrate Industry 4.0 technologies and benefit the society at large, has yet to be studied. Hence, our research is exploratory in nature and requires qualitative methods to conduct an in-depth analysis and get a richer and thicker understanding of this complex phenomenon in its real-life context (Eisenhardt, 1989; Yin, 2009). As a consequence, a single case study of an Italian Smart-health project – SMARTAGE- has been purposefully (Patton, 1990) chosen to shed light on how the aforementioned QH-DT framework can be applied in the designing process of Society 5.0 solutions. As a matter of fact, this project was chosen for its revelatory potential as it offers a distinctive setting to explore the phenomenon under investigation and to gain insights that other cases would not be able to provide (Coviello and Joseph, 2012; Siggelkow, 2007). Firstly, as described in the following section, the SMARTAGE case perfectly fits the Society 5.0 depiction, since it aims to improve socio-health and social-welfare services by integrating physical and virtual spaces, thereby deploying the opportunities created by I4.0 technologies. Secondly, different actors - representing the different helices of the QH model - were involved during the entire DT process, thus providing us the opportunity for gathering insights about the innovative theoretical and operational potential of the proposed QH-DT model in implementing S5.0 solutions. Consequently, since the goal of theoretical sampling is to choose cases which are likely to replicate or extend the emergent theory (Eisenhardt, 1989), SMARTAGE appears a suitable representative case for a single case study (Yin, 2009), that was then built on the action research methodology (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009).

Case description

The SMARTAGE project is part of a 2018 funding programme (the POR FESR 2014–2020: Regional Operational Programme POR, European Regional Development Fund *FESR*) of Le Marche Region in Italy, which supported the development and the enhancement of social enterprises in the areas affected by the earthquake that hit Central Italy in 2016 and significantly damaged people, homes, and infrastructure. The funded programme must pursue the following objectives: new opportunity creation for social enterprises in the citizen services market, relationship and synergy development between social enterprises and structures operating in the health and wellbeing domain, and innovative solution testing to create products and services with performance requirements that best meet the needs of users.

Accordingly, the SMARTAGE project was conceived to solve the social issues that emerged from the combination of two important phenomena: the earthquake and the rise of the elderly population. Notably, analysing the rapid growth of the world population, the over-60 segment is experiencing the greatest increase. According to Global AgeWatch Insights, this phenomenon is mainly due to the achievable progress in the fields of healthcare and, concurrently, overall economic development. The number of people aged 60 or over is expected to reach two billion by 2050 (United Nation, 2017). Also, the phenomenon is becoming increasingly considered in Italy—the most aged country in Europe with an 18.6% seniority rate. As a matter of fact, the earthquake greatly complexified the elderly population's access to health and social services, especially because they mostly lived far away from the main urban centres, sometimes even in isolated areas. Consequently, social-assistance interventions require longer shifts, thereby affecting the frequency and effectiveness of the intervention. Also, with the COVID-19 pandemic emergence, the situation has dramatically worsened.

To solve these problems and improve the way social enterprises may deliver health assistance and services to older adults living in isolation, introducing technological innovation in the field of homecare, social inclusion, and active ageing seemed to be the right solution. From a cooperative viewpoint, new technology-driven services could have brought both benefits and challenges. While they may contribute to improving competitiveness by reducing costs and creating new market opportunities, they probably would have to acquire new skills and competences regarding the virtual spaces and the technologies adopted. Consequently, a partnership among various actors (see Table 2) that constantly intertwined and collaborated during the entire DT process was formed. However, the "environment" helix is not represented as an actor but rather as an element that needs to be taken under consideration during the entire DT process. Regarding the role of the University, the collaboration between different departments has been divided into two macro-areas: the first area concerns the design, testing, and relative release of the technological solutions; the second area, closely related to the previous one, and is focused on management, organisational, and business-related aspects. Here, the team members supported the social cooperatives in defining new business models aimed at introducing new services into their portfolio.

Table 2: Actors involved

Corresponding Helices	SMARTAGE Actors	Description
Government/ Institutions	Le Marche Region (IT)	2018 funding program (within the POR FESR 2014–2020) for supporting the development and the enhancement of social enterprises in the areas affected by the 2016 earthquake
Government/ Institutions	Municipal administrations*	Six urban centres belonging to the "crater area" of the 2016 earthquake, Italy: - Ascoli Piceno (49.209 inhabitants) - Acquasanta Terme (2.855 inhabitants) - Venarotta (2.051 inhabitants) - Force (1.212 inhabitants) - Montegallo (462 inhabitants) - Palmiano (171 inhabitants)
Industry/Business	Social Cooperative #1	As project leader, it promotes social inclusion through activities and workshops relating to vegetable garden management and the creation of handcraft products. In this perspective, the cooperatives' ideas of involving elderly volunteers is particularly relevant
Industry/Business	Social Cooperative #2	Founded in 2012, its mission is to contribute to the prevention of discomfort, the promotion of wellbeing, and social integration through the design and implementation of psychosocial, health, and educational services. The cooperative participated in the project to extend its range of services, which are already present in the region
Industry/Business	Social Cooperative #3	Since 2003, it has offered numerous social services. The cooperative collaborates with numerous professional figures. It is also embedded within an articulated institutional network
Industry/Business	Technology Provider #1	Company A

