

Sustainable Technologies for Older Adults

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Abstract: The exponential evolution of technology and the growth of the elderly population are two phenomena that will inevitably interact with increasing frequency in the future. This paper analyses scientific literature as a means of furthering progress in sustainable technology for senior living. We carried out a bibliometric analysis of papers published in this area and compiled by the Web of Science (WOS) and Scopus, examining the main participants and advances in the field from 2000 to the first quarter of 2021. The study describes some interesting research projects addressing three different aspects of older adults' daily lives—health, daily activities and wellbeing—and policies to promote healthy aging and improve the sustainability of the healthcare system. It also looks at lines of research into transversal characteristics of technology. Our analysis showed that publications mentioning sustainability technologies for older adults have been growing progressively since the 2000s, but that the big increase in the number of research works in this area took place during the period 2016–2021. These more recent works show a tendency to study those factors that improve healthy aging, ensure the social inclusion of the elderly through technology and prolong the time in which they can live independent lives thanks to smart environments. Current research gaps in the literature are also discussed.

Keywords: older adults; sustainability; technology; readability; Internet of Things; sustainable development goals; smart cities; robotics; gerontology; health care

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1. Introduction

Globally, life expectancy is increasing and society is aging. In 2019, there were 703 million people aged 65 years and it is estimated that in 2050 there will be 1500 million [1], representing 16% of the total population. Forecasts predict that in 2050, for the first time in history, the population over 65 years of age will outnumber the population under 10 years of age (Table 1). The reasons for these demographic changes vary, although the principal explanations are the reduction in the fertility rate and improvements in the probability of survival at advanced ages. This population aging will transform age-patterns of production and consumption and constitute a challenge for the sustainability of public pension systems. It is also estimated that the adult population will become a vulnerable group, being affected mainly by two of the 17 Sustainable Development Goals enacted by the UN General Assembly for 2030 [2]: Goal 1—No poverty and Goal 5—Gender equality.

Table 2 shows the poverty levels of older adults in the most populated OECD countries according to the OECD report Pensions at a glance: OECD and G20 Indicators [3]. People are considered to be in poverty if they have an income that is less than half of the national mean equivalized disposable household income. The data show how poverty is more frequent among the elderly and the gap is wider when we consider gender. Older women are poorer than older men.

Table 1. World population trends for under 10 s and over 65 s. Bold data indicates the outnumbering of the young population (source: [1]). Figures are expressed in thousands.

Location	Age	2015	2020	2040	2050
World	<10	1,315,380	1,342,381	1,362,524	1,376,017
	>65	607,548	727,606	1,300,516	1,548,854
Africa	<10	346,678	381,403	496,260	545,328
	>65	39,729	47,096	97,501	143,103
Asia	<10	731,698	726,754	653,233	622,039
	>65	331,498	411,604	802,394	954,680
Europe	<10	80,088	79,821	68,157	69,258
	>65	130,515	142,905	188,280	199,896
Latin America	<10	105,561	103,887	91,447	85,470
	>65	48,356	58,651	113,560	144,623
North America	<10	44,857	43,706	46,069	46,153
	>65	52,787	61,901	89,894	96,278

Table 2. Percentage of income poverty in older adults in the most populated countries in the OECD (source: [3]).

Country	Percentage of Total Population Living in Poverty	Older Adults Poverty (All)	Older Adults Poverty (Male)	Older Adults Poverty (Women)	Difference Total vs. Older Adults	Genre Difference
China	28.8	39	37.9	40.1	10.2	2.2
Mexico	16.6	24.7	23.3	25.9	8.1	2.6
United States	17.8	23.1	19.6	25.9	5.3	6.3
Japan	15.7	19.6	16.2	22.3	3.9	6.1
United Kingdom	11.9	15.3	12.5	17.7	3.4	5.2
India	19.7	22.9	21.9	24	3.2	2.1
OECD	11.8	13.5	10.3	15.7	1.7	5.4
Russia	12.7	14.1	8.4	17	1.4	8.6
Turkey	17.2	17	14.9	18.5	−0.2	3.6
Germany	10.4	9.6	7.4	10.6	−0.8	3.2
Brazil	20	7.7	7.5	7.8	−12.3	0.3

To mitigate the macroeconomic impact of this population aging, the UN proposes promoting lifelong learning systems, extending health care to the entire population, encouraging healthy lifestyles, advocating savings, improving the employability of the elderly, avoiding the gender gap, delaying the retirement age and improving family reconciliation [1].

