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Study and development of an algorithm for the identification of products-services tailored to seniors' clinical and social needs for the prevention of acute events

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To my beloved granny Ornella,
for teaching me the meaning of
"looking after".

I. Acknowledgments

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1 Introduction

The challenges ahead for the health and social care services are enormous and without precedents. The world population is rapidly ageing more quickly than in the past and this will have profound consequences and implications for the care systems. From 2020 to 2050, the proportion of people aged 65 years or more in the world will nearly double (from 9% to 16%). This highlights health and care needs issues.

Longer life is certainly one of the most modern remarkable collective achievements, which reflects advances in social, economic, as well as health developments, and for this reason it's also an incredibly valuable resource. However, good health is what makes the difference in these extra years of life and the opportunities that arise from increasing longevity depend strongly on Active Ageing concept.

Active Ageing is developing and maintaining the functional ability that enables well-being in older age. This is, as a first step, the response to the health needs of older people and includes supportive policies, plans, and regulatory frameworks. Active ageing is relevant to everyone, and not just to those who are free of disease: this will require a shift in focus from considering health as the absence of disease, to the use of the intrinsic capacities of the individual to do what values. Concerted and sustained actions to improve Active Ageing will be needed at multiple levels and in multiple sectors to prevent disease, promote health, maintain and enable the functional abilities.

To face the increasing demands for health care by the growing number of older adults, the fragmented care system should be replaced by a person-centred integrated care, that requires a comprehensive assessment of the health and social needs of the older people, and that engages every individual in the community, included the elderly person, in the healthcare management.

The information and communication technologies (ICTs) will help health and social care services to deliver personalised integrated care to older people, as they offer much promise to improve access, quality, safety of health, and cost-effectiveness of services.

In particular, ICTs can be used to monitor, evaluate, and plan care to improve the quality of life of the older people. They are exactly becoming the first target users of this new approach, since they are more prone than other population groups to be affected by multimorbidity (e.g., the presence of multiple chronic conditions at the same time), situation that requires continuous care and monitoring.

Based on this evidence, many studies have explored the adoption of these encouraging solutions in the various settings of the healthcare context and in various applications. Among them, the SMART VILLAGE project, which is the backdrop of the present work. The project develops and implements a new home and personalised social and healthcare assistance model, directed to elderly people. Main objective is to prevent acute events, favour elderly staying at their own home (thus reducing hospitalizations) and make them active and independent in their countries. These areas belong to the seismic crater of the Central Italy (Fermo and Macerata provinces), and thus secondary objective is to contrast the increasing depopulation phenomenon by revitalizing these territories with improved and more accessible services. The core of the SMART VILLAGE project is the Smart Village platform which guides the social and medical operator in the analysis of the physical-cognitive characteristics of the patient as well as his/her social context, to identify the best set of products and services to assist him/her in the daily life. Then, the platform, connected to the digital devices, will inform doctor, formal caregiver, and family members about clinical parameters or behavioural patterns out of range to allow prompt interventions and to prevent the onset of acute events.

In this context, the aim of the present work is to study and develop an automatic algorithm for the identification and assignment of products and services, tailored to seniors' social and clinical needs. The case study was carried out on a target population of 50 participants over 75 years old (mean age 83 year old, exclusion criteria: cognitive and mobility impairments) recruited from the SMART VILLAGE project. Data for the algorithm involve a combination of self-reported, sensors- and questionnaires-based information from multidimensional sessions of screening to explore the multifactorial nature of the frailty condition.

Motor-function, cardiological-cardiovascular, nutritional, psychological, and social domains are investigated.

These input data, after processing and cleaning in Excel, are used to feed a decision tree-like algorithm designed to match, by means of conditional control statements, the specific characteristics of the patient's profile and his inclination to the technology (boundary condition) as well as the technical features of the devices, and to generate as output the best personalised set of products and services for that patient. Then, the algorithm is implemented in Visual Basic for Application (VBA) to translate the decisional model into code language.

The result of the implementation is exactly a set of products and services suggested for each participant of the study. First of all, the results give information about patients candidate to a fall and/or a cardiac monitoring. Validation by comparison with the clinical evaluation generated by the specialists occur. To assess the validity of the algorithm detection statistical analysis is conducted and to quantify its performances sensitivity and specificity parameters are calculated. High sensitivity and good specificity are measured in both cases, meaning that overall people who presents conditions for which a monitoring is required are accurately identified.

Following these findings, also a discussion about the type and features of assigned devices and services is proposed.

The main study objective has been achieved and the algorithm presents as a valid and robust decisional method to perform quick and automatic identification of products-services set personalised to the individual characteristics.

2 State of the art

2.1 Population ageing

In all countries around the world, both the proportion and absolute numbers of older people in the populations are increasing dramatically, and population ageing becomes one of the greatest challenges for now and the future years.

Consequently, ageing is emerging as a key issue for policies and programmes development as a measure to help older people remain healthy and active.

2.1.1 The changing demographic context

The world population is ageing, and people worldwide are living longer and, for the first time in history, can expect to reach their sixties and beyond, according to World Health Organization (WHO) [1].

Throughout the world, virtually every country is experiencing increasing in population ageing, which makes it a global phenomenon. These changes in population age structure started in more developed regions (Europe, Northern America, Australia, New Zealand, and Japan) where at present the population is already significantly older than in other parts of the world. But it is now less developed regions (Africa, Asia, and Latin America) that are experiencing the greatest and fastest increase of older population. In these low- and middle-income countries, this is the result of a large reduction in rate of infant mortality, infection, and disease-related mortality. In high-income countries, two processes contribute to this demographic transformation: the continuous increasing in life expectancy (longevity) on one side, which means a drastic reduction of the mortality among those who are older, and the counterposed decreasing in birth rate (natality) on the other side.

Population ageing concerns with a growth both in the size and number of older persons in the population, as United Nations (UN) report [2].

There were 703 million persons aged 65 years and over in the world in 2019, but this will double to 1.5 billion in 2050. In particular, the number of people aged 80 years or older is expected to triple between 2020 and 2050 and to reach 426 million. Globally, the percentage of the population aged 65 years or over increased from 6% in 1990 to 9% in 2019. And this proportion is projected to rise further to 16% by 2050, so that one in six people in the world will be aged 65 or over. This dynamic of population ageing reflects the above-mentioned improvement in life expectancy: a person aged 65 could expect to live additional 17 years in 2015-2020 and an additional 19 years by 2045-2050.

Similar trend is observed in Europe (EU-27), in which at the beginning of 2019 there were 90.5 million older people (those aged 65 years or more), which correspond approximately to one fifth (20.3%) of the total population. This number is expected to increase, and by 2050 there will be 129.8 million older people (29.4%), as revealed by Eurostat data [3]. Interestingly older people, in general, prefer to live in rural or intermediate regions than in urban regions, which may not guarantee services and basic needs, such as health, care, transport and may be problematic for those who need assistance because of reduced mobility, presence of morbidity or solitude.

Even Italy is experiencing a fast ageing of its population: Istat reports that to date the 65-and-older population represents the 23.2% of the total population and by 2050 this number would grow to the 35%, corresponding to an old-to-young people ratio of about 3:1 [4]. Figure 2.1 graphically presents and compares ageing phenomenon in EU-27 and Italy: this projection highlights that people aged 65 and over in Italy will increase more with respect mean European trend, in the same period which goes from 2020 to 2050.

2.1.2 Ageing and health

Longevity is a conquest in itself and this process of demographic ageing may be considered a success without precedent in human story. But these demographic changes have important implications not only for the individual and his family, but also for the economy, the society, the healthcare, and prevention systems.

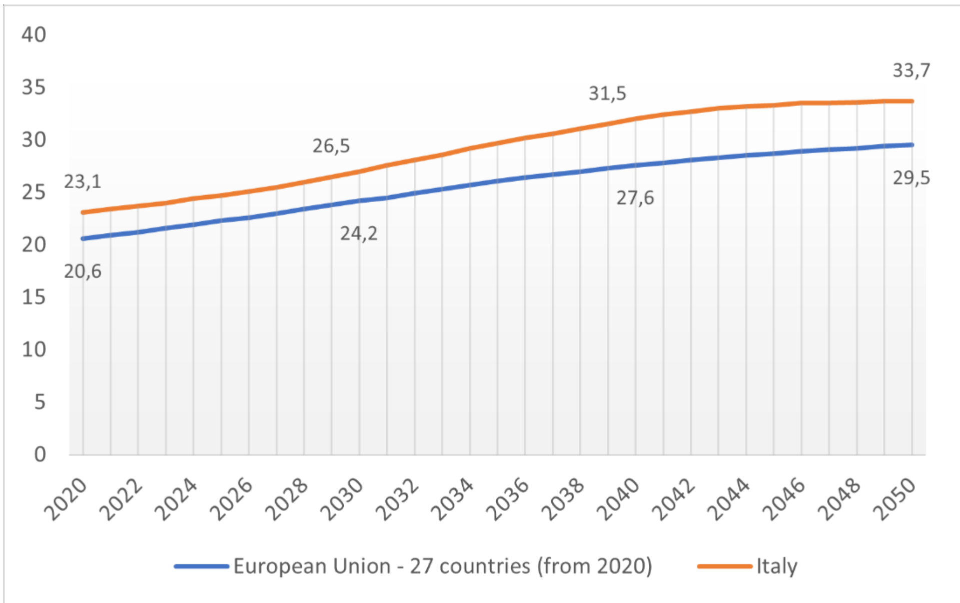

Figure 2.1 Projection people aged ≥ 65 years, 2020-2050. X-axis is the selected time period (year), while y-axis is the mean proportion value (%) of older people with respect the total population (blue: EU-27, orange: Italy). Source: Eurostat online data

In fact, older people represent a human and social resource, because they are involved in many social contexts and activities in the family, the community, and the society.

The opportunities connected to population ageing, however, are strictly dependant on one key element: the health. In its constitution, WHO affirms the basic principle that looks at health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [5]. This definition highlights that being healthy is not only determined by the absence of disease, even though it may represent an important contributor. Instead, health should be separated into the three main domains physical, mental, and social well-being, that all together build the path to better health.

If good health certainly adds life to years, the opposite is not always true, and longer life is not necessarily accompanied by better health. So how well people age depends on many factors.

Some of these are inevitably related to the biological nature of the ageing phenomenon, which causes changes at molecular and cellular levels that lead to a gradual decline in physical and mental capacities and to an increasing risk of diseases.

But a very important role is also played by behaviours and lifestyle choices people take throughout their entire life. These include, for example, what they eat, how physically active they are and how much they are exposed to risks of smoking, alcohol consumption or other toxic substances like air pollution.

The picture of ageing which results from these considerations is that of a long and complex process that starts from the first years of life, continues during early and late adulthood until the old age. So ageing is not an arrival point, but concerns all the people, whether young or old.

Depending on how old people experience their extra years, they can impact on the society in different ways: if they are in good health, age doesn't not limit their activities and participation and they are free to do things they value; but if these added years are predominantly affected by reduced functional and mental abilities, the effects for older people and the society may be much more negative. For example, older people with health problems may require other family member, usually a woman, to renounce to their work or activities in order to provide them with support and assistance.

2.1.3 Human rights of older persons

To address the challenges resulting from this demographic transformation, a healthy ageing strategy has been proposed. In 2002 WHO laid the foundations for the modern concept of Active Ageing by approving an international legal and policy framework, contained in two reference documents [6] and motivated to respond to the numerous questions the population ageing phenomenon raised. In fact, right from the beginning, the Political Declaration promulgated in that occasion explained its intent "to respond to the opportunities and challenges of population ageing in the 21st century and to promote the development of a society for all ages" (Article 1).

The idea at the base is as simple as fundamental: every life has equal value and human rights do not diminish with age.So age should not be a limit and the society should enable older people to fully enjoy their age, providing guidance in the areas of independence, participation, care, self-fulfilment and dignity, and eliminating all forms of preconception, discrimination, neglect and abuse (ageism). For this reason, since 2002 policies on ageing have been developed at national and international levels, to encourage concrete actions and positive changes in social, economic and health sectors, and to pursue the ultimate goal of equality for persons of all ages.

Specific policies should focus on the promotion of a healthy lifestyle across the life-course, on the creation of age-friendly environments that protect and favour participation of older people in family and community life and, on the easy accessibility to basic primary and long-term cares. Everybody – from politicians and city leaders, passing through healthcare and social assistance providers, arriving to older people, their caregivers and family - is called to take an active part in this collective action, that claims good health (physical, mental, and social well-being) as the essential element for a good and independent life in the old age.

2.2 Digital transformation of care

In the middle to long term period, the projected growth in the number of older people will inevitably pose an increasing demand for care and protection that, if not adequately addressed, can undermine the stability of social and economic structure of countries.

An important help comes certainly from the digital world and in particular from the information and communication technologies (ICTs) whose integration in the social and health care domains offers the possibility to convert the traditional care model into a more efficient, proactive and patient-centred system.

The solution is not simply based on adopting such technologies (eHealth) but involves a strict and profound collaboration and interchange of information between patient, who has a starring role, carers, and providers of technologies.

This digital transformation of the health care sector is direct consequence of the new industrial revolution that is affecting currently European and non-European countries in the world. Since in the chronological history of industrial revolutions this is considered to be the fourth, it is called Industry 4.0 revolution. This term was adopted for the first time in Germany, indicating a global and rapid transformation of the whole industrial sector (design, manufacturing, processes, and services) through the use of digital technology and Internet that transform the traditional industry into automated and interconnected one.

Above all, Industry 4.0 stands out by its multidisciplinary nature in which a wide range of new technologies, closely interrelated each other, combines and merges the physical and the digital worlds together, as presented in [7, 8]. Some of the most relevant technological developments, named ICTs paradigms or characteristics, that make Industry 4.0 a reality include Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and Analytics, Cloud and Fog Computing, Augmented Reality, Artificial Intelligence (AI), and Robotics. Obviously, the progresses of Internet infrastructure are at the base of Industry 4.0 and essential to allow global communication and interaction between distributed entities (both humans and machines).

Industry 4.0, making full use of these technological paradigms and combining them into a new level of organization and control, is able to extensively achieve digitalization, automation, and data exchange, that lead to more efficient and less costly processes, that is finally one of the main purposes of industry.

2.2.1 The concept of Healthcare 4.0

The potential of the intelligent ICTs allows extension of Industry 4.0 concepts and tools beyond the boundaries of industrial sector to a variety of additional others, such as health and social care services, to respond to the increasing needs of the populations.

This new vision that contaminates the healthcare sector initiates the Healthcare 4.0 revolution, in analogy with the definition of Industry 4.0 and from which it takes inspiration to find new and more efficient solutions both for economic, social and care aspects in health domain, as discussed in [9].

The new opportunities provided by these advanced technological progresses aim to improve the medical and social services while reducing the healthcare cost, which is rising because of constant population growth and ageing. This can be made possible also by the spread and availability, without precedent, of wireless connectivity and mobile devices, that become suitable for all, independently from the membership social and economic class.

Among all the ICTs paradigms that characterise Industry 4.0, some have a crucial role in supporting healthcare and here they found fertile soil for novel applications and scenarios, according to the classification proposed by [10, 11]. In particular, three disruptive enablers establish themselves as the fundamental pillars in the framework of Healthcare 4.0 for their importance: IoT, Cloud Computing and Big Data, as explored in [12].

The term IoT refers to the process of connecting everyday physical objects and places at Internet, creating an interconnected network of smart "things" with specific properties and functionalities that communicate and cooperate with each other and with humans.

Devices, machines, systems, implants elevate to smart objects and acquire a digital identity that confer them an active role in collecting, transferring, receiving, and elaborating data and information thanks to the network connection.

Therefore, IoT operates technically across four different logical layers, arranged according to a pyramidal structure: (i) perception layer, made up of variety of smart objects such as mobile phones, sensors, and actuators; (ii) transmission layer, conveying sensed information to the upper layers (digital communication infrastructures); (iii) computation layer, deputed to processing data and taking decisions (Cloud Computing and Big data); (iv) application layer, for high-level goals, such as healthcare, home automation, transport, manufacturing, etc…

Currently, the concept of IoT has been extended and declined in different ways to emphasise peculiarities related to health and social care sectors: thus, new terms as Wearable Internet of Things (WIoT), Internet of Medical Things (IoMT) and Internet of Health Things (IoHT) have been coined and rapidly became popular. Apart from the taxonomy, they all express the interconnection of medical devices and their integration to a wider network with the aim to collect and analyse larger volumes of patient's data to improve patient's health.

The basic architecture of this technological infrastructure includes three elements, as presented in [13]. Wearable Body Area Sensors (WBAS) are prominent components responsible of sensing, computing, and communicating patient's data to allow monitoring of human factors and enhance patient's quality of life in terms of health, wellness, and behaviours. Then, WBAS are not standalone systems, but on the contrary, they transmit their data to paired devices such as smartphones, tablets, computers or remotely located cloud computing servers, for storage, further analysis, and decision support. These close companion devices, acting as gateway devices, require communication standards and protocols to transmit relevant data and exchange information with the other devices: Bluetooth technology, for example, is used to communicate with wearable sensors, while Wi-Fi and Global System for Mobile communication (GSM) are used to send data to the cloud.