Industry/Business	Technology Provider #2	Company B
University	University Department #1	Department of Information Engineering—Faculty of Engineering—Marche Polytechnic University
University	University Department #2	Department of Industrial Engineering and Mathematical Science—Faculty of Engineering—Marche Polytechnic University
University	University Department #3	Department of Management—Faculty of Economics—Marche Polytechnic University
Civil Society	End Users	15 elderlies
Environment	–	The environment was considered a *passive actor*. If a precise interlocutor, representing the interests of the environmental system in an active DT perspective, was not referable, then the attention to the specific environmental prerogatives (2016 earthquake and COVID-19) was paid by all the actors involved.

* To complete the picture, it is appropriate to include the administrations of the municipalities of the areas involved. Their role was particularly relevant, especially in the first stages of the process for raising awareness in the local communities.
Source: Authors' elaboration

Data collection and analysis: the action research methodology

The case study was built and analysed relying on the action research methodology (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009), which involves observations, document analysis, and the direct participation of researchers. Specifically, three researchers among the authors were directly involved during the entire project, starting from the kick-off stage. Since the project under study was developed through the DT approach and witnessed the participation of numerous actors, action research represents the most suitable methodology. In fact, during action research, researchers not only observe phenomena, by overviewing the entire system of interactions among the actors involved, but they can also intervene and participate in the subject under study (Baskerville et al., 1999). In doing so, the direct participation of researchers enhances knowledge acquisition through active involvement (Ripamonti et al., 2015; Siggelkow, 2007; Yin, 2009).

The entire period of observation and direct participation lasted 14 months, from June 2019 to August 2020. Additional data—in-depth semi-structured interviews, email correspondence, and documents—were collected, codified, and analysed to better understand the entire process that induced the S5.0 solution design and triangulate the findings (Eisenhardt, 1989; Yin, 2009) (Table 3). The interviews were conducted in Italian, audio-recorded and transcribed verbatim and were based on open-ended questions within a semi-standardised protocol to ensure both guidance and consistency in the interviewing style and an adequate level of freedom in answering. The interviews primarily aimed to determine the final individual and organisational viewpoints from which the contributions of the present case could be derived.

The study development followed an iterative approach (Lofland et al., 2005) and covered the three macro-phases of the DT process implementation (Brown, 2008; Chou, 2018) that are used to develop the narrative. The direct observation of each phase allowed us to identify the context in which the SMARTAGE solutions occurred, the needs and social/technological issues to be solved, and the role of each actor involved, thus revealing the knowledge flow and the QH–DT interactive dynamics generated during the entire process.

Table 3: Summary of data source

Source	**Volume**
Direct participation at meeting (offline/online)	11 meetings; approximately 25 hours
Meeting reports	11 documents; 24 pages
SMARTAGE project documents	6 documents; 103 pages
Email correspondence	43 email with 11 different people
Face-to-face interviews	19 interviews, ranging from 30 to 90 minutes; approximately 15 hours
Other documents	two documents; 80 pages

Source: Authors elaboration

5. Designing Society 5.0 solutions: The Case of SMARTAGE Project

5.1 Inspiration: Three scenarios to solve the problems

The "inspiration" phase of the DT process witnessed the participation of all the actors involved in the project since the very beginning, when the kick-off meeting mostly dealt with understanding the guidelines provided by Le Marche Region and how to put them into practice for supporting the territories affected by the earthquake. Then, the social cooperatives, with the help of the University began to investigate the most perceived obstacles and challenges in delivering their services to the elderly population living in those areas. Specifically, the University researchers interviewed different members of social cooperatives, the elderly, and their caregivers as a sample of potential users. From this first analysis, some critical issues emerged. For instance, the need to remotely monitor the health state of cooperatives' patients, giving the cooperatives' operators the possibility to reduce the number of direct interventions in a territory where the earthquake's damages made mobility and direct intervention a critical problem. Moreover, since the cooperatives' mission goes beyond solving health-related issues to embrace a much broader role in ensuring the elderly's social inclusion, it emerged that the monitoring activity should have been applied not only in their homes but also in other environments that foster the elderly's social relationship and participation. At this point, it was clear that technology would have played a key role in resolving these issues. However, the cooperatives still had no idea how this was going to happen.