The United Nations defines sustainability in a broad sense, as actions to meet the needs of the present without compromising the ability of future generations to meet their own needs. Under this premise, the UN proposed the sustainable development goals as actions and priorities to be carried out in order to reduce poverty, improve health and education, reduce inequalities, grow economically, preserve nature and reduce the risk of climate change [2]. Achieving sustainable development goals requires addressing three essential challenges: economic, social and environmental. Tables 1 and 2 show data concerning sustainability problems. It is clear not only that the elderly will in the future take on greater sociodemographic importance, but also that there is a problem of economic insufficiency, especially in relation to the female gender. Technologies to tackle these problems should thus address the aspects of population growth, poverty and gender.

One factor that cannot be ignored is the impact of aging on health. Low fertility and mortality rates have not only a demographic but also an epidemiological impact. In the coming years, diseases will be more closely linked to aging populations with greater resources. By 2030, the WHO [4,5] has predicted increases in heart disease, cancer and diabetes, and decreases in perinatal mortality, parasitic infections and malnutrition. Mo-

bility impairment and dementia will follow a pattern of growth, especially in countries with fewer resources. According to the aforementioned report, in developed countries 30% of the elderly over 85 and 50% of those over 90 suffer from dementia. Older adults face conditions that may have been acquired during the course of their lives, such as brain injuries or dementia. Aging increases the risk of dementia, the most common cause of which is Alzheimer's disease (70%), with symptoms such as forgetfulness, temporal and spatial disorientation and communication difficulties. According to the Ageing Report, in 2050 one third of the European populations will be over 65 years old. The WHO [6] estimates that 5–8% of this population will suffer from dementia. In this regard, ageism (discriminatory attitudes towards certain age groups) is growing. The data show that ageism has a negative impact on the health of older adults. In [7], prevalence of this prejudice was estimated to affect 50% of the population.

The economic impact of declining health and decreasing retirement ages is a growing concern. Deteriorating health coupled with increased longevity requires long-term care. The experience gained, the existence of less strenuous jobs and the likelihood of reaching old age while maintaining good health mean that retirement policies must be evaluated. Another aspect worthy of consideration is loneliness; support for families would benefit both families and older adults. Despite this fact, the number of people living alone, in institutions or alone with their spouse has increased in recent years. All these aspects can be improved by keeping the elderly healthy for longer. The UNO report on "Ageing, Older Persons and the 2030 Agenda for Sustainable Development" raised the question of why ageing and older adults matter for development. The report highlighted the importance of the elderly in economic development as a workforce in roles which include unpaid care work in support of their families, political and associative participation and active volunteering in their communities.

This article reviews technological initiatives aimed at the older adult population. The technological proposals identified are addressed from the point of view of sustainable technologies and how they can prolong older adults' health for longer, promote their social and work participation, facilitate independent living for longer, provide onsite medical care and remote medical surveillance and improve well-being, and the extent to which older adults can contribute, with their experience, to the community. Even though, in this regard digital divide should be studied in his group. Digital divide problems are related to different factors: on the one hand, digital skills and the degree of literacy of the elderly, on the other, the way information is published (issues of web design, text readability, legibility, etc.).

The rest of the paper is structured as follows. In the next section, the materials and the method followed are described. A quantitative analysis is then presented, explaining the evolution of this field of study and the progress made. This section also details the network of documents and the citation analysis. In the next section, the main projects and lines of research in the different subfields of the subject are summarized, and finally there is a discussion of the main findings.

2. Materials and Methods

We conducted a systematic literature review based on Kitchenham's procedures [8] and adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Statement) guidelines [9]: identification, screening, eligibility and inclusion. To perform the review, it was necessary to determine the research questions, the data source, the analysis process and the study's limitations.

2.1. Research Question

First, we identified the research question. The main research questions addressed by this study were:

RQ1: What are the main patterns observed in the publication of research in this area?