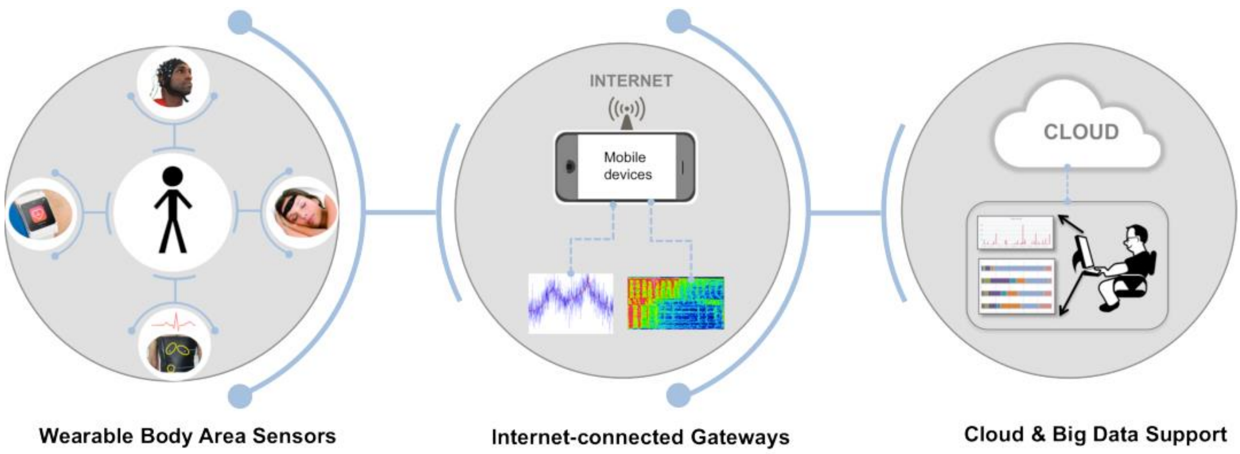

Figure 2.2 Architectural elements of Internet of Things (IoT) paradigm using wearable sensors

The scheme shown in Figure 2.2 describes all the components of a IoT architecture, which uses wearable sensors, and their interconnections, in particular with gateway device and Cloud and Big Data paradigms.

As previously mentioned, Cloud Computing offers fundamental support to IoT and in fact it represents one of its upper layers (computation layer). The main characteristic of Cloud Computing and its related paradigms, such as Fog Computing, Mobile Computing or Edge Computing, is to simplify processing and computing operations consistent to the unprecedented data volumes generated by IoT sensors, thus providing computing resources (computational power, storage, related networking resources, and Big Data analytics) in real time and with minimal interaction with the provider.

Indeed, like every other industry, healthcare organization is producing data at a tremendous rate, and this fact presents many advantages but also challenges at the same time. More generally, whole today's world is literally flooded with tons of data coming from every aspect of people's life, such as social activities, science, work, health, etc… In this context, medical Big Data refers to this great and variegated amount of data that are produced continuously and in real time in the different healthcare scenarios. That's why Big Data is usually described by a five-V characterisation – volume, velocity, variety, veracity, and value – that highlights the main properties inherent to the concept of Big Data and justify the increasing innovations over data management techniques and tools in recent years, as reported by [14]. In fact, many are the sources of Big Data in healthcare sector and, these include hospital records, medical records of patients, result of medical examinations, and of course devices that are part of IoT. Adequate infrastructure should be considered to extract value and derive meaningful information from challenging amount of data, with the ultimate goal of improving public health and assistance.

Finally, since these technological systems store and process very sensitive data, and change the way information is shared, both security and privacy aspects are commonly considered critical issues to be addressed in order to guarantee maximum protection to the patient.

2.2.2 Healthcare 4.0 application scenarios

Healthcare is confirmed the most promising and stimulating, even if not completely mature yet, application field that can benefit from Industry 4.0 paradigms.

In fact, healthcare sector is moved by pressing social and economic push to find new and more efficient solutions to improve its services, adapting them to the present needs: the rising cost of treatments, the increase in elderly population and consequently the spread of chronic diseases, such as diabetes, obesity, or cardiovascular disorders, necessarily require a transformation of healthcare from a hospital-centred to a patient-centred system.

The latter concept is contained in the P4 Medicine approach, which proposes as the response to this growing need. The idea is that medicine should be predictive, preventive, personalized and participatory and thus treatments should be tailored and targeted to the individual characteristics of the patient. This allows reducing healthcare costs, as well as unnecessary and costly hospitalization and procedures.

Thanks to IoT, Cloud and Fog, and Big Data technologies, novel solutions can be designed and adopted in the healthcare context to efficiently renew its practises while facing and mitigating the main stringent healthcare issues.

Figure 2.3 Healthcare 4.0 application scenarios

These innovative methods are more and more shared and widely implemented in various healthcare settings.

The main health-related scenarios enabled by the three ICT paradigms are represented in Figure 2.3 and deeply studied in the following.

Digital health technologies have the potential to assist medical doctors and carers in more efficient and effective monitoring of patient's health status to improve his quality of life. This is especially important dealing with elderly people, who are facing major challenges from health point of view and thus they are becoming the first target users of this new approach. They are, in fact, more prone to be affected by more than one chronic condition, situation that requires continuous care and monitoring.

The recent COVID-19 pandemic finally puts again attention on this situation and gives important impulses to increase the use of digital technology in clinical practice and particularly in care and treatment of elderly.

Despite these significant benefits, limitations come from the digital divide which characterises the elderly population and rises age-related barriers, consequence of the low degree of diffusion of technologies for older adults. This highlights the necessity to improve promotion of Internet and related technologies among the elderly, as presented in [15, 16]. However, criticism and difficulties come not only from a patient perspective, but also from infrastructural fragilities.

That said, nowadays a variety of applications enable improved communication beyond the physical boundaries of the clinic, reducing the doctor-to-patient distance, by growing patient's awareness about his health status (proactive) and allowing the clinician or carers to assist in real time the patient and to provide him prompt help in case of an emergency situation.

In the specific case of older people, digital technologies have the potential to promote independent living, both outside and inside home, leaving them the possibility to maintain autonomy in their activities while receiving assistance, if necessary, thus significantly improving their quality of life.

First, the concept of "ageing in place" emerges to guarantee older people to remain in their own home, avoiding them unnecessary hospitalization or to move in a care-facility, even if they may require some care or assistance. This aims to preserve and increase their confidence, sense of security and resilience, living in a familial and loving environment, without letting themselves go.

Several ICT technologies are involved in this situation to transform a home environment into an enhanced living environment (ELE): non-wearable ambient sensors, also called Smart-Home systems, are integrated into everyday objects, and provide remote monitoring by collecting patient and home data. These sensors can be classified in different ways, depending on the physical principle used, as pointed out by [17]: the most common are passive infrared (PIR) motion sensors, video sensors, pressure sensors, sound sensors, floor sensors, Doppler radar sensors and combination between them or even with wearable sensors.

Ambient sensors can be placed in different locations of the smart home (for example, installed on walls or ceilings, chair or bed, floor, and furniture), to monitor human behaviour and health status, by extracting important features from detected target events, such as Activities of Daily Living (ADLs), falls, gait, user localization, time out of the home or room, sleeping or activities in the night etc… Then, many of these systems generate alert if any deviation occurs and send messages and data to family members, carers, or specific assistance centres, so they can only work in homes equipped with Internet access.

At the same time, the idea of "active elderly" acquires international fame, in that it associates to a large extent quality of life in old age on whether older people have the capacity to maintain mobility and independence to reach their purposes, according to their possibilities.

Thus, a considerably variety of assistance systems for monitoring mobility and physical activity is becoming increasingly common in the healthcare sector. These wearable sensors can be used alone when the elderly is outside the home or they can integrate ambient sensors when the elderly is within the home, creating the so called Ambient Assisted Living (AAL).

On-body wearables enable comfortable and non-invasive health and movement monitoring because they can be embedded in clothes, belts, insoles, bracelets, necklaces, wristwatch etc…

For example, such systems are designed to monitor and ensure safety for mobility, and in this case they are referred as "tracking systems" (Global Positioning System, GPS), because they are particularly useful in locating older people, especially if they manifest the first signs of dementia. But also, they can be arranged with specific accelerometers or gyroscope sensors that measure user's walking ability and balance for fall detection. Finally, they can collect data on vital signs (physiological, chemical, or optical), at rest or during physical activity, such as heart rate, oxygen saturation, glucose etc… or information about diet and eating habits and even emotional status (anxiety, stress, depression).

Last but not least, Internet and digital communication technologies have created new opportunities for older people to cultivate social relationships with family members and friends, especially if they live far away, thus reducing the risk of social isolation and filling the void of loneliness. But it is important to highlight those virtual connections cannot replace real and in-presence relationships at all.

2.3 Active ageing

Population ageing put increased attentions on economic and social sectors, in addition to the healthcare one, for the intrinsic changes it brings with it. This requires a choral response which results in a diversified action but supervised by a reference policy framework.

2.3.1 Basic pillars

The term active ageing, developed by WHO in 2002, was defined as "the process of optimizing opportunities for health, participation and security, in order to enhance quality of life as people age" [18].

These are exactly the three active ageing pillars, graphically presented in Figure 2.4, and WHO recommends all societies the implementation of focused interventions in these areas:

- "Health" pillar means physical, mental, and social well-being, to allow people enjoy both a longer and higher-quality life. Aim is to prevent diseases and disabilities and to reduce the risk factors associated with them. This can be carried out by means of some changes that improve the quality of life of people as they age. Firstly, screenings, medical examinations, cares, and treatments must be promoted. Then, public and private buildings must be made more accessible for all people: environments should be modified to match age-friendly and barrier-free criterions to guarantee safety and protection for elderly. If it's not, support and assistance services must be provided to old people and their families.
- "Participation" in turn is intended as several activities older people can perform in the social, economic, cultural, civic, spiritual, and work worlds, accordingly to their needs, inclinations, and abilities. Education and lifelong learning should be provided as the powerful tools that get elderly in step with the times and enable them to develop new skills and behaviours that enhance their participation in all aspects of family and community life. Particularly relevant is the digital gap that exists between older and younger generations: this can be filled by promoting information technologies between the elderly people.
- "Security" finally refers to older people access to safe and protect physical and social environment, but also to economic stability. Laws and policies protect rights and needs of elderly, while preparing them for facing health, social and financial challenges of old age.

So active ageing is a multidimensional concept, because it concerns with many different interconnected life spheres, and it aims to produce advantages for both the interested persons and the societies in which they live. Families and communities should be supported in efforts to care for their older members.

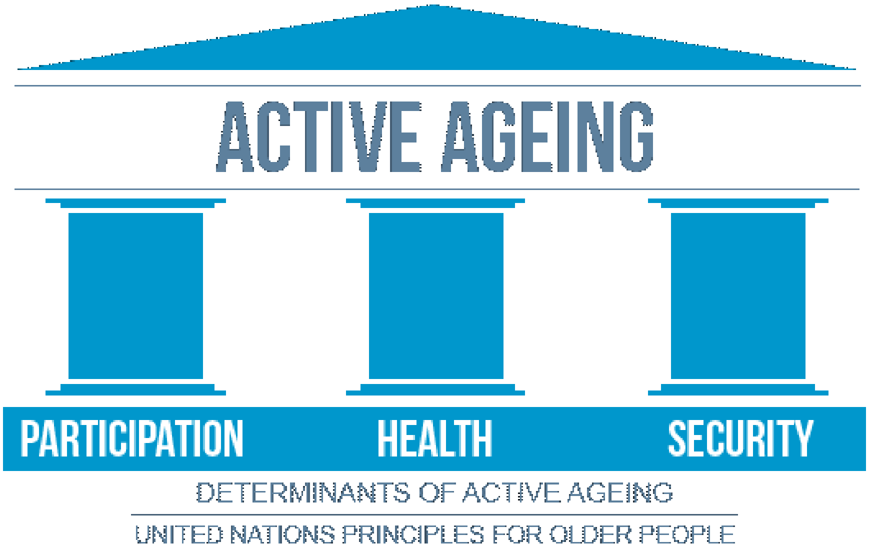

Figure 2.4 The three pillars of a policy framework for active ageing

2.3.2 Determinants of active ageing

The concept of active ageing recognises the important influence of all experiences in the lifetime in the way people age. Some of these factors can potentially act as determinants of active ageing since they affect health, well-being and finally the process of ageing itself. Actually, these determinants apply to the health of all age groups, but here the emphasis is put on the health and quality of life of older people.

The determinants of active ageing thus represent the strategic priorities for health promotion and disease prevention within policy frameworks, and they are integral part of programmes and interventions directly targeted to older people.

Culture and gender are the two cross-cutting determinants of active ageing. Culture includes values, attitudes, and traditions that, varying from region to region in the world, influence the way people look at health and ageing process. Gender still now is unfortunately considered an element which can be associated with different conditions, not always favourable for active ageing. For example, women in many countries have less opportunities and possibilities to access to education, personal and professional growth, health services, etc.

They are also involved in looking after children, relatives, and older parents, putting them before their own well-being and sometimes leaving employment.At the same time, men are more exposed to debilitating injuries related to more dangerous work or to bad habits.

There are many other factors that have an important role in the promotion of active ageing, and they are grouped in domains. First, determinants related to health and social service systems to monitor and improve health of people as they age. These are accessibility to health care services and disease prevention (primary, secondary and tertiary prevention).

Then, it’s never too late to embrace healthy lifestyles, such as appropriate and regular physical activity, a balanced diet, stop smoking and reducing alcohol consumption at very low levels. These behavioural determinants, together with an active personal care (screenings, correct use of medicines and medical devices), can prevent disease and functional decline by enhancing quality of life and extending longevity.

Some other determinants of active ageing are related to personal factors, and particularly to biology and genetics. In fact, even though external, environmental, and behavioural factors have a greater influence on how a person age, also genetic, hereditary, and internal factors can contribute to this process. The biological nature of ageing does so that body and mind naturally decline with age, and in some extent, this can be associated with predisposition to develop specific disease.

Physical and social environments are key factors to enhance health, participation, and security of elderly. In the first instance, this means age-friendly and safe house to reduce the risk of injuries and disabilities due to fall, which are as common as preventable events among older people. Then, support services and public transportation services must be of easy accessibility and usability to allow people reaching essential services, treatment centres, places of worship and social clubs, thus preventing poor health and risk of social isolation.

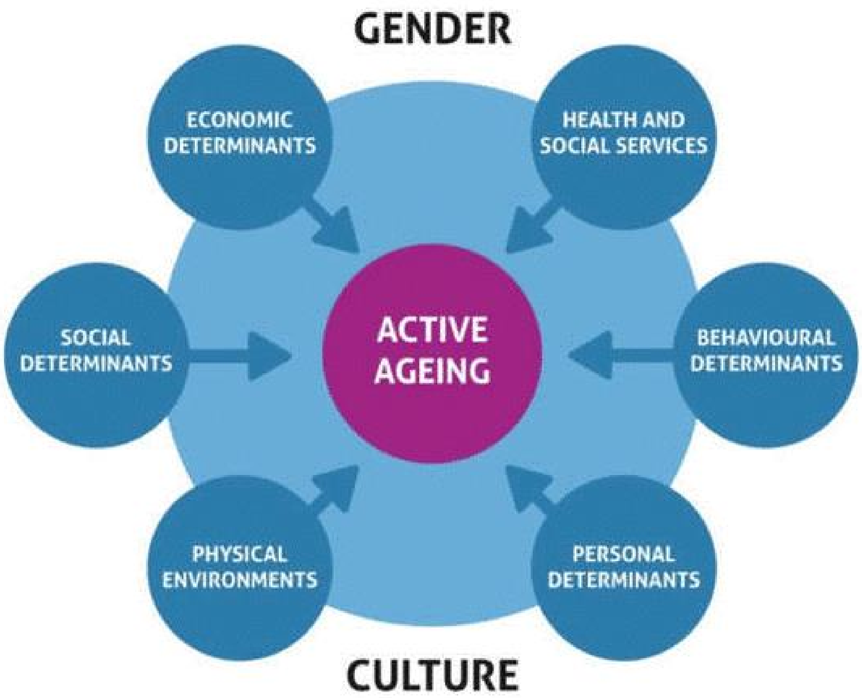

Figure 2.5 The determinants of active ageing

Lastly, economic determinants, such as sufficient incomes, dignified work, and social protection, have significant effect on active ageing: state and private sectors should develop measures to help needy people and guarantee their social security.

Figure 2.5 resumes the determinants of active ageing and highlights the interdependence of such factors: it's the combination of genetics, environment, lifestyles and health and social supports that accompanies people in the different stages of life and particularly in the old age.

This classification is still very current and shared among contemporary research in healthy ageing, as described in [19]. Healthy ageing cannot be segmented into isolated factors, but the correlation and mutual influence between them make it a dynamic process, meaning that determinants can vary at individual and population levels.

2.3.3 Why active ageing

Ageing in good health, taking part in the community, succeed in what values, in short ageing actively, paves the way for autonomy and independence principles.

This means the ability for elderly to perform daily activities in the community with no or little help from others.

In fact, as people age, quality of life, which is indispensable to make a positive experience out of a longer life, is largely determined by these values that then must be defended with great tenacity.

Obviously, this won't be possible without a constant and joint effort from a wide range of players in creating a more inclusive society that gives people of all ages space and major possibilities.

In this way, whatever the age, people can have an active role in their society and benefit of a better quality of life, by expressing the enormous potential that they still have, thus reaching the best health state possible.

In brief, active ageing incorporates and extends the concept of healthy ageing: it transmits a larger and more inclusive message than healthy ageing does, because it recognises not only health care, but also many other factors in influencing how individuals and populations age.

Clearly, this process cannot inevitably involve completely not self-dependent older people. However, those ones who are frail or not physically active because they are ill or live with disabilities, can remain active in their families and societies, and lead a healthy and high-quality life too.

Health status, in fact, cannot be able to leave out of consideration physical, mental, and social well-being, which are essential and equally important aspects.

So, a good health state remains the fundamental condition to be active in the old age, and it can be reached with perseverance and dedication by adopting prevention and adequate lifestyles, to delay as much as possible motor and/or cognitive disabilities onset.

Thus, old age is not anymore perceived as a social weight, but instead resources and opportunities connected to this stage of life, rather than limits and obstacles, are highlighted.

2.4 Projects and initiatives about Active Ageing

As people are living longer, the idea that quality of life in old age must be improved becomes a popular belief and drives many different players and teams to develop innovative solutions for supporting independence, health, and well-being of elderly, as reported in the following overview.