Therefore, in this stage, the University helped in shedding light on how disruptive technologies could effectively help cooperatives in designing innovative services based on totally new needs of the elderly, such as psychological and physical protection, social inclusion, and service flexibility.

After various meetings among the University representatives and social cooperatives, in which the need and the competences of the different actors converged, the team eventually ended up proposing the radical transformation of various environments, such as homes, workplaces, and public spaces, by embedding them with I4.0 technological solutions aimed at improving the life quality of the elderly. With this in mind, three scenarios of intervention were proposed and subsequently validated by the cooperatives.

—Scenario no 1: "Social Garden"

Supervised by Social Cooperative #1, it comprises monitoring the elderly while they are gardening in a shared space. Socialisation, activity level, and physiological values are the main parameters to be measured.

—Scenario no. 2: "Diurnal Centre"

Supervised by Social Cooperative #2, this scenario allows the cooperative's employees to monitor the elderly's activities into a recreation centre in which they can interact and socialise with children. Activity and socialisation levels and physiological parameters will be monitored.

—Scenario no 3: "Home Assistance"

Supervised by Social Cooperative #3, this scenario comprises non-invasive monitoring of the elderly users' behaviours in their home environment through non-contact and physiological sensors. Elderly people, living alone with an age above 65, are the target users of this solution. The monitoring will be focused on physiological, environmental, and behavioural parameters.

5.2.2 Ideation: The use cases definition

To better contextualise the aforementioned three scenarios, in the ideation phase, the team members guided by the university researchers developed three use cases identifying the potential users, the problems they might face in each scenario, and the possible solutions the cooperatives can provide through implementing the SMARTAGE platform. By considering the users' issues and needs emerged in the previous stage, the use case definition allowed the university researchers to better identify how to approach each scenario and how to design the technological setting and to select the right components. As a matter of fact, in this stage, the social cooperatives' knowledge regarding patients' needs and characteristics played a key role in defining the recurring problems they faced in everyday life. Certainly, these hypothetical use cases exemplify how social cooperatives can exploit the potential of the SMARTAGE platform to better plan and schedule its intervention, but also to introduce innovative services for local communities.

The Use Case 1—related to the first scenario—identifies Users A and B as a close-knit and dynamic couple in their seventies, who loved going out with their friends and family. Unfortunately, after the 2016 earthquakemost of their friends moved to other cities because of fear and home damage, thereby leaving Users A and B alone in the countryside. Consequently, they were eager to participate in the new social garden initiative proposed by the mayor and Social Cooperative #1, wishing to make new acquaintances while engaging in manual work. In this supposed scenario, the cooperative offers elderly people a space just outside the city, where it is possible to garden without jeopardising their health and by making them feel less lonely and isolated. Therefore, the garden is terraced at one metre of height to prevent the elderly from bending over and allowing them to converse easily while standing up and gardening. Additionally, the entire area is covered by a network of sensors to monitor the level of activity during gardening (Pietroni et al., 2016). In this use case, the SMARTAGE platform analysis helps the social cooperative's employees to constantly monitor the elderly's levels of physical activity and eventually intervene if they do something that endangers them considering their health condition. Few weeks after the opening, the User A and B couple are enthusiastic about the initiative which improves their physical and mental condition.

The Use Case 2—referring to the second scenario—has been designed for User C, who is a 73-year-old man living alone since his wife died. Seeing him alone and inactive, his son decides to enrol him in the Diurnal Centre managed by Social Cooperative #2. The goal of the Centre is to make the elderly socialise through organised activities with children. The entire Centre space is equipped with sensors and vision systems that allow the cooperative to monitor the elderly activity level to understand how they interact with children and to evaluate which of the Centre activities is the most engaging for them. Additionally, to monitor physiological parameters, the Centre provides User C with a smartwatch that he needs to wear for the entire visit time. In this use case, the SMARTAGE platform analysis allows Social Cooperative #2 to detect an increase in User C body weight—a symptom of better health—due to some specific activities with children inside the Centre. This allows the cooperative to better define the Diurnal Centre activities by selecting those that relate more to higher levels of health. Finally, after a month of his father attending the Diurnal Centre, User C's son is pleased to see his father happier and more willing to go out, thus making him grateful and satisfied with the cooperative's service.