RQ2: What topics and research areas are addressing older adults?

RQ3: How have sustainable technologies for older adults evolved?

RQ4: What research topics require further attention?

2.2. Resources

To answer these questions, a search for sustainable technologies for older adults was performed in the WoS and Scopus databases. The Clarivate Analytics Web of Science (WoS) database was created by the Institute for Scientific Information (ISI) in the fifties. Scopus was launched in 2004, although it had been compiling papers prior to that year. These resources complement each other insofar that their coverage is different. Some countries, such as Spain or India, have larger coverage in Scopus. In 2016, Mongeon and Paul-Hus [10] analyzed the overlap, showing relevant different levels of overlapping in different fields. Both resources represent the main data sources used in bibliometric and bibliographic studies. The search strategy was unaffected by temporal, geographical or subject limitations. The two databases cover different resources, including disciplines from different fields such as social sciences, technology, natural sciences, medicine or humanities. Scopus and WoS are the largest databases of abstracts and citations of peer-reviewed literature.

2.3. Search Process

The search process, to identify articles relevant to our study, was designed focusing on words related to the three main areas (Table 3), with “older adults”, “sustainability” and “technology” being searched for in abstracts. Specific words, synonyms and near words were selected. For “older adults”, the following words were searched for: (old * NEAR adult *) OR (old * NEAR people) OR (elder * OR “senior citizen *” OR geriatric * OR gerontology). For “technology”, the words selected were: (technol * NEAR sustaina *) OR (digital * NEAR sustaina *) OR (ICT NEAR sustainab *) OR (greentech OR cleantech OR cybernetics OR robotics OR “artificial intelligence” OR “big data” OR informatics OR computer OR software OR IOT). Finally, terms related to “sustainability” were searched for in titles, abstracts, sources or categories. These words were Sustainab *, “foot print”, CSR, Greentech, cleantech or “corporate social responsibility”.

Table 3. Search queries (SQ) performed in WoS and Scopus. Asterisks are used as wildcards, replacing zero or more characters at the end of the word.

Objective	Query Scopus	Query WoS	Justification
SQ1: Identify topics and related research areas addressing older adults	(ABS (old * W/5 adult *) OR ABS (old * W/5 people) OR ABS (elder * OR “senior citizen *” OR geriatric * OR gerontology) AND NOT ABS (elderberry * OR elderflower *))	(AB = (old * NEAR adult *) OR AB = (old * NEAR people) OR AB = (elder * OR “senior citizen *” OR geriatric * OR gerontology) NOT AB = (elderberry * OR elderflower *))	Terms such as elderberry and elderflower has been discarded to avoid retrieving irrelevant documents.
SQ2: Identify how technology is used in this group and for what purposes	AND (ABS (technol * W/5 sustaina *) OR ABS (digital * W/5 sustaina *) OR ABS (ICT W/15 sustainab *) OR ABS (greentech OR cleantech OR cybernetics OR robotics OR “artificial intelligence” OR “big data” OR informatics OR computer OR software OR IOT))	AND (AB = (technol * NEAR sustaina *) OR AB = (digital * NEAR sustaina *) OR AB = (ICT NEAR sustainab *) OR AB = (greentech OR cleantech OR cybernetics OR robotics OR “artificial intelligence” OR “big data” OR informatics OR computer OR software OR IOT))	Terms have been selected based on common technologies used in this group. Technologies such as greentech and cleantech are sustainable.

Table 3. Cont.

Objective	Query Scopus	Query WoS	Justification
SQ3: Identify the extent to which the use of technology contributes to sustainability in a broad sense (technology, people and systems).	AND ((TITLE-ABS-KEY (SUSTAINAB *) OR SUBJAREA(SUSTAINAB *) OR SRCTITLE(SUSTAINAB *)) OR (ABS ("foot print" OR "corporate social responsibility" OR CSR OR greentech OR cleantech)))	AND ((TS = (SUSTAINAB *) OR KP = (SUSTAINAB *) OR SO = (SUSTAINAB *)) OR AB = ("foot print" OR "corporate social responsibility" OR CSR OR greentech OR cleantech))	The generic term "sustainability" has been used in a broad sense to encompass mainly sustainability applied to technology, but also people's standard of living and the sustainability of the global systems that support them.