2.4.1 Background projects

The ACTivating InnoVative IoT smart living environments for AGEing well (ACTIVAGE) project, funded by European Union's Horizon 2020 research and innovation programme and lasted from January 2017 to the end of September 2020, was pioneer in this field. The project, in fact, fulfils the ambitious plan of creating the first European IoT ecosystem for Healthy and Active Ageing (AHA) supported by an open service platform which integrates and has access to all heterogeneous systems and devices, enabling interoperability across use cases they work on. These latter are various representative scenarios dealing with the elderly everyday life: activities of daily living (ADLs), integrated care, monitoring outdoor, emergency triggers, promoting exercises for fall prevention, preventing cognitive decline, preventing social isolation, offering safety and comfort, and support for transportation, all domains that should be paid attention to with deployment and operation of IoT-based AHA solutions.

ACTIVAGE, which is proposed as a multicentric large-scale pilot, involves nine deployment sites in Europe distributing across Spain, France, Italy, Germany, Greece, Finland, United Kingdom, and addresses a subset of use cases to each pilot to demonstrate the importance of IoT paradigm in improving quality of life of older people.

Among them, the Madrid deployment site, described in [20], thanks to IoT infrastructure will provide a non-intrusive monitoring of ADLs of elderly individuals' living environments such as private homes, care centres, public transportation systems, and other areas of interest.

The evaluation of three specific use cases aims at detecting and preventing (i) decreasing of cognitive performances by cognitive stimulation, (ii) risk of falling by physical training and exercises promotion, and (iii) social isolation by encouraging users to establish and maintain active social interactions through mobility. This is possible because stakeholders, including end users, participate personally in the so called co-creation process, and provide both inputs and feedback that permit to formulate personalized and ad hoc intervention, by means of products and services, in any situation.

Greece also, being one of the most aged countries in Europe, participates to ACTIVAGE project, and its Central Greece pilot focuses particularly in supporting elderly users that live alone in prevention of frailty, but also assists professional caregivers or relatives as well as health care providers, as presented in [21]. The main objective is to use the digital-interconnection-based concept of IoT to make older persons safer, contributing to their staying independent and having an active social life, as well as reducing the negative impact involved in chronic disorders and degeneration. So the Greek study meets this challenge by carrying out four use cases in two application scenarios, which are smart home and mobility contexts. To enhance the autonomous living of older adults, number of services are provided such as daily activities and behaviours at home monitoring, health tele-monitoring and tele-care services, as well as support for transportation and mobility. Equipment deployed includes motion sensors, door/window sensors, alarm button, installation in the city.

The large-scale pilot, thus, adopts a multilayer and multidimensional operating strategy based on integration of global and local features (GLOCAL approach) that allow to constitute a coherent and structured evaluation framework, on the base of which it will be possible to properly correlate and compare outcomes of the same use case scenario implemented in different pilot sites in order to assess the relevance of global and local specific indicators and adequately identify and respond to everyday needs of elderly.

In line with the previous study, the Pilots for Healthy and Active Ageing (PHArA-ON) project, understanding socioeconomic implications of the ageing phenomenon, aims to provide support for Europe's ageing population, by integrating digital services, devices, and tools into open and interoperable platforms, that go beyond the application limits of each singular technology. This range of digital tools includes connected IoT devices, AI, robotics, cloud computing, smart wearables, big data and intelligent analytics and, as an example, the integration of one of such solution (namely SmartHabits) in the PHArA-ON ecosystem is reported in [22].

PHArA-ON integrated platforms focus on a user-centric approach that provides personalised and optimised healthcare delivery, to meet the specific user's needs and requirements while reaching the highest acceptance and usability possible.

The process of determining the needs and preferences of older adult users is described in the study of the Italian pilot [23], a prioritization analysis conducted by mean of structured interviews and questionnaires on older people (recruitment criteria: (1) Absence or presence of physical frailty; (2) Mini Mental State Examination (MMSE)≥24/30; (3) Absence of sensorial issues (hearing and vision)) and their caregivers. This Italian Pilot is one of the five projects underway that compose the large-scale pilot (together with those involving Spain, the Netherlands, Slovenia, and Portugal), running from December 2019 until November 2023. It's to be noted that most of the older adults, as well as their caregivers, declared they frequently use digital systems like smartphone, computers, or tablets. To achieve the goal, participants are evaluated for their attitudes and preferences toward the selected technologies, so as to understand which of them can be integrated in the customised service, in relation to user's needs, abilities, and limitations. Two need categories are identified as fundamental and thus require active response: health management and socialization. The first is further divided into physical and cognitive stimulation and health and environmental monitoring; the second, instead, specifically deals with the promotion of social inclusion.

Last piece to conclude this picture about previous attempts and interventions in sustaining AHA, is the My Active and Healthy Ageing (my-AHA) project which focuses all its energies on frailty concept, intended as a weakness in capacity across multiple domains, including physical, cognitive, physiological, social, and nutritional domains, to name but a few. People affected by frailty are not effectively ill, but they are in a state of compromised functions, arising from a reduction in reserve capacity across multiple systems, which places them in a fragile condition that can easily precipitate and degenerate now into clinical disease, that in turn exacerbate the level of frailty experienced. This vicious cycle can be broken by early risk detection and tailored intervention, especially in the early stages like prefrailty is.

So, from here the need to design a multicentre and longitudinal randomized control trial, namely my-AHA, which is a four-years Horizon 2020-European Union funding project (from January 2016 to the end of March 2020) coordinated by the University of Torino and operative in 16 countries in Europe, Asia, and Australia, aiming at fighting the effects of frailty and supporting prevention to reduce related risk of negative outcomes (including death) in older adults.

The my-AHA project maps an individual's frailty risk profile across mentioned multiple domains (baseline assessment) and consequently delivers a specific package of ICT-based interventions individually tailored to those subjects who meet the clinical criteria for frailty. Real-time risk analysis on daily behavioural data and tailored interventions relay on data provided by sensors embedded in the my-AHA platform and integrated hardware (smartphone, JINS MEME glasses, activity trackers, other wearables, or home automation systems).

It's something good to reiterate that, the present as well as the precent studies, adopt a holistic approach and there is no specific intervention offered to all individuals irrespective of their level of risk, but instead the ICT-based solutions proposed are tailored and personalised on the base of the analysis of combined multiple risks for everyone, to ensure the maximal treatment efficacy and response of prefrailty in older adults.

So, the goal of the trial presented in [24] is not to test the efficacy of a singular intervention, but rather of a multidimensional intervention, which is matching the specific needs of each people in the physical, cognitive, psychological, nutrition, and sleep areas. Then, assignment of interventions occurs based on an algorithm developed to meet the need for intervention across each domain and participant preferences and takes data from the my-AHA platform to continuously update and modify the intervention prescription.

In particular, a subsequent study [25] evaluates in a limited number of prefrail older subjects (201 participants recruited who completed the twelve months assessment) the effects of a personalised multidomain intervention, monitored by the my-AHA platform, in preventing or reducing the conversion to frailty.

Even if significant improvements in measures of physical, cognitive, social or sleep function are not observed, which is not surprising since subjects are recruited from the general population and not from the clinical setting so they do not have relevant cognitive or physical impairments, however, in comparison with controls, the intervention packages results to be protective against Quality of Life (QoL) decline in the active group, reducing the level of depression mood and increasing the nutritional status in a remarkable way.

2.4.2 Smart Village project

The gradual extension of the life expectancy which has characterised the last decades has consequences on the types of intervention the welfare state has to implement within the scope of health and aid policies. The various needs of older people should be satisfied starting with a complex and well-structured care and assistance network that face in a systematic way important set of problems, such as social, relational, assistance, and healthcare issues. This is because, like for everyone else, elderly's health status is determined by three concurrent factors, namely physical health, social and environmental well-beings, and psycho-emotional connections, that require thus a multi-directional approach.

This situation poses both criticalities and opportunities at the same time. In Italy, the present social assistance system is mainly “informal”, which means relatives and friends, very often in turn elderly, involved in care and support of their loved ones, assuming the role of caregiver for all intents and purposes. To this organization intensely based on the family support is added a “formal” assistance, which is a private and paid service, supplied mainly by woman foreign workers. Today, it is estimated that there are about one million formal caregivers helping families to respond to the need of a continuous assistance for one of their members, as reported by [26], but this statistical data is often underestimated due to the strong presence of irregular situations. Thus, also quality of care provided and controls cannot be guaranteed.

In front of the increasing number of older people and the extreme unbalance between formal and informal assistance, which implies a reshaping of the families' assistance role in supporting the elderly, it's evident that the social assistance sector must be radically expanded and modernised.

Within this context the SMART VILLAGE project was born and develops, because strong is the feeling that supportive actions for physical, mental, and social well-beings must be promoted and strengthened in favour of the elderly.

The SMART VILLAGE project pursues to create a new home and personalised healthcare and social assistance model, intended to totally enhance the quality of life of older people, especially if they live alone. This is completely new idea of welfare, whose focus is to prevent onset of acute events (e.g., disabling diseases), favour further autonomy at their own place of residence, and make elderly independent and active in the social context of their own country.

The project started in 2018 with the involvement of fifty older participants, aged 75 years and older, coming from some municipalities which compose the so-called seismic crater area of the Central Italy. These are very fragile regions situated in the hinterland of the Marche region that even before being struck by the earthquake of 2016, were affected by a significant and structural depopulation phenomenon.

Thus, the target territory includes twelve experimenter municipalities in the province of Fermo and Macerata, characterised by a population under five thousand residents. They are Belmonte Piceno, Falerone, Massa Fermana, Mogliano, Montappone, Monte Vidon Corrado, Monteleone di Fermo, Petriolo, Monsampietro Morico, Ortezzano, Servigliano and Monte Rinaldo municipalities. In these areas, secondary but not less important objective of SMART VILLAGE project is to contrast this increasing depopulation phenomenon by revitalizing the territory and proposing improved and more accessible services.

The principal phases characterising the SMART VILLAGE project are depicted in the following Figure 2.6, showing the main moments from the screening phase to the telemonitoring phase.

Figure 2.6 The principal phases of the SMART VILLAGE project. In order of appearance: the screening phase, the patient approaching with smart devices, the patient using the smart devices during the day, and the specialist consulting the patient's medical record through the digital Smart Village platform

In the period between June and October 2021 the fifty elderly participants went to Monte Vidon Corrado, locality which was chosen as the reference centre of operations, where a laboratory-ambulatory is prepared and equipped with advanced instrumentations and tools and designated to clinical and social activities.

Here an equip of specialised doctors and social workers carried out in-depth multidimensional analyses of elderlies by means of assessment questionnaires, functional tests, and anamnesis questions. Participants' health status was evaluated with wide-range examination, considering motor-functional domain as well as cardiological-cardiovascular, nutritional, psychological, and social domains. In fact, it's important not only to oppose the physical fragility of the individual, but also work hard to improve his quality of life by means of social inclusion and active involvement, and to do this a global evaluation must be carried out.

The data collected during the screening phase are used to fill a technological platform, named Smart Village platform, that will constitute sort of web medical record of each patient, and thus becomes point of reference for constant consulting and updating the patient's information. Successively, the result of the social and clinical assessments will provide to the specialists the criteria for choosing a personalised set of smart devices for each of the user. This initiates a second phase focused on the patient's health conditions home-monitoring, by means of the above-mentioned wearable and environmental sensors, that respond to non-invasiveness and easy usability requirements. Everyday data are collected by the Smart Village platform and inform the clinicians, as well as formal and informal caregiver, about current patient's health status, thus favouring immediate response in case of emergency as well as anticipating the worsening of suspected critical conditions when the first signs appear. This approach will facilitate the work of the general practitioner, reducing the physical distance with his patients and highlighting as soon as possible health problems, thanks to the integration between technological devices and platform.

An overview of the logical architecture of the Smart Village platform, is graphically depicted in Figure 2.7.

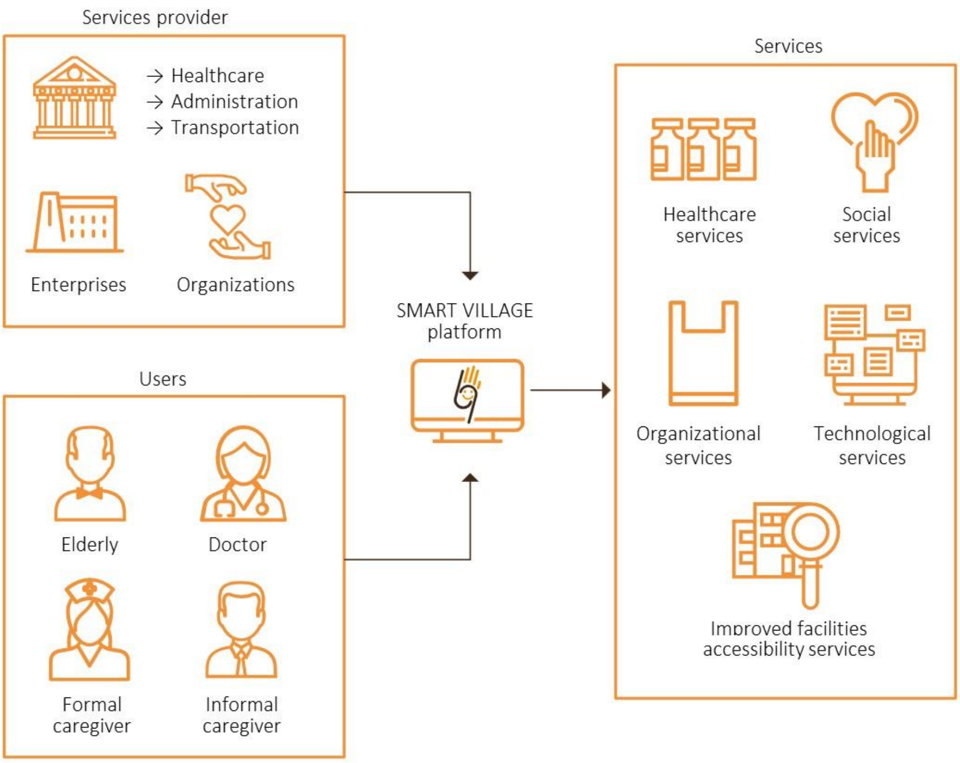

Figure 2.7 The logical architecture of the Smart Village platform

Recent insights have come to light the need to direct attentions toward improvement of quality of life in old age, rather than extension of life duration, by supporting maintenance of physical and cognitive functionalities, while preventing diseases onset.

One of the main issues addressed by the SMART VILLAGE project is falls prevention, a condition that, when present, provokes serious consequences both for the subject experiencing the fall and the national healthcare system (NHS, or SSN in Italian terms). In fact, incidence of falls, fall circumstances and sequelae are major health problems for elderly that can irreparably undermine their quality of life.

The multifactorial nature of the fall event, that sees rarely a fall being attributed to just one risk factor, but instead it's the result of a complex and dynamic interaction of many risk factors, requires a multidimensional interventional approach.

So wide-ranging analyses are needed to classify the fragilities of the elderly, in terms of, for example, gait and balance disorders, nutrition, muscle weakness, cognitive and cardiovascular diseases, vision and hearing impairments, etc.…

Then, depending on the level of criticality that emerges, different modalities of health status monitoring and strategies for preventing fall must be identified. Wearable sensors have proved to be very useful and efficient for this purpose, but another option can be to adopt healthier lifestyles. This personalised system that is offered to elderly and that includes integrated software and hardware operative solutions represents the innovation of the methodological approach of SMART VILLAGE resolved to prevent fall phenomenon in pre-fragile and fragile elderly. Within a global perspective, finally, the data collected from patients at this stage will constitute the documentary material available to the different welfare actors in the future to improve quality of life of all patients who will need it over years.

A second important challenge taken up by the SMART VILLAGE project concerns the prevention of cardiac acute events. Cardiovascular diseases (CVDs), together with chronic respiratory disease and diabetes, represents one of the major problems for world public health: these non-communicable diseases, in fact, are the first cause of morbidity, disability, and mortality and they have serious impact on social, healthcare, and economic sectors. CVDs are characterised by a multifactorial aetiology, because there are many factors that contribute contemporary to their development and increase the probability of CVDs onset. Apart from congenital and non-modifiable risk factors, the most important behavioural risk factors of heart disease and stroke are unhealthy diet, physical inactivity, tobacco, and alcohol uses. These are modifiable risk factors and by lowering their level adopting healthier lifestyles it's possible to reduce the cardiovascular risk or to maintain it at a favourable level. As emerged by Progetto Cuore, supported by Italian Istituto Superiore di Sanità (IIS), the cardiovascular risk is reversible, and CVDs are preventable. That's why nowadays the most effective strategies and actions to reduce the cardiovascular risk, consists in primary and secondary prevention, that is a life-course and intersectional approach that starts from the early childhood and adolescence and prolong to adulthood and old ages.

Thus, inside the SMART VILLAGE framework, the system of innovative services that use smart technologies to monitor patients' health status pays also great attention to the cardiological aspects.

The aims are numerous, from the constant monitoring of users' cardiologic parameters in order to reduce the risk of unexpected acute events, to the improvement of their habits and lifestyles to reach a favourable cardiac health condition.

In this context many entities, such as Universià Politecnica delle Marche, INRCA and Area Vasta 4 (AV4) Fermo, Ambito Territoriale Sociale (ATS) 17, 18, 19, municipalities, general practitioners, technological enterprises (Vega, Itaca, New System, Namirial, Telemedware) and social cooperatives (Agenzia Res Nuova Ricerca, COOSS Marche, Idea, Utopia) were important actors involved in reaffirming the synergy and essential collaboration between public and private sectors.