In Use Case 3—related to the third scenario—the research team identifies User D, a 75-year-old who lives alone in his apartment a few metres away from his sons, who cannot actively take care of him all day long. Due to a stroke he had when he was 59 years old, User D had trouble walking despite the rehabilitation sessions made. Since his wife died, User D has dramatically reduced his outdoor activity, thus making his sons worried about his health. Consequently, they call Social Cooperative #3 to look after their father. In this hypothetical scenario, a network of sensors remotely controlled by Cooperatives #3 are placed in User D's home to monitor his daily activities, environmental and home salubrity parameters, and some physiological parameters (e.g., blood pressure and body weight) (Casaccia et al., 2019; 2020a). Particularly, three passive infrared (PIR) sensors are installed in the kitchen, in the bathroom, and at the entrance, plus two door sensors, one on the entrance door and one in the kitchens' cabinet medicines. After a few weeks, the social cooperative can detect some interesting insights about User D's home activity. For example, they discovered that he had never opened the door for three days straight since nobody visited him, and he lost weight and the house's comfort level decreased. By collecting and analysing this data, the SMARTAGE platform in this use case allows the cooperative to plan a new schedule to look after the User D. They decide to visit him twice a week, to call him every morning, and thus invite his sons to visit him more often. After two months of following the scheduled activities, User D starts to go out more frequently and gain weight, thereby improving his comfort at home.

Alongside the definition of the use case, a technology scouting process was performed by the University team members and two different technology providers. The interface between them occurred in two aspects: the use cases' technical and financial feasibility; the definition of the most suitable technological configuration of each use case, considering different users' and environments' characteristics.

5.2.*3 Implementation: The human-centric integrated platform*

In this last phase, guided by the designed scenario and the layout of each use case, the team members started to effectively implement the SMARTAGE platform, thus focusing on integrated and interconnected solutions. Certainly, the research team, guided in this phase by the researchers of the engineering department, agreed to develop an open Cloud Infrastructure that can easily communicate with third party actors. Consequently, in selecting the applicable devices in each scenario, the research team considered their functionalities and technical features and concurrently another important manufacturer's capability—the possibility of acquiring and then integrating remote sensor data within a cloud infrastructure by providing, for example, APIs that third-party developers can use to extend programmes, applications, and platforms. Indeed, the ability to read data from interconnected devices allows the SMARTAGE Cloud to better analyse and then display the results. Furthermore, the interconnection level was designed in a modular way so that multiple devices and data analysis algorithms can be added to make the Cloud architecture readily adaptable to the environment and user needs. For the multi-source data analysis from both wearable and non-wearable sensors, the team members chose to implement machine learning (ML) to identify and extract features within the database of the generated data (Casaccia et al., 2018; Casaccia et al., 2020b; Monteriù et al., 2018; Scalise et al., 2016). Unlike traditional algorithms, ML allows for managing sparse data metrics, avoiding deleting data, and imputing median values.

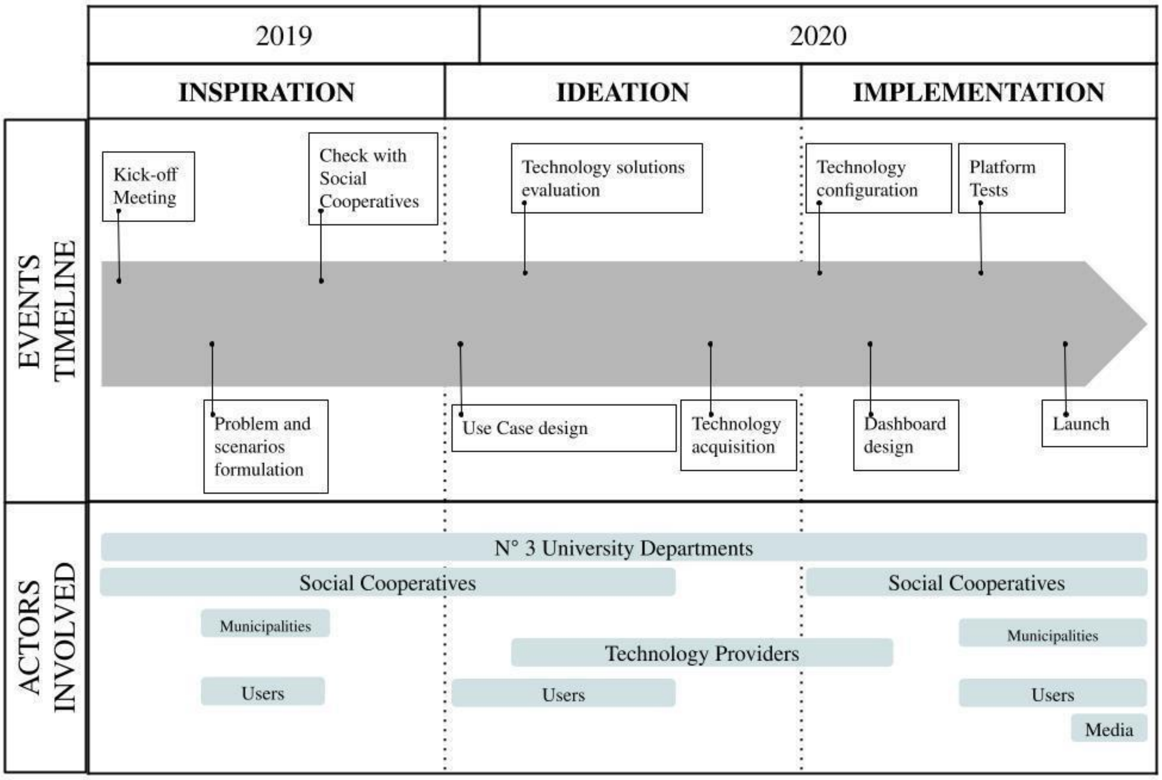
At the same time, a research was conducted on the target users who, as early adopters, would be the first to test the implemented solutions. Furthermore, their direct involvement was also necessary to test the usability level of the user interface. The early adopters engaged in this phase were identified through an open call delivered through the official communication channels of the local government (municipalities).