In the screening process, we checked the query until results were obtained which included as little document noise as possible. The study targeted all types of documents, including papers, conference papers and book chapters. We excluded duplicated papers.

2.4. Data Collection Analysis

The publications found in WoS and Scopus were analyzed in two different phases. First, a descriptive analysis was performed, showing how the topics and areas in this domain had evolved and identifying the main actors involved in the research. Secondly, those papers which, in our opinion, better described the advances made and current proposals were subject to a content analysis. This phase concentrated on advances in the main fields that make up this area of study. In the first phase, bibliometric features, subjects and keywords were analyzed. From each paper, the following data were extracted and tabulated:

- Type of document (book chapter, paper, conference paper).
- Author: full name and affiliation (in order to identify institutions and countries conducting research into sustainable technologies for older adults).
- Title and abstract (to explore technological trends and methods).
- Keywords assigned (to explore topics and subjects).
- Research area categories (to identify emerging areas).
- Source title (to determine what journals are significant in this area).
- Publication year (to learn about how research in the area has evolved over time).
- Number of citations (to identify relevant studies).
- Funding organization (to identify organizations that fund this type of research).

2.5. Study Limitations

The technologies discussed in this article are currently widely used not only with the elderly but also with other population groups. Our search focused on those articles in which the authors expressly stated in the abstract that sustainability was improved through the application of their technology to the elderly. In other words, we excluded articles which, despite describing applications of technologies to older adults, did not mention or relate the research to sustainability. The query was executed in both databases in English, and the results obtained therefore contained text in that language. No other restrictions related to document type, publication period or geographical location were applied in the search.

3. Results

In this section, we summarize the results of the study.

First, we show the results of the search process, which will allow the partial detection of the main patterns observed in the publications of the research in this area (RQ4). Then, the results of the data analysis are shown, allowing to answer the RQ1–RQ4 research questions.

3.1. Search Process Result

As a result of the search in databases, 207 resources were identified in WoS, and 246 studies in Scopus. In total, the two databases analyzed provided 330 different articles. Of the total number of documents, 122 (37%) were found only in Scopus, and 84 (25%) were found only in WoS, while 124 (38%) were shared by both. From the results of the query, 7% of the publications in the dataset were rejected due to noise.

3.2. Data Analysis Results: Timeline and Publication Sources

The timeline for publications about sustainability technologies for older adults began to increase in the 2000s. The number of publications increased steadily from 2008 to 2016, and then significantly from 2016 onwards. Figure 1 shows the distribution of the scientific works published during the period 1999–2020. The number of documents collected from WoS and Scopus is different, because each database is fed by different research sources. However, the trend is similar in both databases.

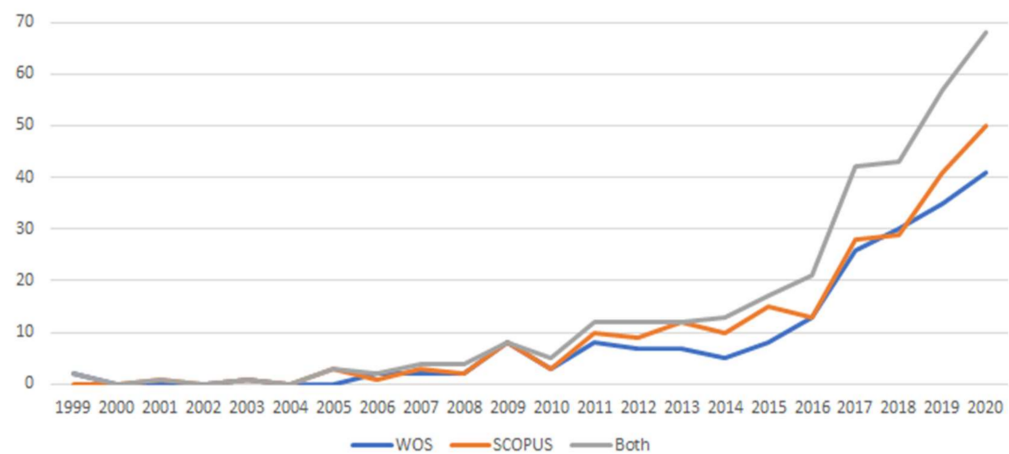


Figure 1. Distribution of research works during the period 1999–2020.