2.5 Personalised assignation algorithms

Prescription and delivery of products and services in the present work is achieved by means of a personalised automatic decision algorithm that connects elderly patient's needs across multiple domains with devices and services features, to evaluate the best set of solutions tailored to the specific patient. In this section the results of a conducted scientific literature research that looks for similar algorithms are presented: the interest is for personalised allocation and assigning strategies and methodologies that match input needs with output interventions.

It has been already mentioned in previous paragraph the my-AHA project [24] that through the use of an information and communication technology platform connected with multiple devices within the older adult's own home, designs and measures individual's risk factors for frailty across the multiple domains selected and then delivers a personalised intervention to the individual. Assignment of interventions occurs exactly based upon algorithms developed to match the prefrailty domains and participants' interests. Moreover, new data and information are continuously fed into the system, so that the platform can update and modify intervention packages for the individual with respect his current situation.

These data source for interventions and the specific interventions assigned are reported in the supplementary tables of that study. Just as an example, the physical interventions selected to target the key physical markers for frailty considered, which are weight loss, physical weakness, reduced energy, motor slowing, reduced physical activity, and of course fall history, involve strength and balance training, to reduce the fall risk and improve gait pattern and postural control. These activities can be deployed as group or home exercises with different repetition frequencies according to patient's preferences and characteristics.

Differently from previous study, the Stop Elderly Accidents, Deaths, and Injuries (STEADI), presented in [27, 28] and based on evidence and inputs from the healthcare providers, develops a toolkit algorithm to help clinicians in primary or other care settings with fall risk assessment and interventions in clinical practice.

The STEADI algorithm is designed as a flowchart that takes inputs from older adults, evaluates the level of fall risk using standardised and validated scale (e.g., the Time Up & Go, the 30-seonconds chair stand, and the 4-stage balance tests), and provides specific and tailored fall prevention activities and practices. The algorithm proposed individualised interventions for any level of risk (low, moderate, or high); even the lower-risk patients, namely those who have not fallen and/or not have gait or balance problems, are directed to primary prevention, which includes fall risks education and community exercise or fall prevention programs. When, instead, the fall risk is higher the treatment translates into activities in various clinical setting, such as follow-up visit with physical therapists, neurologists, and podiatrists.

Lastly, an interesting study [29] focuses on the use of ICT solutions to meet the increasing needs of elderly with cognitive impairments and to support their autonomous living. The study designs an hybrid matchmaking approach that uses both a rule-based and a statistical matchmaker in order to select automatically the most proper set of services in two main scenarios: (a) emergency case resolution, and (b) tool recommendation.

In the first case, for example, if the elderly falls, an alarm notification is sent to the platform connected to the monitoring system, and consequently a corresponding set of services is selected, which results in a SMS with the coordinates of the person sent to his connected caregiver. In the second case, when the user directly interacts with the application web interface of the platform, this provides him a personalised control panel with the most suitable tools and contents according to his profile. Depending on his personal and health information, personalised AAL services or tools are presented to the user. They are divided into categories, like carers support, independent living support, social well-being support, travel support, etc… In turn, these tool categories sort into many other groups of services: for example, the independent living support includes within itself online exercising, mental training, physical activity monitoring, daily function assistant, and others.

In conclusion, this brief and limited literature research has pointed out, to the best of our knowledge, the advantages of some personalised and automatic methods and algorithms for allocation of products and services in specific case studies. But on the other hand, the same survey has highlighted the need to improve this area of investigation by extending the benefits of decisional mechanisms to other applications to be optimised.

3 Method

The present work aims to study and develop an automatic algorithm that aspires to help the clinicians finding the best personalised set of products and services to be assigned to older people with respect their social and clinical needs, within the SMART VILLAGE framework. "Automatic" and "personalised" are key words for the purpose of this study. The automatic configuration of the algorithm, in fact, allows to scan and execute set of predefined criteria and items quickly and with high accuracy, after a manual data entry. A personalised approach, instead, is fundamental to understand the heterogeneous nature of the elderly population, which is characterised by high variability and numerous specificities, influenced by complex factors, both intrinsic and extrinsic to the individual.

The workflow adopted to identify the optimal decisional model with the above-mentioned characteristics follows five phases, which are listed below and graphically represented in Figure 3.1:

1. Screening: it's the data collection phase across multiple control domains by specialists, to gather information about the social and health status of the patient.
2. Smart Village platform: the data collected during the screening are reported in the platform to obtain a digital medical record of the patient.
3. Data processing and cleaning: this is essential phase to transform and convert the data from the platform into a standardised format, that is a consolidate and uniform Excel structure for optimal analysis.
4. Algorithm development: designed as a decision tree, that is a flowchart diagram showing the various outcomes from a series of decisions. This decision-making tool allows the identification of products and services based upon the patient's profile.
5. Algorithm implementation: Virtual Basic for Application (VBA) is chosen as programming language to translate the decisional model into code.

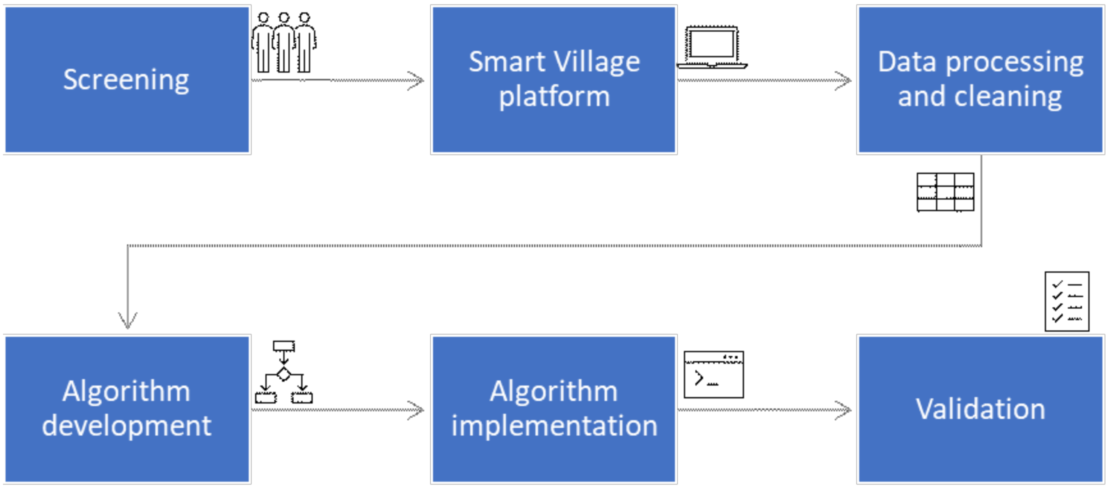

Figure 3.1 Block scheme of the study workflow

6. Validation: the process of comparing algorithm and clinical evaluation output, in order to assess quality, reliability, and consistency of the algorithm itself.

Specifically, the algorithm can be represented at this stage as a black box which receives as input the characteristics of the patient and the information about products and services, elaborates them according to a specific logic, and produces as output the personalised assignation of products and services to match the specific clinical and social needs of the patient. Figure 3.2 shows the black box representation of the algorithm.

In the following sections, the description of how the experimentation was done, and the rational for the procedure adopted.

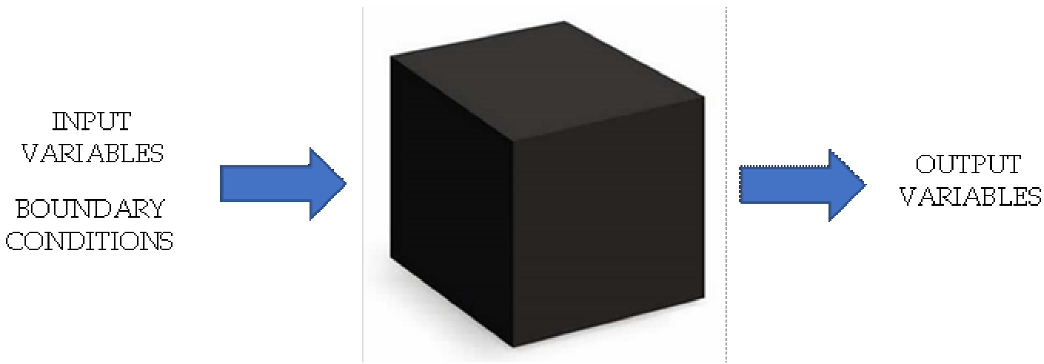

Figure 3.2 The black box representation of the algorithm

3.1 Data sample

The data employed in the study originate from the various screening sessions conducted between June and October at the Monte Vidon Corrado operative centre, by a multidisciplinary equip of specialist and within the framework of the SMART VILLAGE project. The first phase of the study consists exactly in creating an Excel database to reserve these elements.

Physiatrist, cardiologist, psychologist, nutritionist, and social worker who carried out deep analyses to assess the health and social condition of the patients, report the information within the Smart Village platform. From here, data were extrapolated and translated into an Excel workbook and ordinately divided into separated worksheets, one per each visit: rows store the participants to the study, while columns are filled with the correspondent value of all the significant items selected from each visit. Table 3.1 presents a synthetic description of the five different visits to which the patients underwent, with the main features extracted. Deeper description of the evaluation tools (questionnaires, tests, and scales) adopted by the specialists will be described in the next paragraph.

In parallel, a scientific literature research has been conducted to examine and characterize the risk factors that may have crucial role in causing a fall or an acute cardiac event, which are the main issues addresses by the present work. This second phase will be preparatory for the next one in which the actual algorithm is developed: here, in fact, the context and the main determinants of such critical events are analysed and then, just a subset of them is selected to be integral part of the decisional workflow.

A fall is an "unexpected event that results in a person coming to rest inadvertently on the ground, floor, or other lower level", as defined by [30], and WHO reports in [31] that a third of people aged 65 and older falls at least once per year. Thus, many studies have focused their attention on the epidemiology of fall, which is one of the most serious problems affecting elderly people health status and quality of life, to establish and evaluate reported risk factors for fall [32-37].

Table 3.1 Data collection during the five different visits of the screening session

SOCIAL AND CLINICAL VISITS	
Physiatry visit	Quantitative scales: Walking Handicap Scale (WHS), Time Up & Go (TUG), Berg Balance Scale (BBS), Modified Barthel Index (MBI), stabilometry analysis
	Articular physical examination: inflammatory and mechanical pain, limited range of motion (ROM), deformities
	Neurological physical examination: neurological deficit, hypertonia, hyposthenia, hypoesthesia, muscle hypotrophy
	Fall history and dynamic
	Gait characteristics and anomalies
Psychological visit	Validated scales: Geriatric Depression Scale (GDS), Zung anxiety scale, Mini Mental State Examination (MMSE)
	Quality and quantity of relationships, recent loss, financial means and management, compliance, well-being definition
Cardiological visit	Preliminary anamnesis: risk factors (smoking, hypertension, diabetes, cholesterol, familiarity, and obesity), pathologies, drugs
	Clinical exam: auscultation, percussion, and ECG exam
	Systematic Coronary Risk Evaluation for Older People (SCORE-OP): if any precedent events, diabetes, Chronic Renal Insufficiency (CRI), hypercholesterolemia, and hypertension
	Syncope and possible causes.
Nutritional visit	Nutritional status: handgrip test, circumferences, Body Mass Index (BMI), Mini Nutritional Assessment (MNA) questionnaire, Bioelectrical Impedance Analysis (BIA) examination (body composition analyses: %FAT, % Fat Free Mass (FFM), % Total Body Water (TBW), % Extracellular Water (ECW))
Social visit	Validated tools: Physical Activity Scale for Elderly (PASE), Short Form (SF)-12 test
	Social context: house pet, Wi-fi, architectonic barriers, means of transport, cohabitants, domestic assistance, assistive devices (prostheses, implanted device, glasses, hearing aid, education level)

In Italy, a remarkable project supported by ISS is the so called Passi d'Argento, a monitoring system dedicated to elderly people which aims to characterise and describe health and behavioural risk factors that may be connected to chronic non-communicable disease, and so many significant insights about the fall event and related risks are provided. Table 3.2 resumes the principal risk factors for fall which have been identified.

On the other hand, many efforts are also made to reduce the burden of cardiovascular diseases (CVDs), both at individual and population levels. The most important way to prevent CVDs remains healthy lifestyles promotion throughout the life, in particular by adoption of healthy nutrition, regular physical activity, stop smoking and alcohol drinking. In addition, in recent years cardiovascular risk charts have been widely used as clinical assessment tools for cardiovascular risk stratification.

Table 3.2 Main risk factors for fall

FALL RISK FACTORS	
Non-modifiable	Age, gender, race
Physical decline	Mobility, balance, and gait loss, muscle weakness, joint and functional limitations, visual and hearing deficits
Mental decline	Cognitive impairment, depressive symptoms, fear of falling
Comorbidities	Osteoporosis, osteoarthritis, drop attack, syncope, Parkinson', cardiovascular diseases, sarcopenia, postural hypotension, malnutrition, urinary incontinence
Pharmacy	Polypharmacy, psychotropics
History of previous fall	
Environmental characteristics	Hazard and obstacles, narrow steps, slippery surfaces, poor lightening, walking aids, footwear
Social aspects	Sedentary life, social isolation, ADLs, education level, economic state

Table 3.3 Cardiovascular risk factors and medical and cardiac history influencing patient's health status

CARDIOVASCULAR RISK FACTORS	
Non-modifiable	Age, gender, race, familiarity
Behavioural	Smoking, alcohol consumption, nutrition, physical activity, sleep
Medical	Hypertension, diabetes mellitus (high glycemia), triglycerides, hypercholesterolemia, overweight and obesity (BMI), waist circumference, psychological stress
Cardiac	Syncope, atrial fibrillation, heart failure, angina pectoris, acute myocardial infarction, ischemia, ictus, coronary artery disease, percutaneous coronary intervention, coronary artery bypass graft, cardiac pacemaker, implanted cardioverter defibrillator

For example, the SCORE system recommended by European guidelines [38] or the Italian CUORE algorithm [39], permit to evaluate the probability to become ill because of a CVDs in the future years by knowing the level of multiple factors. Moreover, an initial major adverse cardiac event may be predictor of future cardiovascular events. The Table 3.3 above collects and illustrates the main factors influencing the cardiovascular status of the patient.

3.2 Evaluation tools

To outline a multidimensional health profile of the patient, face to face visits are conducted, in accordance with the evidences reported before that document the multifactorial nature of the frailty condition that must be investigated. This includes not only clinical questions and verifications, but also may involve the use of specific validated tools that help the clinician to quantitatively assess patient’s health status.

For instance, among the several fall risk assessment tools available, as explored in [40], here four are considered because they are the most suitable in terms of limited time, economic equipment, and workspace required and moreover, they have good predictive performance in assessing the risk of falling among older people.

The TUG test is a reliable and valid test for quantifying functional mobility, as emerged in [41, 42]. It takes only few minutes to complete, and in this test the subject is asked to stand up from a chair, walk 3 m, turn, walk 3 m back and sit down again. The time taken to perform this task is measured and it indicates high or low falls risk, respectively if it is under or over the threshold set at 20 seconds.

The BBS evaluates a participant's balance based on 14 items scored along a 5-points scale and takes 15-20 minutes to complete. The score for each item ranges from 0 to 4 points, with an overall maximum score of 56 points. The subject is asked to perform a series of movements, that involve sitting, transferring, and standing positions, and that relate with the ability of a patient to maintain balance while in motion, as described in [43, 44].

The WHS presented in [45], instead, is a quantitative system to assess person's level of walking ability at home and in the community, based on a 19-items questionnaire that allows to assign the patient to one of the six functional walking categories, depending on if his mobility is classified independent, supervised, assisted, wheelchair, or unable.

Finally, the MBI proposed in [46] measures the individual's performance on ADL functions in order to determine the level of independence of the subject. MBI has been developed to improve the sensitivity of the original BI in scoring those individuals who require assistance. In fact, MBI better categorise and differentiate the quantity and quality of assistance required. Here MBI is characterised by a 10-items form that consists of 10 ADLs including feeding, bathing, grooming, dressing, bowel and bladder control, toilet use, transfers, mobility, and stairs climbing. Items are rated in terms of whether patient can perform the task independently, with minimal assistance, with moderate assistance, unsafe without someone's help, or is totally dependent. The values assigned to each item are based on time and amount of actual physical assistance required if a patient is unbale to perform the activity. The total score is calculated by adding up the individual scores, and ranges from 0 (total dependence) to 100 (total independence).

The Table 3.4 explains in detail description and cut-off points of such scales.

Table 3.4 Quantitative scales to assess motor-functional abilities

Test	Description	Cut-off points
TUG	Time to perform a 300 m walking test: walking ability and endurance	<20 s high performance ≥20 s low performance
BBS	Static and dynamic balance abilities during 14 predetermined tasks	41-56 low fall risk 21-40 medium fall risk 0-20 high fall risk
WHS	Mobility classification in terms of 19 ambulatory activities into six functional walking categories	1 physiological 2 limited household 3 unlimited household 4 most-limited community 5 least-limited community 6 community
MBI	Self-care assessment about performance in ADL functions to determine level of independence	0-24 total dependence 25-49 severe dependence 50-74 moderate dependence 75-90 slight dependence 91-99 minimal dependence 100 independent

For what concern the evaluation of the psychological status of the patient, three validated scales are here presented and adopted.

The Geriatric Depression Scale (GDS) consists of a 30 questions survey designed to rate depression in elderly patients [47]. The survey is easy to administer and is used as a screening instrument in evaluating an elderly patient. It is not recommended to use GDS when patient is characterised by severe dementia (MMSE≤15). Binary answers (yes/no), instead, make this instrument suitable for mild-to-moderate dementia. The points of each answer are then added together to form the total score for the GDS, which ranges from 0 (not depressed) to 30 (maximum depression), with cut-off value set at 11 for clinically relevant depressive symptoms.