Today, the SMARTAGE Cloud platform and the ad-hoc developed dashboard allow both parties (the cooperatives and the elderly's families) to easily access and manage useful medical information about the patient, previously acquired through the sensors. Consequently, it becomes easier not only for the cooperatives but also for the families to decide whether and how to intervene in the elderly's activities.

Finally, it is important to highlight that the entire DT process concerning the SMARTAGE project has been profoundly marked by the advent of COVID-19. However, thanks to the iterative nature of the DT process, it was possible to add new features to the project (such as body temperature, blood saturation, and social distancing sensors), which allowed us to tackle new and urgent needs faced by both cooperatives and elderly people due to the pandemic. As regards the environment aiming at fostering elderly social inclusion and interactions the anti-Covid-19 regulations were introduced, therefore, accesses were limited, and social distance maintained. From this point of view, the use case that presented the most critical issues was the scenario of "Diurnal Center" (no.2) in which users would interact in a closed place. Consequently, in the implementation phase, the team initially focused on developing the other two use cases - the no. 1 scenario of "Social Garden") and the no. 3 of "Home Assistance", thus postponing the implementation phase of the Diurnal Center.

To better display the results, the entire project flow timeline and the related involvement of the actors are illustrated in Figure 3.

Figure 3: the SMARTAGE project workflow



6. Discussion

Despite the nature of the single case study generates findings that may not be generalizable to all kinds of settings, the use of the SMARTAGE case provides in-depth and rich data about the phenomenon investigated.

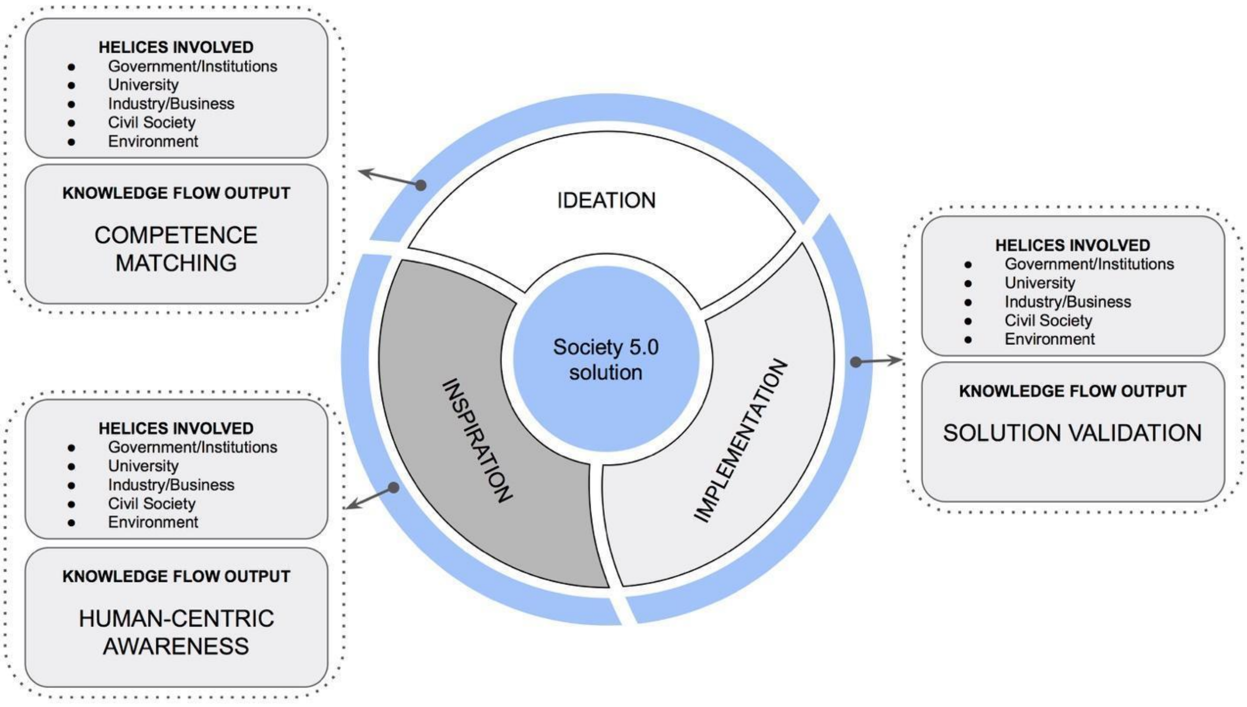
As emerged from the findings, the SMARTAGE project was conducted from the beginning through interactions, cooperation, and knowledge flow among different helices (Carayannis et al. 2017; 2018b) (Figure 4). Consequently, it appears that by following the proposed QH-DT approach it is possible to design and implement S.5.0 solutions which are human-centric.

Specifically, the findings revealed the important role of DT as a frame, a constant superset that regulates the interaction among the individual subsystems, ensures stakeholders' collective participation in various capacities, and contributes to feeding the circuit of knowledge creation and sharing (Nieto and Santamaría, 2007; Oh et al., 2016; Walch and Karagiannis, 2019; Zuh et al., 2019). For example, if the *government-institution* subsystem provides the lines of regulatory intervention concerning the *environmental context* (administration of the territories affected by the earthquake and regulations for security measures regarding the COVID-19 pandemic), the *social cooperatives* contribute to the knowledge flow by sharing their long experience and the related competencies in the field of healthcare and social services for the elderly. Nonetheless, the social cooperatives lack the professional background to fully understand the potential impact that I4.0 technologies can bring to their business. In this sense, a crucial role was played by the *university* whose team acted as a bridge between the cooperatives and the *technology providers*, thus allowing the design of a solution that considers both perspectives—social cooperatives' needs and issues from one side and technological constraints from the other (Bai et al. 2020; Jabbour et al., 2018).

Additionally, the findings also confirm the fact that in a S5.0 context in which sustainable and human-centric (rather than technocentric) services and technologies are becoming more and more important, the user (civil society, humans, people, and citizens) should be at the heart of the entire innovation process. Consistent with Arnkil et al., 2010, the users' involvement, especially during the design of the user interface, was pivotal for the success of the entire QH–DT process. For example, only by considering the needs of the elderly and the knowledge and experience of the social cooperatives, the development team could define the three use cases and design the right solutions for them. This is in line with DT's founding principle, which entails the process of examining and solving a specific problem by an interdisciplinary team, whose members are characterised by their various backgrounds and types of expertise (Taratukhin et al., 2018). Furthermore, to promote the launch of the SMARTAGE project and highlight the importance of the new services implemented the *media* were involved, thus supporting the dissemination of the first results, and increasing the reach of the initiative among potential users.

Figure 4 summarizes what we have just discussed by highlighting the process, the main stages, and most relevant knowledge flow outputs that occur in applying a QH-DT model for the design of S.5.0 solutions. As illustrated in the diagram, the DT allowed the actors involved (QH) to contribute both directly and indirectly to the project by ensuring a continuous flow of knowledge made by know-how and experience spillovers among the parties involved.

Figure 4: The QH-DT model in action for Society 5.0 solutions



In particular, in the first DT phase (Inspiration), the knowledge flow contributes to increase the awareness of all actors about the research context and the issues faced by the elderly, cooperatives and municipalities, thus aligning all the subjects regarding the need to adopt a human-centric perspective. Afterwards, the second phase (Ideation) entails the competence matching between the actors involved. As stated before, the continuous knowledge flow among actors allowed the integration of different skills and competences. For example, during this phase the technological and managerial expertise brought by the different University departments matches with the cooperatives' knowledge and expertise in the social field. Finally, in the third and last phase (Implementation), the flow was translated into a feedback system between the parties aimed at validating the solution in terms of technical feasibility, market opportunities, and usability by both operators and end users.

7. Theoretical implication

Analysing the SMARTAGE project case allows us to generate some theoretical implications about the ever-important paradigm of S5.0, thereby highlighting how to design and manage complex Society 5.0 solutions, capable of exploiting the potential of I4.0 technologies to solve important social issues. SMARTAGE was indeed born with the aim of solving social problems faced by cooperatives and municipalities in an area which was struggling with the rise of the elderly population hit by a severe earthquake through the implementation of I4.0 technologies. Theoretically, by identifying an innovative framework suitable for effectively responding to the implementation requirements of new healthcare products and services, this paper contributes to the Society 5.0 literature in different ways.