Then, a rating instrument proposed by Zung [48] allows the measurement of anxiety, and it can be used both as a self-rated scale or as interviewer-based administration scale. Zung anxiety scale presents 20 items that asks about how patient feels or behaves during the past several days. The items are judged on a four-points system, considering severity. The total score is obtained by a summation of the rated responses for each of the 20 items and ranges between 0 to 80. Four anxiety categories are identified and the higher the total score, the higher the anxiety level.

The cognitive function was assessed using the Mini-Mental State Examination (MMSE), which contains seven domains (orientation to time, orientation to place, three-word registration, attention and calculation, three-word recall, language, and visual construction), each with an assigned point value totalling 30. An MMSE score greater or equal to 24 is considered normal cognitive function, while scores less than 24 indicate cognitive impairment. Then the MMSE score can be corrected according to age and education. An interesting study highlights the relationships between MMSE domain score and falls [49]; in particular low MMSE scores are related to an increased number of falls.

The Table 3.5 illustrates the three main psychological assessment tools just described, while the Table 3.6 reports the numerical factors used to correct the MMSE results with respect age and education information.

Table 3.5 Validated scales for assessment of psychological status

Questionnaire	**Description**	**Cut-off points**
GDS	Depressive symptoms evaluation	0-10 normal, not depressed 11-16 mild-moderate depression 17-30 severe depression
Zung anxiety	Measure of anxiety level	0-20 slight or no anxiety 21-40 mild level of anxiety 41-60 moderate level of anxiety 61-80 severe level of anxiety
MMSE	Cognitive functional test	>24 high performance ≤24 low performance

Table 3.6 MMSE correction factors for age and education

Age	**65-69**	**70-74**	**75-79**	**80-84**	**85-89**
Education					
0-4	+0,4	+0,7	+1,0	+1,5	+2,2
5-7	-1,1	-0,7	-0,3	+0,4	+1,4
8-12	-2,0	-1,6	-1,0	-0,3	+0,8
13-17	-2,8	-2,3	-1,7	-0,9	+0,3

Then, the nutritional evaluation is carried out by means of the Mini Nutritional Assessment (MNA) test. This is a reliable screening test that allows rapid assessment of nutritional status in elderly, as expressed in [50, 51]. The MNA-short form (MNA-SF) especially is a shortened version of the full MNA. It consists of six items that incorporate anthropometric measurements (BMI), dietary intake and global- and self-assessment components. The maximum score for MNA-SF is 14 points; patients are categorised as normal, at risk of malnutrition, and malnourished with respect a cut-off threshold of 12. The lower the MNA result, the higher the risk of malnutrition. The test should be completed at regular intervals for continuous assessment of the patient, and, in case of undernutrition, nutritional interventions should be considered.

To conclude this overview about quantitative evaluation tools used during the multidimensional examinations and that will be included in the next decisional analysis, the characterisation method for sarcopenia should be mentioned. European guidelines define sarcopenia in [52] as a progressive and generalised skeletal muscle disorder that is associated with increased likelihood of adverse outcomes including falls, fractures, physical disabilities, and mortality. The proposed algorithm starts evaluating sarcopenia measuring the muscle strength from grip strength test which is simple and inexpensive: sarcopenia is probable when low muscle strength is detected. Secondary parameter considered is muscle quantity, reported as Muscle Mass (MM), which is estimated from the Bioelectrical Impedance Analysis (BIA) based on whole-body electrical conductivity. A sarcopenia diagnosis is confirmed by the presence of low muscle quantity.

Table 3.7 MNA-SF questionnaire and evaluation parameters for sarcopenia detection

Test	Description	Cut-off points
MNA-SF	Nutritional status evaluation	12-14 normal 8-11 risk of malnutrition 0-7 malnourished
Handgrip	Muscle strength measurement	<27 kg low strength for men <16 kg low strength for women
BIA	Muscle mass estimation	<20 kg low muscle quantity for men <15 kg low muscle quantity for women

The algorithm eventually continues evaluating physical performance, for example by means of TUG test, and to identify the severity of sarcopenia, but for the purposes of the present study just the first two parameters are considered because in clinical practice this is enough to trigger assessment of causes and to start interventions.

The Table 3.7 reports the thresholds for nutritional status evaluation by means of the MNA-SF, and also the muscle strength and muscle mass cut-off points for the detection of sarcopenia, respectively for men and woman.

3.3 Products and services set

The algorithm elaborates the input data related to patients' clinical and social characteristics and needs, presented in the previous section, as well as the technical features of the different digital devices available, to produce as output the best personalised set of products and services, that are going to be described here.

The devices are non-invasive and easy to use systems that aim to provide continuous assistance to the patient, both in-home and outside the home, and to monitor his health status while also improving the social inclusion. The main focus is to prevent serious circumstances, like a fall, or acute events, like the onset of cardiac episodes.

Fall monitoring devices include an ambient sensor, and a wearables smartwatch, and pendant. The distinction between ambient and wearable sensors just leap out.

The first is a Vayyar Home that is mounted on the wall or ceiling of the house and uses Wi-fi connection for 24/7 monitoring of the elderly. If a fall happens, this is automatically detected by the system which sends a mobile alert to the formal or informal caregiver who can provide prompt intervention, increasing the safety and wellbeing of the patient. This solution is suggested for those people who spends a lot of time at home, but it's not compatible with the presence of cohabitants or house pets that can generate false alarms in the domestic environment. Moreover, fall and deteriorating health patterns can be monitored just in few rooms because of the limited network coverage of the system.

Another solution is the GPS fall detector, which is an age-friendly device in that is designed to be used, according to patient's preferences, as a pendant, a key chain, or even it can be attached to the belt or put into the bag. As the name suggests, this device takes advantage of the GPS technology to inform at any time relatives and caregiver about the position coordinates of their elderly by means of a real-time geolocation. This option is particularly helpful in case of falls, that are automatically detected by the system, that sends immediately emergency notification and call to the connected smartphone or computer with the current position of the elderly. Security zones can also be set up to receive a notification when the elderly enters or exits them. Moreover, the device allows to receive and send voice calls just by pushing a big button on the front. The simplicity and ease of use make the wearable GPS fall detector suitable for any type of patient, irrespective of his characteristics.

The Apple Watch (series 6), then, is a smartwatch which allows fall detection and intervention by putting the elderly in touch with emergency services or contacts if necessary. In fact, when the watch detects stillness for about a minute, it alerts the patient with a tap on the wrist and an audible alarm, and shows an alert message on the screen so that the person can tap the emergency SOS, or the alarm reset if he's fine.

With respect the previous fall detection system, the Apple Watch requires higher technological abilities from the patient and moreover, it's not suggested for those who have prostheses at both hands to do not compromise the efficacy of use of the device itself, or to those who present implanted cardiac devices, like pacemaker (PMK) or defibrillator (DFB), for safety reasons because dangerous electrical interferences may generate.

The potentialities of the Apple Watch express also by the monitoring of some physiological parameters of the patient like the saturation (O_2 level), and the heartbeat; in addition, it allows to draw an electrocardiogram (ECG) from which information about heart rhythm and the presence of any abnormalities may be derived. These data stored and shared through the specific Health app enable to prevent the onset of cardiac event, by study promptly and deeply the causes that have generated some cardiac anomalies.

Alternative device to the smartwatch is the pocket-sized KardiaMobile, which consists of a mobile single- or six-leads ECG device for remote patient monitoring. Everywhere and anytime this pocket electrocardiograph, positioned on the knee or on the ankle and with the thumbs on the superior electrodes, records the ECG, and the heartbeat, that can be shared with the medical doctor to diagnose or manage cardiac anomalies. Even in this case, patients with both hands prostheses as well as PMK or DFB implanted, are advised against the use of this device. Then, since slightly more complex operations are required to perform with the KardiaMobile to obtain an ECG track, this kind of monitoring is suggested for patients with higher technological abilities.

To conclude the overview about cardiac monitoring devices, also the blood pressure monitor should be mentioned. Enrolling the cuff around the upper arm, the Omron EVOLV system measures the arterial blood pressure (BP) and detect irregular heartbeats, at home or on the go. Results and progresses can be saved and followed, which is particularly helpful to manage patients with hypertension condition.

The smart body scale, instead, permits deep body composition analysis, by keeping track of body weight, BMI, body fat, water percentages, skeletal muscle, fat free body weight, muscle mass, bone mass, proteins etc… Goals can be set and progresses can be tracked so that patient can be monitored in his weight condition or adherence to a specific diet, for example.

Finally, the tablet device can be used with a dual functionality. On one side, as communication device, it enables the elderly to remain in contact with his relatives and friends, as well as with the medical doctor. This prevents social exclusion and may have positive impact on the psychological and emotional status of the patient himself. On the other side, it proposes games and activities for recreational function or cognitive improvement.

It has been mentioned many times that some devices use an app to store and share data, or to send notifications and alarms. In the absence of a network connection, if the patient has been assigned to a device which implies an app or requires the Wi-fi, a smartphone which works as a mobile hotspot can be provided.

These digital devices just presented are for sure the core of the study, because they help to monitor the status of the patients remotely and continuously, both in terms of physiological parameters as well as movement patterns and falls. But in some cases, even a specific service is offered to the patient to improve his general well-being.

These can include, for example, some social supports: a domestic assistance if the patient encounters difficulties because of architectural barriers; a transportation and accompaniment (T&A) service if the patient presents walking mobility problems or is not a car owner and would like to reach desired areas of interest; a social worker for animation and entertainment activities; elderly particularly active and with no mobility limitations may be proposed for volunteering activity in their community, which is a great opportunity to share own experiences, help needy people, and make new friends; some kind of physical activity at low or moderate intensity is very important at old age and it's associated with many health benefits.

Psychological supports may be indicated for those patients who have fragile or critical psychological status.

Group therapy for listening and talking sessions or occupational therapy (gardening, yoga, breathing and low-impact exercise, etc…) engage the elderly in group activities with other elderlies favouring social interaction, participation, and positive emotional and behavioural responses, thus promoting quality of life.

Finally, among the services suggested there are also follow-up visits to carry out some verifications about certain conditions: neurological, nutritional (divided into weight control, sarcopenia, and diet consultation), renal functionality, hearing, vision, and fall reconstruction examinations.

In addition to input and output variables, boundary conditions are required in the decisional analysis to make the process more efficient.

The patients are classified into two categories on the base of their predisposition and inclination to the technology. If they are part of the "active" group, named class A, they may be associated with high-technological impact devices, while if they belong to the "passive" group, named class B, they may be assigned to the low-technological impact devices.

Then, the algorithm in the cardiological investigation area receives feedback from the data from the fall risk evaluation, so that if the patient has already been addressed by the logic to a smartwatch for fall monitoring, this device, in case the patient would require also a cardiological monitoring, will be confirmed.

The following Table 3.8 resumes products and services offered to patients.

Table 3.8 Products and services assigned in the algorithm

Products	Wearables: BP, O_2 level, ECG, fall detection
	Non-wearables: body composition smart scale
	Ambient: fall detection
	Communication: tablet and smartphone
Services	Social support: domestic, T&A, animation, walking aids, volunteering, physical activity
	Psychological support: group therapy, occupational therapy
	Follow-up visits: neurological, nutritional, renal functionality, hearing, vision, fall reconstruction

4 Case study

In the following, the algorithm logic is explained, and it is developed to take as inputs the previously described variables from the screening tests, and to produce as outputs specific products and services that are offered to participants.

4.1 Study participants

Participants are the fifty elderly people recruited during the first phase of experimentation within the SMART VILLAGE project. They are 16 males and 34 females over 75 years old, and with mean age about 83 years old. The target population, coming from the twelve municipalities of the seismic crater areas of the Central Italy (Fermo and Macerata provinces), meets the three inclusion criteria: (i) grade I, II or III according to the Rankin modified scale [50], which means a good-to-moderate level of autonomy; (ii) they can or cannot live alone; (iii) they can present comorbidities and pathologies to organs and systems (e.g., cardiological, vascular, endocrine-metabolic, neurological, sense organs, renal, hepatic, gastrointestinal, respiratory, bones and joints problems, etc…) as well as they can have joint prostheses or implanted cardiac devices. The only exclusion criterion consists in the presence of severe cognitive impairment (MMSE) that will not guarantee adequate and reliable experimentation. The following Table 4.1 resumes the inclusion and exclusion criteria that are considered for the study.

Table 4.1 Selection of study participants: inclusion and exclusion criteria

Inclusion criteria	(i)	Grade I, II, III (Rankin modified scale)
	(ii)	They can or cannot live alone
	(iii)	Comorbidities, joint prostheses, and implanted cardiac devices accepted
Exclusion criteria	Severe cognitive impairments (MMSE)	

Table 4.2 Statistical description about the target population (1)

Item	Percent Yes	Item	Percent Yes
Technological Class:		**Living alone**	50%
Active	20%	**Recent loss**	28%
Passive	80%	**Social relationships**	76%
House pet	30%	**Normal hydration**	24%
Wi-fi	36%	**Smoking**	26%
Several floors home	60%	**Hypertension**	98%
Car owner	42%	**Diabetes**	16%
Prostheses:		**Familiarity**	34%
Hand	2%	**Hypercholesterolemia**	62%
Knee	6%	**Smoking**	26%
Hip	4%	**Hypertension**	98%
Shoulder	4%	**Obesity**	38%
Eye deficit	54%	**Cardiopathy**	80%
Hearing deficit	48%	**FA**	20%
Smartphone	22%	**IMA**	10%
Education level:		**CIC**	16%
Elementary school	48%	**Ictus**	6%
Intermediate school	10%	**Heart failure**	2%
High school	6%	**PMK**	4%
University	4%	**DFB**	4%
Previous falls	50%	**Previous syncope**	24%
Walking aids	36%	**Physical inactivity**	24%
Living alone	50%	**CRI**	18%
Recent loss	28%	**CIC**	16%
Social relationships	76%	**Normal hydration**	24%

Then, Table 4.2 and Table 4.3 report the statistical description of the target population. The second table, in particular, contains mean values and standard deviations of questionnaires and tests for physical performance (MBI, TUG, BBS, WHS), psychological evaluation (GDS, Zung anxiety scale, corrected MMSE), physical and mental quality of life and health (SF-12), and nutritional assessment (handgrip, muscle mass, and MNA).

Table 4.3 Statistical description about the target population (2)

Questionnaire/Test	Mean ± dev. std	Questionnaire/Test	Mean ± dev. std
SF-12:	27,80 ± 2,59	**GDS**	12,06 ± 7,65
PCS-12	41,78 ± 9,13	**Zung anxiety**	34,46 ± 6,53
MCS-12	46,79 ± 10,82	**Corrected MMSE**	23,22 ± 5,11
MBI	94,46 ± 15,13	**Handgrip**	17,14 ± 7,81
TUG	17,00 ± 9,31	**Muscle mass (BIA)**	22,43 ± 6,34
BBS	44,94 ± 12,38	**MNA**	12,41 ± 1,91
WHS	4,66 ± 1,34		

4.2 Decisional analysis

The algorithm has been developed in Excel as a decision tree: this decision support tool which uses a tree-like model contains conditional control statements that, by means of sequences of binary divisions (dichotomy approach), drives the assignation of products and services available for the study to each user, depending on his/her clinical and social requirements.

The flowchart, a simple and intuitive graphical representation of the algorithm, uses geometrical shapes and arrows to explain the decisional process at the base of the algorithm itself. It is illustrated from Figure 4.1 to Figure 4.6. Several standard symbols are applied in a flowchart: oval is for terminal box (start/end), rhombus is for decision, parallelogram is for input/output information, rectangle is for process/instruction, and arrows are the connectors between all these elements.

Initial hypothesis is the information, education, and communication for all. This premise to the algorithm consists in providing to whole target elderly population indiscriminately advices and interventions to increase trust and awareness about everyday risks.

This includes, for example, informing the patients about the environmental and health risks for fall and the behaviours that should be adopted to prevent it. But also, these advices concern cardiovascular prevention, nutritional and lifestyle habits, and thus periodic screening by general practitioners suggested.

Then, the algorithm contains different investigation areas that manage and integrate patient's information, elaborate it, and produce an output. Conditions (rhombi) are tested and depending on the response different output (parallelograms) are proposed to the patient. As extensively described in the previous section, these outputs can include digital devices, with different functionalities and technological impact depending on the particular ability of the patient; or output can be services and visits that are offered and suggested to the elderly in order to improve their well-being and quality of life in the specific area they need more.