First of all, this study is one of the first attempts to bring S5.0 research beyond its definitional aspects, thus providing an empirical contribution on how to create solutions that can fit the Society 5.0 domain. As a matter of fact, despite the literature (e.g., Ghobakhloo, 2020; Pinzone et al., 2020; Beier et al., 2020) call for studies regarding the Society 5.0 paradigm to overcome some shortages about the role of I4.0 technologies in society, little has been done so far. Consequently, this study is a first attempt to explain how important social problems can be solved by integrating I4.0 technologies via a practical case analysis (see Beier et al., 2020; Khan et al., 2021). Particularly, by following a step-by-step DT approach (Chou, 2018), the narrative showed how it became possible to define and design more human-centric products and services capable of benefiting various publics, such as users and citizens (the elderly and their related communities), governments and regions (Le Marche Region and the six cities involved), industries and organisations (the social cooperatives, the technology providers and the healthcare industry), universities (Università Politecnica delle Marche), and the environment. This allows us to answer recent calls (Khan et al., 2021; Benitez et al., 2020) on more holistic studies focusing on the synergies between different actors in order to unlock I4.0 potentials in fostering social, economic and environmental value. Additionally, we confirm the importance of the role of innovation ecosystems in addressing the complexity of technological solutions (Benitez et al. 2020). Indeed, the SMARTAGE innovation ecosystem fostered a value co-creation process among the helices involved; process that was able to contextualize I4.0 technologies within wider innovative solutions.

Another noteworthy contribution from a S5.0 perspective, is the importance of a regional orientation (Potočan et al., 2020) in developing these kinds of solutions. As emerged from the narrative, the regional orientation of the entire project helped to build more applicable solutions and support more human-oriented development by increasing the interests of all the actors in participating in the project. Particularly, the local population, the social cooperatives and the municipalities were the utmost invested in contributing to the project, since they experienced first-hand the pressure of the social issues emerging first from the earthquake and then from the pandemic. In line with Keidanren (2016) and Potočan et al. (2020), SMARTAGE confirms how the ability of different actors to solve social problems of individuals in the local environment is one of the most important aspects in developing S 5.0 solutions. Moreover, the SMARTAGE project confirms the need to integrate innovation policy (from the government side), entrepreneurial spirit (from society side), and entrepreneurial skills (from civil society and institutions) in developing S5.0 solutions (Yousefikhah, 2017), ensuring that its implementation is not just a political-ideological concept, but something achievable and effective.

Additionally, the paper contributes to the DT and QH literature by unravelling their importance in the development of human–centric solutions (see Przybilla et al., 2020; Nieto and Santamaría, 2007; Carayannis et al. 2017). Notably, the discussion of the narratives allowed us to identify the knowledge flows that resulted from the interaction among the different actors involved during the entire DT process. In doing so, we confirm the fact that innovation is created through knowledge sharing and circulation, and this reiterated interaction generates and fuels innovation itself (Carayannis et al., 2012; Dewangan and Godse, 2014; Dziallas and Blind, 2019).

Specifically, by framing the conceptual model according to the stages of DT, we extend the theoretical understanding of the QH literature providing a new possible helices configuration suitable for the S5.0 paradigm. This was possible by observing the knowledge flow generated among the actors involved during the entire innovation process. In doing so, the case findings allow us to stress the link between knowledge and innovation (Carayannins and Campbell, 2010), as both *knowledge creation* and *production* and *knowledge application, diffusion and use* took place in the same environment. In this regard, Carayannis and Campbell (2009, p. 225) already highlighted the importance of a "knowledge swing" and of a cross-communication between helices. This study enriches their findings by identifying different forms of knowledge flow output that are crucial for designing S.50 solutions. Finally, by concentrating on how to create solutions that can fit the S 5.0 domain, the present study may eventually help to overcome some of the emerging key shortages about the social impact of I4.0 technologies (Ghobakhloo, 2020; Neumann et al., 2021; Khan et al., 2021) and confirm once again the need to embrace a S5.0 domain. Firstly, unlike other studies (Brozzi et al., 2020; Frank et al., 2019), by focusing on healthcare services, it takes the social impact that I4.0 technologies may have outside the production and manufacturing domains, thus unravelling its potential in other sectors. In doing so, we enrich the current literature by embracing a much broader meaning of human-centric technology that goes beyond workplace safety and human-centric factories issues (Pinzone et al., 2020). Additionally, the SMARTAGE project is based on the interplay of different actors which are equally important in the design process of human-centric solutions thanks to knowledge flows and spillovers created among them. Consequently, even if the role of Industry (technological providers and social cooperatives) is crucial for the success of the initiative, we highlight the importance of each helix thus overcoming the narrow focus of firms' adoption of I4.0 for creating sustainable value (Yadav et al., 2020; Birkel and Müller, 2021).

Finally, the study findings expand and broaden the meaning and importance of designing human-centric technologies capable of benefiting the society at large by integrating users' needs from the beginning of the entire technological development process and do not consider the social impact as a technology's add-on features (Beier et al., 2020).

8. Managerial implications

From a managerial viewpoint, the SMARTAGE narrative could provide useful implications to different audiences. First of all, the discussed results could provide policymakers with valuable guidance on how to design and implement social care solutions to address important and urgent issues, such as the elderly's isolation caused by natural disasters. Consequently, they should fund projects featuring the active participation and commitment of different actors and their respective subsystems, including those who will be the end users to develop new products and services (or even new production models), which can be considered S5.0. Additionally, this work has implications even for those directly involved in the design and implementation of S5.0 solutions. They should therefore develop these solutions by considering that different forms of knowledge (technological, industry-based, user-based, and market-based) should circulate during the entire workflow, thus creating a spillover effect, which allows each project members to properly assimilate them. Furthermore, creating an inclusive work environment characterised by listening and contamination should be encouraged. Therefore, the study demonstrates that those participating in this type of project should address this issue by combining their viewpoints with an external perspective.

Further, the paper confirms the vital role of technology in designing Society 5.0 solutions; it shows how to use technologies, such as wearable and non-wearable sensors, ML, and cloud architectures, to improve the way cooperatives and governments serve elderly people in their everyday lives, This is possible by monitoring not only their health systems but also their social activities and interactions, thus offering cooperatives huge amounts of data with which to sustainably improve quality of life and social responsibility. Also, these human-centric technology solutions in healthcare seemed to represent a valuable opportunity to solve the problems and issues caused by the global COVID-19 pandemic: sensors could grant the monitoring of elderly people remotely by constantly reporting their health state and preventing them from going out for a medical visit in case of symptoms. In the use cases proposed, these innovative solutions will allow cooperatives to maintain social distancing without creating social alienation.

For the reasons above, the SMARTAGE project allowed us to highlight the potential dynamic nature of a QH–DT approach when developing S5.0 solutions. By integrating and interacting the five helices during the entire design process, the team could adapt the innovative solutions to the actual user needs and develop services that are compliant with the recent health regulations provided by the Italian Government.

9. Conclusion

In a global scenario recently characterised by different challenges, it appears mandatory to understand how I.4.0 technologies could benefit the entire society. Therefore, starting from the need to overcome some I.4.0 shortages, this study recognizes the ever increasing importance of the Society 5.0 paradigm, thus explaining how to design more human–centric solutions, capable of better integrating the I4.0 technologies and human needs. To achieve this, we first defined a new conceptual framework that combined the QH innovation ecosystem model and the DT process. This seems to be a suitable approach because it allowed the actors of the five helices to cooperate in a systematic way, fulfilling the different needs and favouring the circulation of dissimilar knowledge and skills. Then, a practical application of the proposed model in the field of healthcare service was presented. By applying action research, we developed the SMARTAGE case, describing how the QH–DT approach can help all the actors involved to design and develop S5.0 inclusive solutions. The findings showed how it was possible to provide technological solutions that meet the needs and expectations of different actors, perfectly in line with the S5.0 paradigm.

Obviously, the study has certain limitations which suggest various opportunities for future research. First of all, it is an explorative study that relies on a single case – the SMARTAGE project – and on a specific field of application – the healthcare industry and the emergencies deriving from the administration of areas affected by earthquakes and the current pandemic context. Hence, the methodology may limit the generalizability of the observations to other companies and industries. Notably, even though generalizability is not the aim of the study - like the majority of qualitative research (Strauss and Corbin, 1998) - future researches could apply the QH-DT model proposed in this study to prove its effectiveness also in other industries and contexts. In doing so, the validity and representativeness of the QH-DT model proposed will eventually improve.

Besides, the study suffers from the emergence of the COVID-19 pandemic which inevitably implied changes during the entire DT process. Although the proposed model shows a great flexibility and versatility allowing the actors involved to react and adjust their solutions to the new issues faced by the local population during the pandemic, it could be interesting to investigate other situations dealing with the pandemic since the initiation phase.

Furthermore, the feedback provided by the actors of the five helices could be extended even more, involving new social aggregates and communities, along with new businesses, universities, and institutional partnerships, to build new social infrastructures and social innovation ecosystems.

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Highlights

- The adoption of I4.0 technologies with a S5.0 perspective can lead to new human-centric solutions.
- A Quintuple Helix-Design Thinking model is proposed for implementing S5.0 solutions.
- The SMARTAGE project represents the first practical application of the QH-DT model.
- The QH-DT model was found to be potentially suitable for other S5.0 contexts.