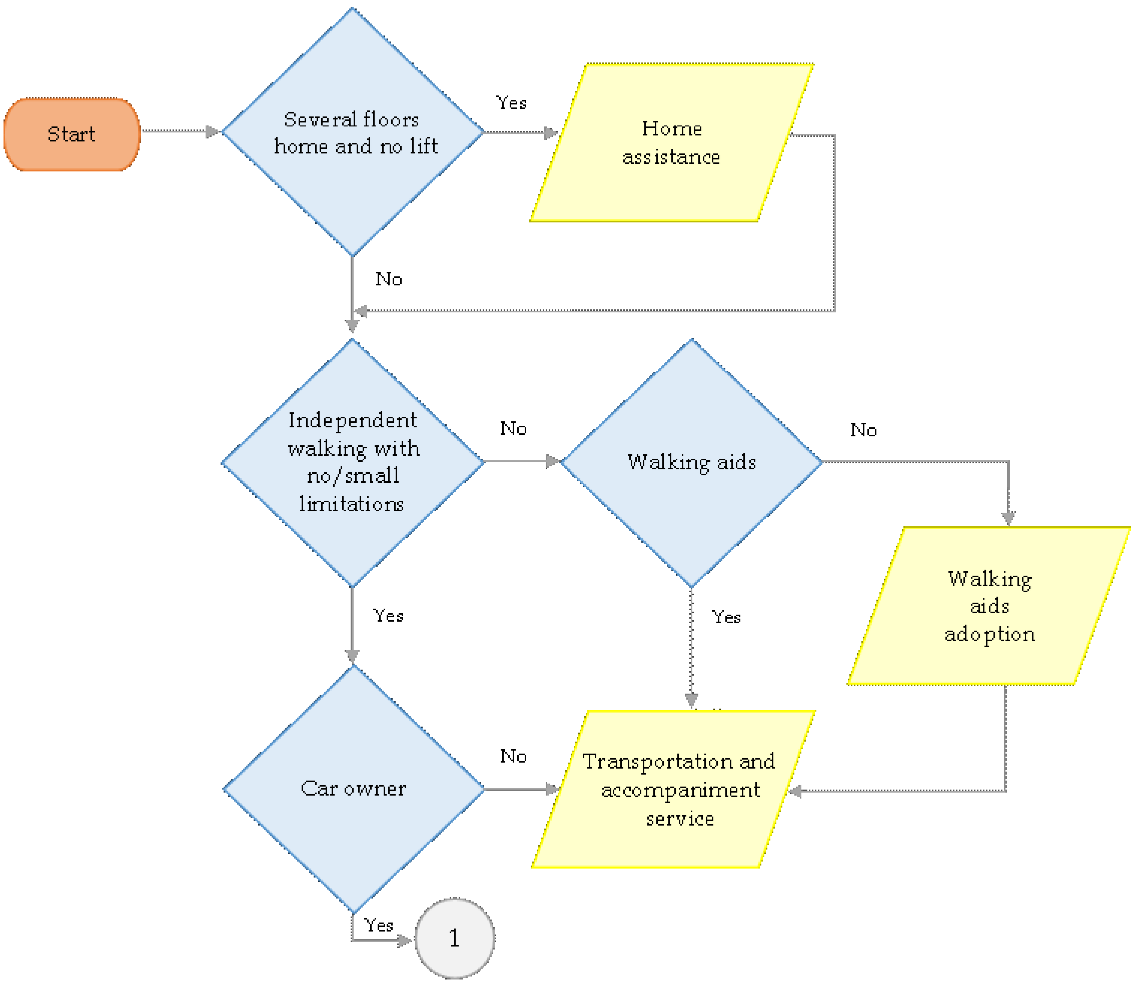

Figure 4.1 Decisional flowchart - part I

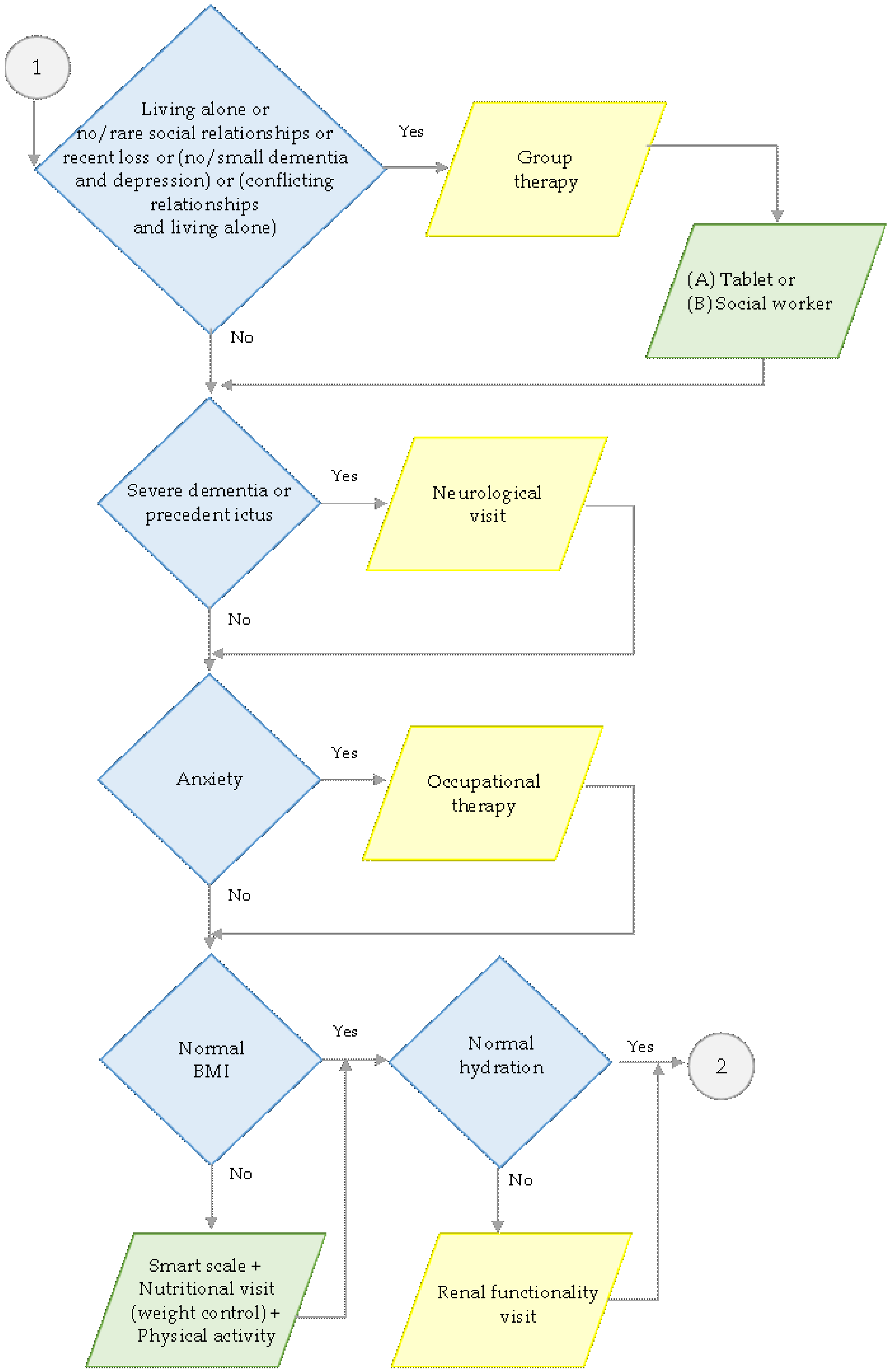

Figure 4.2 Decisional flowchart – part II

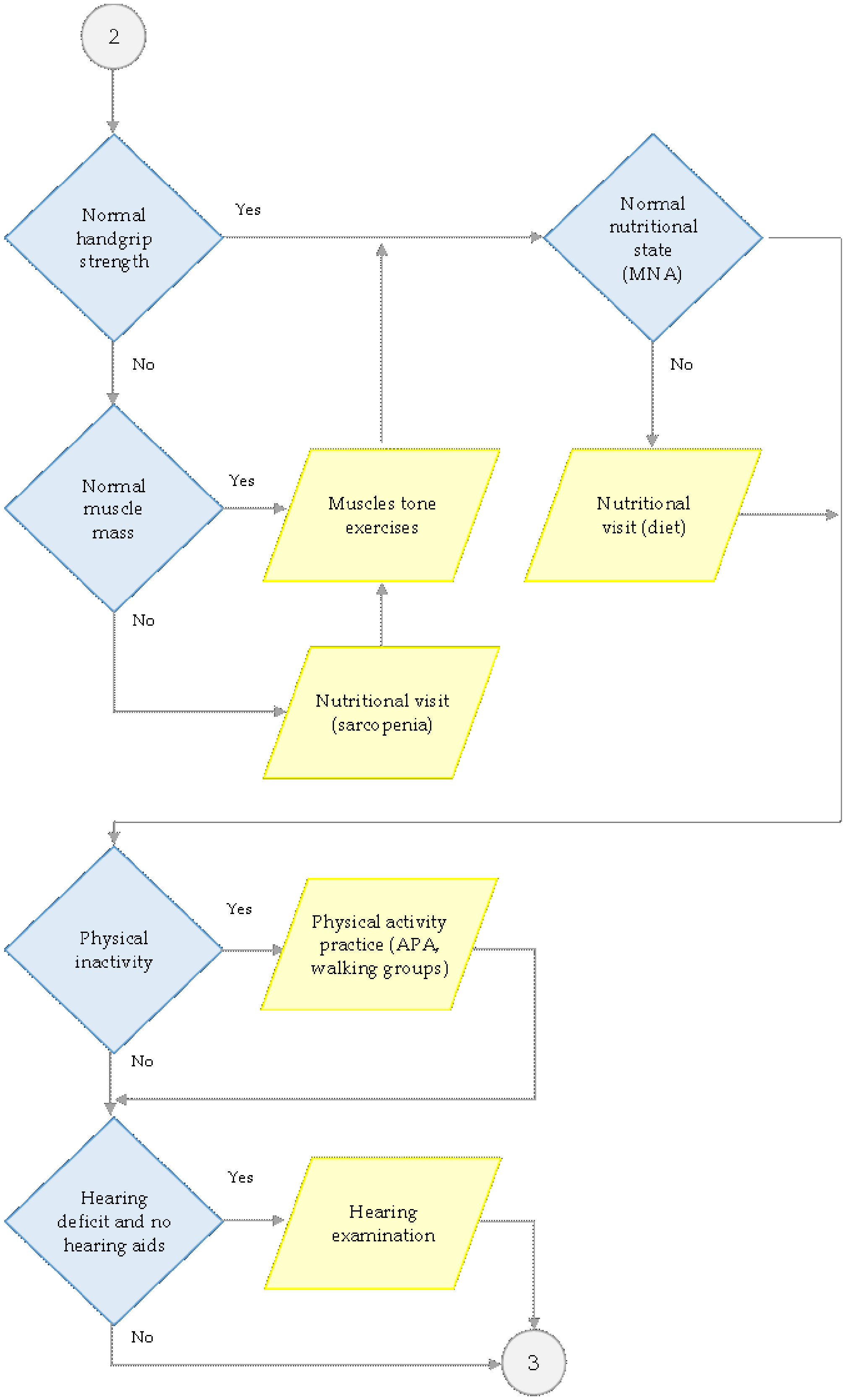

Figure 4.3 Decisional flowchart - part III

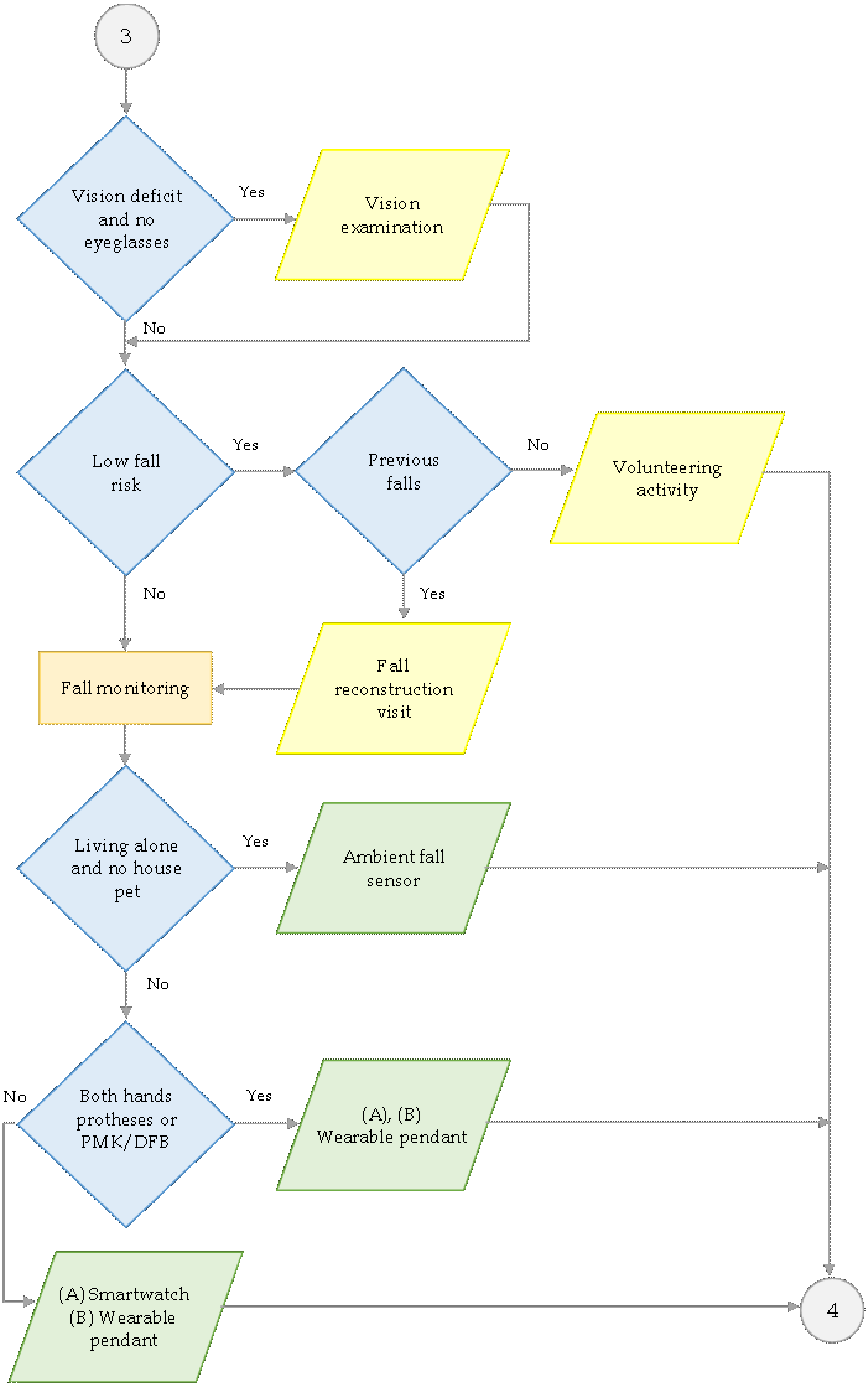

Figure 4.4 Decisional flowchart - part IV

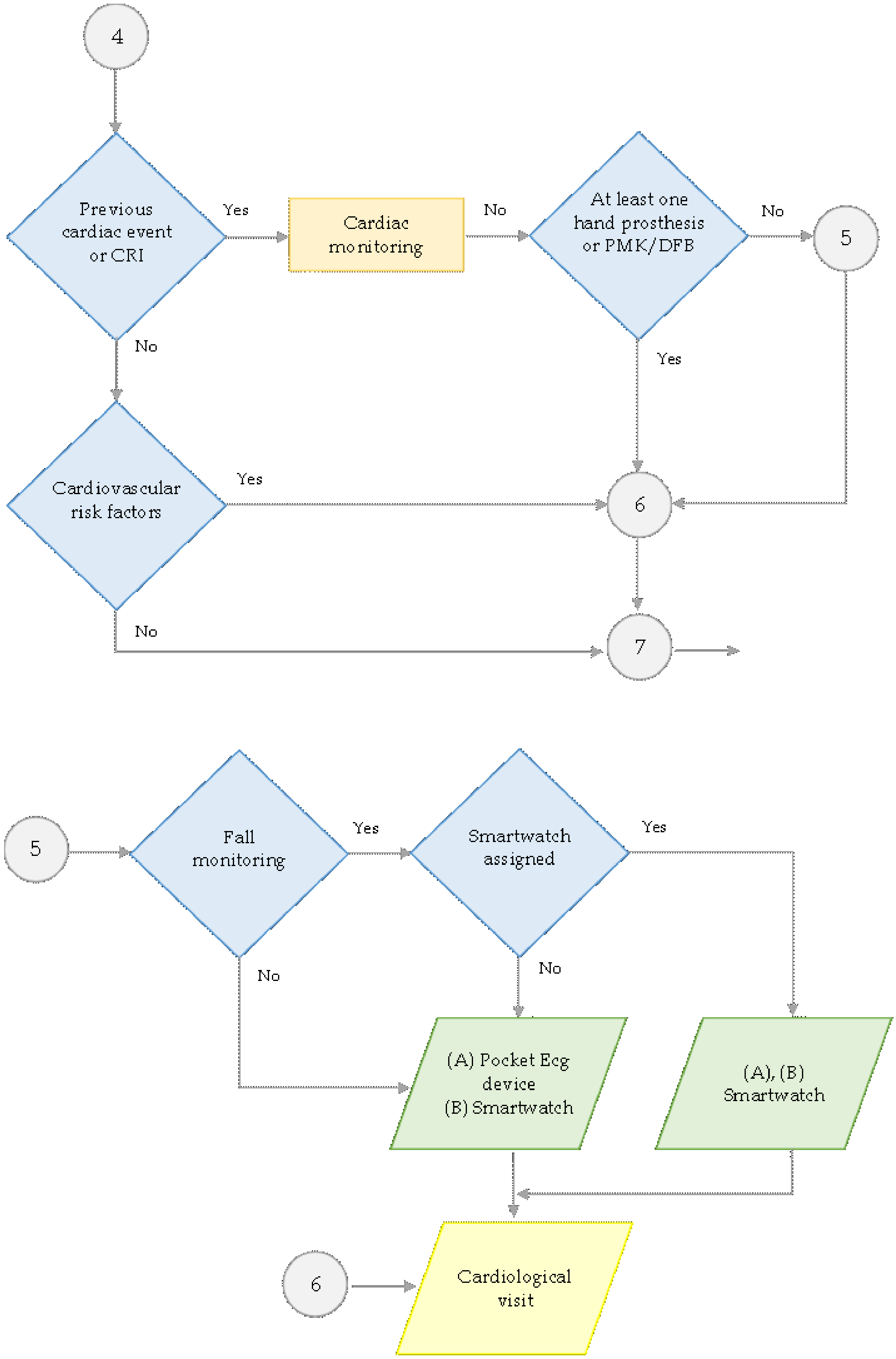

Figure 4.5 Decisional flowchart - part V

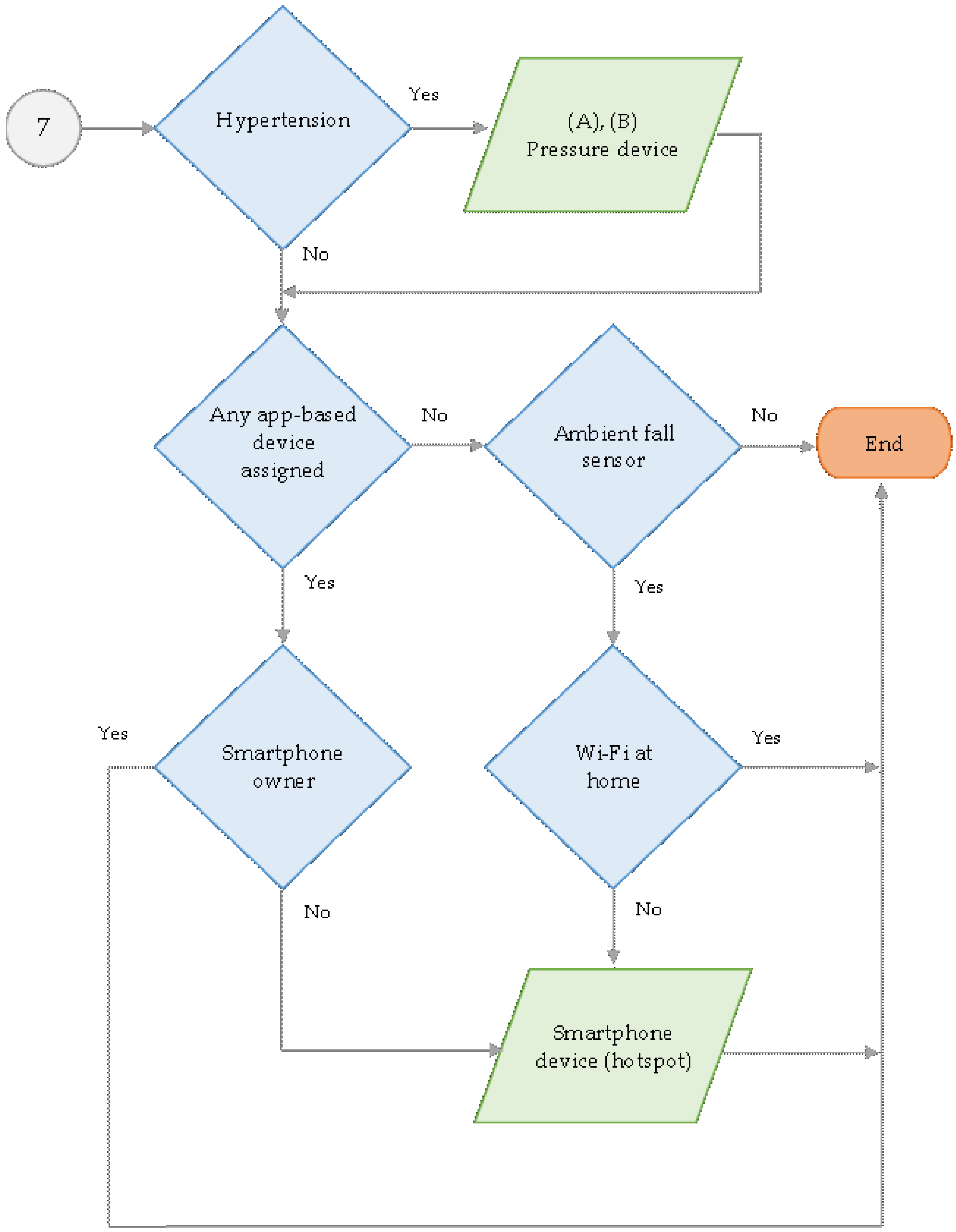

Figure 4.6 Decisional flowchart - part VI

4.3 Algorithm implementation

The algorithm has been implemented on VBA which is event-driven programming language that enables to extend Office applications, like Excel. VBA allows to record, create, and edit macros (also called subroutines or procedures), which use functions and objects to perform automated set of operations.

Taking advantage of the great potential of VBA programming, the decisional workflow is converted into code that interacts with the patients database Excel worksheet by means of "If … Then … Else" statements iterated within a "Do while" loop. The conditional statements have been composed so that if information is lacking, the algorithm acts cautiously conservative and prudently assigns corresponding device or service. The resultant outputs are stored inside another Excel worksheet called "Assignation" in which the set of products and services for each patient is finally identified. From Figure 4.7 to Figure 2.1 the complete code algorithm implemented on VBA is illustrated.

```
Private Sub CommandButton1_Click()

Dim i As Integer
Dim result As String
i = 5
Do While Cells(i, 2).Value <> ""                                    'Finchè c'è un Nome nella colonna Utenti

    'Prima interrogazione
    If Cells(i, 9).Value = "Sì" And Cells(i, 10).Value = "No" Then    'Casa su più piani E non ha l'ascensore
        result = "Sì"
    Else
        result = "No"
    End If

    Worksheets("Assegnazione").Cells(i, 3).Value = result             'result = ASSISTENZA DOMICILIARE


    'Seconda interrogazione
    Dim result1 As String, result2 As String

    If Cells(i, 108).Value >= 5 Then                  'Cammino indipendente e senza limitazioni (WHS>=5)
        If Cells(i, 11).Value = "Sì" Then             'Autonomunito
            result1 = "No"
            result2 = "No"
        Else
            result1 = "No"
            result2 = "Sì"
        End If
    Else                                              'Cammino non autonomo o con limitazioni
        If Cells(i, 56).Value <> "No" Then            'Utilizza già ausili per il cammino
            result1 = "No"
            result2 = "Sì"
        Else                                          'Non utilizza ausili
            result1 = "Sì"
            result2 = "Sì"
        End If
    End If

    Worksheets("Assegnazione").Cells(i, 4).Value = result1      'result1 = ADOTTARE AUSILI PER IL CAMMINO
    Worksheets("Assegnazione").Cells(i, 5).Value = result2      'result2 = SERVIZIO DI TRASPORTO E ACCOMPAGNAMENTO


    'Terza interrogazione
    Dim result3 As String, result4 As String, result5 As String

    If Cells(i, 138).Value = "Sì" Or Cells(i, 141).Value = "Mai/raramente" Or Cells(i, 143).Value = "Nessuna" Or Cells
        result3 = "Sì"

        If Cells(i, 37).Value = "Attivo" Then                   'L'assegnazione di Tablet o servizio operatore sociale dip
            result4 = "Sì"
            result5 = "No"
        Else
            result4 = "No"
            result5 = "Sì"
        End If

    Else
        result3 = "No"
        result4 = "No"
        result5 = "No"
    End If

    Worksheets("Assegnazione").Cells(i, 8).Value = result3        'result3 = PSICOTERAPIA DI GRUPPO (ASCOLTO/PAROLA)
    Worksheets("Assegnazione").Cells(i, 28).Value = result4       'result4 = TABLET
    Worksheets("Assegnazione").Cells(i, 6).Value = result5        'result5 = OPERATORE SOCIALE (ANIMAZIONE, INTRATTE
```

Figure 4.7 VBA implementation code – part I

```
'Quarta interrogazione
Dim result6 As String

If Cells(i, 136).Value < 15 Or Cells(i, 214) = "Sì" Then                'Grave demenza o ictus
    result6 = "Sì"
Else
    result6 = "No"
End If

Worksheets("Assegnazione").Cells(i, 10).Value = result6         'result6 = AAPROFONDIMENTO NEUROLOGICO


'Quinta interrogazione
Dim result7 As String

If Cells(i, 133).Value > 40 = Sì Then        'Stato di ansia (Zung)
    result7 = "Sì"
Else
    result7 = "No"
End If

Worksheets("Assegnazione").Cells(i, 9).Value = result7          'result7 = TERAPIA OCCUPAZIONALE


'Sesta interrogazione
'Valuto assegnazione bilancia, attività fisica e vis. nutrizionale per controllo del peso
Dim result8 As String, result9 As String, result10 As String

If Cells(i, 160).Value <> "Normopeso" Then                      'BMI non è nella norma
    result8 = "Sì"
    result9 = "Sì"
    result10 = "Sì"
Else
    result8 = "No"
    result9 = "No"
    result10 = "No"
End If

Worksheets("Assegnazione").Cells(i, 29).Value = result8         'result8 = BILANCIA PESAPERSONE
Worksheets("Assegnazione").Cells(i, 20).Value = result9         'result9 = ATTIVITA' MOTORIA
Worksheets("Assegnazione").Cells(i, 11).Value = result10        'result10 = VISITA NUTRIZIONALE PER CONTROLLO PESO


'Valuto Idratazione (BIA) per eventuale approfondimento clinico della funzionalità renale
Dim result11 As String

If Cells(i, 171).Value = "Nella norma" Or Cells(i, 171).Value = "Nella norma con tendenza ECW" Or Cells(i, 171).Val
    result11 = "No"
Else
    result11 = "Sì"
End If

Worksheets("Assegnazione").Cells(i, 14).Value = result11        'result11 = APPR. CLINICO FUNZIONALITA' RENALE


'Valuto sarcopenia
Dim result12 As String, result13 As String

If Cells(i, 3).Value = "M" And Cells(i, 158).Value < 27 Or Cells(i, 3).Value = "F" And Cells(i, 158).Value < 16 The
    If Cells(i, 3).Value = "M" And Cells(i, 168).Value < 20 Or Cells(i, 3).Value = "F" And Cells(i, 168).Value < 15
        result13 = "Sì"
        result12 = "Sì"
    Else
        result13 = "No"
        result12 = "Sì"
    End If
Else
    result12 = "No"
    result13 = "No"
End If

Worksheets("Assegnazione").Cells(i, 19).Value = result12        'result12 = ESERCIZI SPECIFICI DI TONIFICAZIONE MUS
Worksheets("Assegnazione").Cells(i, 12).Value = result13        'result13 = VISITA NUTRIZIONALE MIRATA PER LA SARCO


'Valuto stato nutrizionale (MNA)
Dim result14 As String

If Cells(i, 176).Value < 12 Then           'Stato nutrizionale NON nella norma
    result14 = "Sì"
Else
    result14 = "No"
End If

Worksheets("Assegnazione").Cells(i, 13).Value = result14        'result14 = VISITA NUTRIZIONALE PER PIANO ALIMENTAR
```

Figure 4.8 VBA implementation code – part II

```vba
'Ottava interrogazione
Dim result16 As String

If Cells(i, 27).Value = "Sì" And Cells(i, 28).Value = "No" Then         'Problemi di udito e non ha l'apparecchio
    result16 = "Sì"
Else
    result16 = "No"
End If

Worksheets("Assegnazione").Cells(i, 15).Value = result16        'result16 = VISITA CONTROLLO UDITO


'Nona interrogazione
Dim result17 As String

If Cells(i, 25).Value = "Sì" And Cells(i, 26).Value = "No" Then         'Problemi di vista e non ha gli occhiali
    result17 = "Sì"
Else
    result17 = "No"
End If

Worksheets("Assegnazione").Cells(i, 16).Value = result17        'result17 = VISITA CONTROLLO VISTA


'Decima interrogazione
'Valuto assegnazione dei dispositivi per monitoraggio cadute
Dim result18 As String, result19 As String, result20 As String, result21 As String, result22 As String

If Cells(i, 105).Value >= 91 And Cells(i, 106).Value < 20 And Cells(i, 107).Value >= 41 And Cells(i, 108).Value >=

    If Cells(i, 41).Value = "No" Then       'No cadute pregresse
        'risultato preliminare1: MONITORAGGIO CADUTE
        Worksheets(2).Cells(i, 34).Value = "No"

        result18 = "Sì"                     'Assegno servizio di volontariato
        result19 = "No"
        result20 = "No"
        result21 = "No"
        result22 = "No"

    Else                                    'Ci sono state cadute pregresse

        'risultato preliminare1: MONITORAGGIO CADUTE
        Worksheets(2).Cells(i, 34).Value = "Sì"

        result18 = "No"
        result19 = "Sì"

        If Cells(i, 138).Value = "Sì" And Cells(i, 7).Value = "No" Then     'Se vive solo e Non ha animali domesti
            result20 = "Sì"     'Solo il rilevatore ambientale
            result21 = "No"
            result22 = "No"
        Else                    'O non vive solo O ha animali domestici
            result20 = "No"

            If Cells(i, 19).Value <> "Entrambe" And Cells(i, 219).Value = "No" And Cells(i, 220).Value = "No" Then

                If Cells(i, 37).Value = "Attivo" Then
                    result21 = "No"
                    result22 = "Sì"
                Else
                    result21 = "Sì"
                    result22 = "No"
                End If
            Else
                    result21 = "Sì"
                    result22 = "No"
                End If
            End If
        End If
    Else

        result18 = "No"
        result19 = "No"

        'risultato preliminare1: MONITORAGGIO CADUTE
        Worksheets(2).Cells(i, 34).Value = "Sì"


        If Cells(i, 138).Value = "Sì" And Cells(i, 7).Value = "No" Then     'Vive da solo E Non ha animali domesti
            result20 = "Sì"     'Solo il rilevatore ambientale
            result21 = "No"
            result22 = "No"
        Else
            result20 = "No"
```

Figure 4.9 VBA implementation code - part III

```vba
    Else
        result20 = "No"

        If Cells(i, 19).Value <> "Entrambe" And Cells(i, 219).Value = "No" And Cells(i, 220).Value = "No" Then

            If Cells(i, 37).Value = "Attivo" Then
                    result21 = "No"
                    result22 = "Sì"
            Else
                    result21 = "Sì"
                    result22 = "No"
            End If
        Else
            result21 = "Sì"
            result22 = "No"
        End If
    End If
End If

Worksheets("Assegnazione").Cells(i, 7).Value = result18        'result18 = SERVIZIO DI VOLONTARIATO
Worksheets("Assegnazione").Cells(i, 17).Value = result19       'result19 = APPROFONDIMENTO STORIA DELLA CADUTA
Worksheets("Assegnazione").Cells(i, 22).Value = result20        'result20 = RILEVATORE AMBIENTALE DI CADUTE
Worksheets("Assegnazione").Cells(i, 23).Value = result21        'result21 = CIONDOLO INDOSSABILE
Worksheets("Assegnazione").Cells(i, 24).Value = result22        'result22 = SMARTWATCH


'Undicesima interrogazione
'Valuto assegnazione dispositivi monitoraggio cardiaco
Dim result23 As String, result24 As String, result25 As String, result26 As String

If Cells(i, 204).Value = "Sì" Or Cells(i, 206).Value = "Sì" Or Cells(i, 207).Value = "Sì" Or Cells(i, 208).Value
    Worksheets(2).Cells(i, 35).Value = "Sì"     'Sì al monitoraggio cardio
    result23 = "Sì"

    If Cells(i, 220).Value = "Sì" Or Cells(i, 221).Value = "Sì" Or Cells(i, 19) <> "Nessuna" Then       'Ha almen
        result24 = "No"
        result25 = "No"
    Else        'Non ha pmk/dfb/protesi
        If Worksheets(2).Cells(i, 34).Value = "No" Then     'Non ha avuto monitoraggio cadute
            If Cells(i, 37).Value = "Attivo" Then   'Attivo
                result24 = "Sì"
                result25 = "No"
            Else    'Passivo
                result24 = "No"
                result25 = "Sì"
            End If
        Else    'Ha avuto il monitoraggio cadute
            If Worksheets(2).Cells(i, 24).Value = "Sì" Then     'Ha avuto lo smartwatch
                result24 = "No"
                result25 = "Sì"     'Confermo lo smartwacth
            Else    'Non ha avuto lo smartwatch (quindi ha ambientale o ciondolo)
                If Cells(i, 37).Value = "Attivo" Then   'Attivo
                    result24 = "Sì"
                    result25 = "No"
                Else    'Passivo
                    result24 = "No"
                    result25 = "Sì"
                End If
            End If
        End If
    End If

Else    'No precedente evento cardiaco/IRC

    Worksheets(2).Cells(i, 35).Value = "No"     'No al monitoraggio cardio

    If Cells(i, 192).Value = "Sì" Or Cells(i, 194).Value = "Sì" Or Cells(i, 195).Value = "Sì" Or Cells(i, 196).Va
        result23 = "Sì"
        result24 = "No"
        result25 = "No"
    Else
        result23 = "No"
        result24 = "No"
        result25 = "No"
    End If

End If


Worksheets("Assegnazione").Cells(i, 18).Value = result23        'result23 = VISITA CARDIOLOGICA
Worksheets("Assegnazione").Cells(i, 26).Value = result24        'result24 = MISURATORE ECG TASCABILE
Worksheets("Assegnazione").Cells(i, 25).Value = result25        'result25 = SMARTWATCH

'Valuto a parte l'ipertensione arteriosa
If Cells(i, 193).Value = "Sì" Then      'Ipertensione arteriosa rilevata
    result26 = "Sì"
Else
    result26 = "No"
End If

Worksheets("Assegnazione").Cells(i, 27).Value = result26        'result26 = MISURATORE DI PRESSIONE


i = i + 1
Loop
```

Figure 4.10 VBA implementation code - part VI

```
    'Undicesima interrogazione
    'Valuto assegnazione dispositivi monitoraggio cardiaco
    Dim result23 As String, result24 As String, result25 As String, result26 As String

    If Cells(i, 204).Value = "Sì" Or Cells(i, 206).Value = "Sì" Or Cells(i, 207).Value = "Sì" Or Cells(i, 208).Value =
        Worksheets(2).Cells(i, 35).Value = "Sì"     'Sì al monitoraggio cardio
        result23 = "Sì"

        If Cells(i, 220).Value = "Sì" Or Cells(i, 221).Value = "Sì" Or Cells(i, 19) <> "Nessuna" Then       'Ha almeno
            result24 = "No"
            result25 = "No"
        Else        'Non ha pmk/dfb/protesi
            If Worksheets(2).Cells(i, 34).Value = "No" Then     'Non ha avuto monitoraggio cadute
                If Cells(i, 37).Value = "Attivo" Then   'Attivo
                    result24 = "Sì"
                    result25 = "No"
                Else    'Passivo
                    result24 = "No"
                    result25 = "Sì"
                End If
            Else    'Ha avuto il monitoraggio cadute
                If Worksheets(2).Cells(i, 24).Value = "Sì" Then     'Ha avuto lo smartwatch
                    result24 = "No"
                    result25 = "Sì"     'Confermo lo smartwacth
                Else    'Non ha avuto lo smartwatch (quindi ha ambientale o ciondolo)
                    If Cells(i, 37).Value = "Attivo" Then   'Attivo
                        result24 = "Sì"
                        result25 = "No"
                    Else    'Passivo
                        result24 = "No"
                        result25 = "Sì"
                    End If
                End If
            End If
        End If

    Else    'No precedente evento cardiaco/IRC

        Worksheets(2).Cells(i, 35).Value = "No"     'No al monitoraggio cardio

        If Cells(i, 192).Value = "Sì" Or Cells(i, 194).Value = "Sì" Or Cells(i, 195).Value = "Sì" Or Cells(i, 196).Val
            result23 = "Sì"
            result24 = "No"
            result25 = "No"
        Else
            result23 = "No"
            result24 = "No"
            result25 = "No"
        End If

    End If


    Worksheets("Assegnazione").Cells(i, 18).Value = result23        'result23 = VISITA CARDIOLOGICA
    Worksheets("Assegnazione").Cells(i, 26).Value = result24        'result24 = MISURATORE ECG TASCABILE
    Worksheets("Assegnazione").Cells(i, 25).Value = result25        'result25 = SMARTWATCH

    'Valuto a parte l'ipertensione arteriosa
    If Cells(i, 193).Value = "Sì" Then      'Ipertensione arteriosa rilevata
        result26 = "Sì"
    Else
        result26 = "No"
    End If

    Worksheets("Assegnazione").Cells(i, 27).Value = result26        'result26 = MISURATORE DI PRESSIONE


    i = i + 1
'Ultima interrogazione
'Eventuale assegnazione dello smartphone

'SALVO IN UNA COLONNA L'INFORMAZIONE "Ha ricevuto un dispositivo che usa l'app": sarà result27
Worksheets("Assegnazione").Activate
NumRows = ActiveSheet.Range(ActiveSheet.Range("X5"), ActiveSheet.Range("X5").End(xlDown)).Rows.Count
'MsgBox NumRows

Dim x As Integer, y As Integer, result27 As String

For x = 5 To NumRows + 4
    For y = 24 To 29
        If ActiveSheet.Cells(x, y).Value <> "No" Then
            result27 = "Sì"
            Worksheets("Assegnazione").Cells(x, 32).Value = result27
            Exit For
        Else
            'do nothing
            result27 = "No"
            Worksheets("Assegnazione").Cells(x, 32).Value = result27
        End If
    Next y
Next x
```

Figure 4.11 VBA implementation code - part V

```
'CONTINUA
'Valuto se assegnare lo smartphone a chi ha ricevuto un dispositivo che richiede App
Worksheets("Assegnazione").Activate
Dim k As Integer, result28 As String
k = 5
Do While ActiveSheet.Cells(k, 32).Value <> ""

    If ActiveSheet.Cells(k, 32).Value = "Sì" Then              'Ha ricevuto dispositivo che richiede App
        If Worksheets(1).Cells(k, 31).Value <> "Smartphone" Then    'Non ha lo smartphone
            result28 = "Sì"
            Worksheets("Assegnazione").Cells(x, 32).Value = result27
        End If
    Next y
Next x

'CONTINUA
'Valuto se assegnare lo smartphone a chi ha ricevuto un dispositivo che richiede App
Worksheets("Assegnazione").Activate
Dim k As Integer, result28 As String
k = 5
Do While ActiveSheet.Cells(k, 32).Value <> ""

    If ActiveSheet.Cells(k, 32).Value = "Sì" Then              'Ha ricevuto dispositivo che richiede App
        If Worksheets(1).Cells(k, 31).Value <> "Smartphone" Then    'Non ha lo smartphone
            result28 = "Sì"
        Else
            result28 = "No"
        End If
    Else                                                        'Ha ricevuto ril.ambientale o ciondolo (non richi
        If ActiveSheet.Cells(k, 22).Value = "No" Then           'Non ha ricevuto il ril. ambientale (quindi ha il
            result28 = "No"
        Else                                                    'Ha il ril.ambientale
            If Worksheets(1).Cells(k, 8).Value = "Sì" Then      'Ha la connessione Internet a casa (wi-fi)
                result28 = "No"
            Else                                                'Non ha la connessione Internet a casa
                result28 = "Sì"
            End If
        End If
    End If
    Worksheets("Assegnazione").Cells(k, 30).Value = result28
k = k + 1
Loop
        End If
    Else                                                        'Ha ricevuto ril.ambientale o ciondolo (non richi
        If ActiveSheet.Cells(k, 22).Value = "No" Then           'Non ha ricevuto il ril. ambientale (quindi ha il
            result28 = "No"
        Else                                                    'Ha il ril.ambientale
            If Worksheets(1).Cells(k, 8).Value = "Sì" Then      'Ha la connessione Internet a casa (wi-fi)
                result28 = "No"
            Else                                                'Non ha la connessione Internet a casa
                result28 = "Sì"
            End If
        End If
    End If
    Worksheets("Assegnazione").Cells(k, 30).Value = result28
k = k + 1
Loop


'Colora celle Sì con sfondo verde
Worksheets("Assegnazione").Activate
Dim cell As Range, rng As Range
Set rng = Worksheets("Assegnazione").Range("C5").CurrentRegion
For Each cell In rng
    If cell.Value = "Sì" Then cell.Interior.ColorIndex = 35
Next cell


'FINE



Sub
```

Figure 4.12 VBA implementation code - part VI

4.4 Statistical considerations

The reliability of the algorithm with respect the obtained results has been tested by means of statistical analysis, in terms of sensitivity and specificity.

These mathematical parameters describe, in general, the accuracy of a test in reporting the presence or absence of a determined condition. Individuals for which the condition is satisfied are considered "positive", and those for which it is not are considered "negative".

The test result may or may not match the subject's actual status, who thus can fall into one of the following four categories: (i) true positive (TP), sick people correctly identified as sick, (ii) false positive (FP), healthy people incorrectly identified as sick, (iii) true negative (TN), healthy people correctly identified as healthy, and (iv) false negative (FN), sick people incorrectly identified as healthy.

Knowing these numbers, the sensitivity (true positive rate) and specificity (true negative rate) can be calculated as reported in Equation 1 and Equation 2:

Equation 1 Mathematical expression of the Sensitivity (S)

$$Sensibility = \frac{TP}{TP + FN}$$

Equation 2 Mathematical expression of the specificity (Sp)

$$Specificity = \frac{TN}{TN + FP}$$

In this work, the test is represented by the present algorithm and the condition to be evaluated is the candidature or not of the patient to a fall or cardiac monitoring. This condition has been tested with respect the doctor's clinical opinion in order to evaluate and validate the algorithm performances. The sensitivity indicates the probability of the algorithm to correctly candidate a patient to a fall or cardiac monitoring if he actually requires it. The specificity, instead, represents the probability of the algorithm to do not candidate for a fall or cardiac monitoring a patient that actually doesn't need any monitoring.

5 Results and discussion

In the result section the findings of the study, built upon the methodology applied to gather information, are reported. The algorithm employed allows successfully to generate an automatic and personalised assignation per each patient, which is the main objective of this study. Subordinately this information is elaborated to extrapolate the percent values about specific assignations to the patients.

Fall monitoring and cardiac monitoring preliminary results, as presented in Table 5.1. According to the algorithm definition, the 68% of the total target population (n=50) requires a fall monitoring, with respect the 50% proposed by the clinical evaluation. Matching assignation, which results when the output of the algorithm coincides with the output of the clinician, is reported in 78% of the cases. Non-matching assignation, instead, is 22%. Two situations contribute to this percentage value: the patients who are addressed to a fall monitoring by the algorithm, but not by the clinician, named (C, NC), and the vice versa, that is those patients who are not candidate by the algorithm but candidate by the clinician, and named (NC, C).

This second case represents a more serious situation in that the higher the percentage of (NC, C) the higher the number of patients that need to be followed by a fall monitoring that instead are ignored. However actually, from the study 2% of the cases fall in this group of patients, a very low percentage that corresponds to just one patient who is missed.

To understand the potential of the developed algorithm as well as its reliability, a statistical analysis has been performed in terms of sensitivity and specificity. Sensitivity measures how often the algorithm generates a positive result for people who present the condition that's being tested for, that is the candidature for a fall monitoring, and it's also known as the true positive rate. Specificity, instead, measures the algorithm ability to correctly generate a negative result for people who don't have the condition that's being tested for, and it's also known as the true negative rate.

Table 5.1 Comparison of fall and cardiac monitoring between algorithm and clinician evaluations

	Algorithm	Clinician
Fall monitoring candidates	68%	50%
Matching assignation	78%	
Non-matching assignation	22%	
(NC, C)	2%	
Sensitivity	96%	
Specificity	60%	
Cardiac monitoring candidates	84%	56%
Matching assignation	64%	
Non-matching assignation	36%	
(NC, C)	4%	
Sensitivity	93%	
Specificity	27%	

Specifically, for fall monitoring assessment the algorithm shows high sensitivity (96%), which means it doesn't miss needy patients, and medium specificity (60%), which means the algorithm is not highly performant in ruling out people who are not needy. So this second aspect should be improved.

Continuing the results analysis, the 84% of the total target population requires a cardiac monitoring in accordance with the algorithm method, while the clinician proposes a 56% percentage. This corresponds to a matching assignation in 64% of the cases, and a non-matching assignation in 36% of the cases. Once more, considering the percentage of (NC, C) which contributes to the non-matching assignation, the number of people who would require a cardiac monitoring but instead are ignored by the algorithm can be evaluated: the value is 4%, slightly higher with respect the fall monitoring assessment, but still a very low percentage which indicates that only two patients are incorrectly classified by the algorithm.

Even in this second part, performance and strength of the algorithm are evaluated by means of sensitivity and specificity parameters.

The sensitivity is again a high value (93%), which means patients in need of a cardiac monitoring are correctly identified by the algorithm. However, the specificity is very low (27%), because many patients are addressed to a cardiac monitoring even if they don’t need it.

To take stock of these preliminary results, high sensitivity and low specificity values support the conclusion that the present algorithm adopts a more preventive and protective approach that leads to higher percentages of patients assigned to both a fall or cardiac monitoring with respect those identified by the clinical evaluation. This conservative strategy, however, doesn’t exclude and correctly always recognises the needy patients, apart from very low percentages.

Then, the assignation percentages corresponding to the patients addressed to each specific device included in the present study, are reported in Table 5.2. There are more patients assigned to a wearable sensor, which are low-technological impact devices, both for fall and cardiac prevention. In fact, the wearable pendant is given to the 40% out of the 68% fall monitored, and the smartwatch for cardiac monitoring is given in the 68% of the cases out of the 84% cardiac monitored. This is understandable finding since the 80% of the patients belongs to the passive class, which means low predisposition to the technology, while just the 20% falls in the active class, that means greater inclination to technology.

Table 5.2 Assignation percentages of fall and cardiac prevention devices

Fall devices	**Ambient system**	**Wearable pendant**	**Smartwatch**
Candidates	18%	40%	10%

Cardiac devices	**Smartwatch**	**Pocket ECG device**	**Pressure device**
Candidates	68%	6%	98%

Others	**Tablet**	**Smart scale**	**Smartphone**
Candidates	18%	74%	76%

Finally, significant percentages emerge from the smart scale (74%) and the smartphone assignations (76%). The latter means patients would require connection to use the assigned devices, but they don't have it (Wi-fi or smartphone as hotspot).

Switching to the assessment of services and follow-up visits considered in the algorithm and assigned to the patients, results are reported in Table 5.3 and Table 5.4, respectively.

For what concern the services, the most significant percentages which obtain the highest scores are for social supports like transportation and accompaniment service (64%) to facilities for a visit for example, and social worker (66%), conceived as a person who keep elderly company as well as offers entertainment activities.

But also, very important percent values are recorded for psychological supports, in both group therapy (84%) and occupational therapy (82%), which the highlight need of an intervention in response to a widespread critical depressive and anxious status among the elderly. Then, the importance of exercise training is not fully explored by the fifty elderly participants, because many of them are suggested to improve their physical activity (74%), performing regular exercises on the base of their preferences. In particular, those with risk or confirmed sarcopenia, are indicated for muscle tone exercises (66%) that can increase muscle mass and reduce muscle weakness.

Finally, the most needed visits are the nutritional visit specific for weight control (74%), the renal functionality examination (76%), and the cardiological visit (100%).

Not be entirely negligible is the fall reconstruction visit (30%), assigned to those who are classified at low fall risk according to the quantitative scales, but have experienced single or frequent falls in the recent past that merit consideration.

The cardiological visit results assigned to whole target population because, even if the patients do not report any precedent cardiac event or chronic renal insufficiency (CRI), almost everybody present at least one among the considered cardiovascular risk factors (smoking, diabetes, familiarity, hypercholesterolemia, and obesity).

Table 5.3 Assignation percentages of services

Services	**Social support**				
	Home assistance	Walking aids	T & A service	Social worker	Volunteering
Candidates	14%	8%	64%	66%	32%

	Psychological support		**Physical training**		
	Group therapy	Occupational therapy	Muscle tone exercises	Physical activity	AFA, walking groups
Candidates	84%	82%	66%	74%	24%

Table 5.4 Assignation percentages of follow-up visits

Follow-up visits	**Neurological**	**Weight control**	**Sarcopenia**	**Dietary consultation**	**Renal functionality**
Candidates	22%	74%	14%	28%	76%

	Hearing test	**Eye test**	**Fall reconstruction**	**Cardiological**
Candidates	16%	2%	30%	100%

In conclusion, a comparison about the assignation of the neurological visit between the algorithm and clinical evaluations is reported in Table 5.5. The algorithm, which assigns the neurological visit in presence of severe dementia (MMSE) or history of precedent ictus, candidates the 22% of the patients, compared with the 26% proposed by the clinician. This corresponds to a matching assignation of 88%, and a non-matching assignation of 12%. In this case the number of needy patients who are ignored by the algorithm increases to 4 persons (8%). This can be also appreciated by the low sensitivity (69%) and the high specificity (95%) estimated with the statistical analysis.

Table 5.5 Comparison of neurological visit assignation between algorithm and clinician evaluations

	Algorithm	Clinician
Neurological visit candidates	22%	26%
Matching assignation	88%	
Non-matching assignation	12%	
(NC, C)	8%	
Sensitivity	69%	
Specificity	95%	

6 Conclusions

The present work proposes an automatic and personalised approach which focuses on providing tailored interventions to elderly people with good level of mobility and no cognitive impairments.

The choice of a dichotomous decision-tree like model proved to be effective and simple solution to define the conditional rules for the customised recommendations to the patients.

The decision-making process is designed to undertake multicomponent assessments and actions to improve quality of life of older adults and their living conditions. This incorporates the idea that critical or acute events are often connected to a multidimensional disease state, and that prevention in turn should be targeted to the many and different social and clinical aspects of the person.

This is not new for the health and social care system, but the novelty of the present work is the translation of this concept into an automatic algorithm that promises to be a clinical decisions support instrument.

Thus, the individual frailty risk across multiple domains, namely motor-function, cardiological-cardiovascular, nutritional, psychological, and social domains, is evaluated and will be monitored with technological supports or supplementary analysis, depending on the specific characteristic of patients and tools.

According to the algorithm, the 68% of the patients requires a fall monitoring (in contrast to the 50% proposed by the clinician) and within the 22% non-matching assignation cases, just one patient falls in the group of those who are assigned by the clinician and not assigned by the algorithm (2%), that is the data that must be carefully observed. Fall monitoring assessment shows high sensitivity (96%) and good specificity (60%). Then, algorithm proposes 84% of the patients to a cardiac monitoring (instead, 56% are candidate by clinician), and within the 36% non-matching assignation cases, just two patients belong to the critical group. Sensitivity is still high (93%), but specificity lowers (27%).

The clinical and social experts' evaluations consolidate the results of the fall and cardiac monitoring, demonstrating the ability and efficacy of the developed algorithm in successfully associating the most suitable interventions for each user.

However, the methodology adopts a more conservative and preventive approach, in that some, although few, patients are addresses to the monitoring contrary to the clinicians' classification. Future work will include optimization of the algorithm to improve its ability in recognising with higher accuracy the eligible candidates from those who instead don't need a monitoring system.

In addition, when information is lacking, because for example a test or an examination have not been completed during the screening, the strategy of the algorithm will be modified so that the clinician is informed about this void and provides for fixing the problem.

Deep in the assignation, the majority of patients receives a low-technological impact device for fall or cardiac monitoring, in accordance with the fact that 80% of the population presents low predisposition to the technology (passive class). These findings suggest that older people are lagged behind the rest of the population in having means and ability to access the internet.

So programs and actions should be considered to improve the digital skills of the elderly participants and to close this digital divide in order to give them the opportunity to take advantages of the great benefits the digital technologies can have in their lives.

For what concerns services and follow up visits, the highest scores were observed for social and psychological supports as well as for physical training, and for nutritional, renal functionality, and cardiological examinations, highlighting the need for improving interventions in these areas.

In conclusion, the work achieves the main objective that is to provide elderly people with assistive set of products and services that matches their clinical and social needs, by using an automatic strategy.

The presented algorithm reveals to be promising and reproducible for future applications that aim to extend to a different and wider sample of participants the developed approach.

Future implementations may also include new and update smart technologies to help older adults remaining active and independent within and away domestic context.

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