Regarding publication sources, many papers have been published in research journals, 43.1% of them appearing in 106 journals in Scopus and 46.4% of them appearing in 95 different journals in WoS. The main two journals of each database are shown in Table 4, including the number of papers published. The journal Sustainability is one of the top publication sources and it stands out in both databases for its number of publications related to sustainable technologies for older adults. Other representative publications are associated with the areas of information technology and health, although the results reflect a wide variety of publication sources.

Table 4. Top publication sources (≥ 4 papers) in Scopus and WoS.

Source	Scopus	Source	WoS
Lecture Notes in Computer Science	15	Sustainability	16
Sustainability	13	BMC Geriatrics	4

3.3. Data Analysis Results: Countries, Institutions and Organizations

Figure 2 shows the countries associated with the authors' affiliations. Differences in geographic coverage can be seen between the two databases. The largest contributions come from the United States, the United Kingdom and China, each with 25 papers on the subject. In addition to the United Kingdom, other Western European countries feature prominently. Other geographical areas contributed much fewer publications.

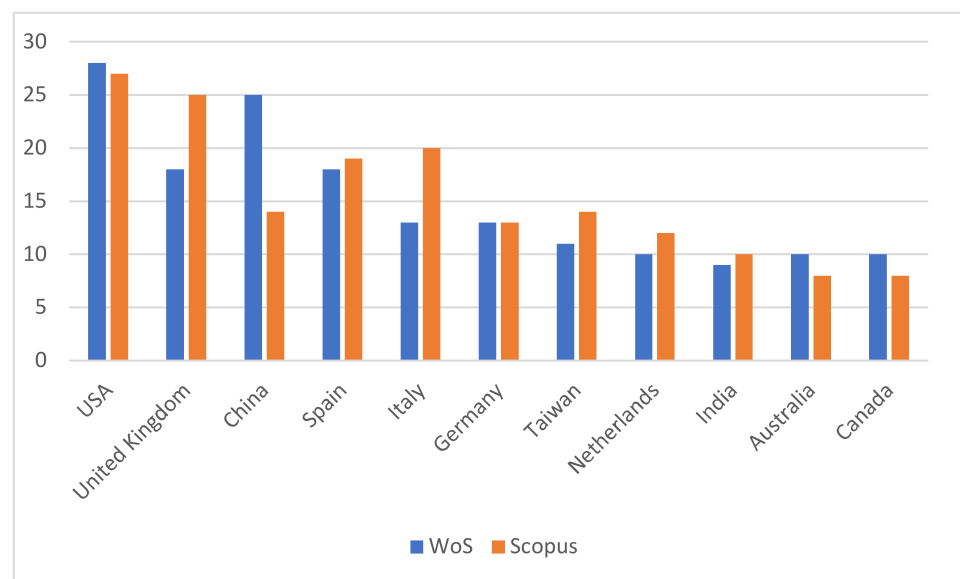


Figure 2. Countries associated with authors and publications from WoS and Scopus.

The relationship between each author and each country is determined by affiliation. In this regard, it is interesting to note which organizations are more prevalent in the two databases. One interesting feature is the large number of authors (researchers) who appeared in both databases. In WoS there were 885 different authors for 207 publications. Only 24 had authored two items, the rest just one. The same pattern can be seen in Scopus, with 992 different authors, of whom only 29 had authored more than one publication. The average number of authors per paper was 4.4 (SD 4.24) in WoS, and 4.1 (SD 3.88) in Scopus. The maximum number of authors per article was 29. Table 5 shows an example of the top institutions that have conducted research in this field, with at least 3 papers published. A total of 13 institutions in Scopus, and a total of 10 institutions in WoS. Note the prominence of Italian research institutions (U. Pisa, CNR) in both databases.

Table 5. Top affiliations in Scopus and WoS.

Affiliation Scopus	#	Affiliation WoS	#
Università di Pisa	4	CNR	4
Loughborough University	3	Univ New South Wales	4
Cumming School of Medicine	3	Arizona State Univ	3

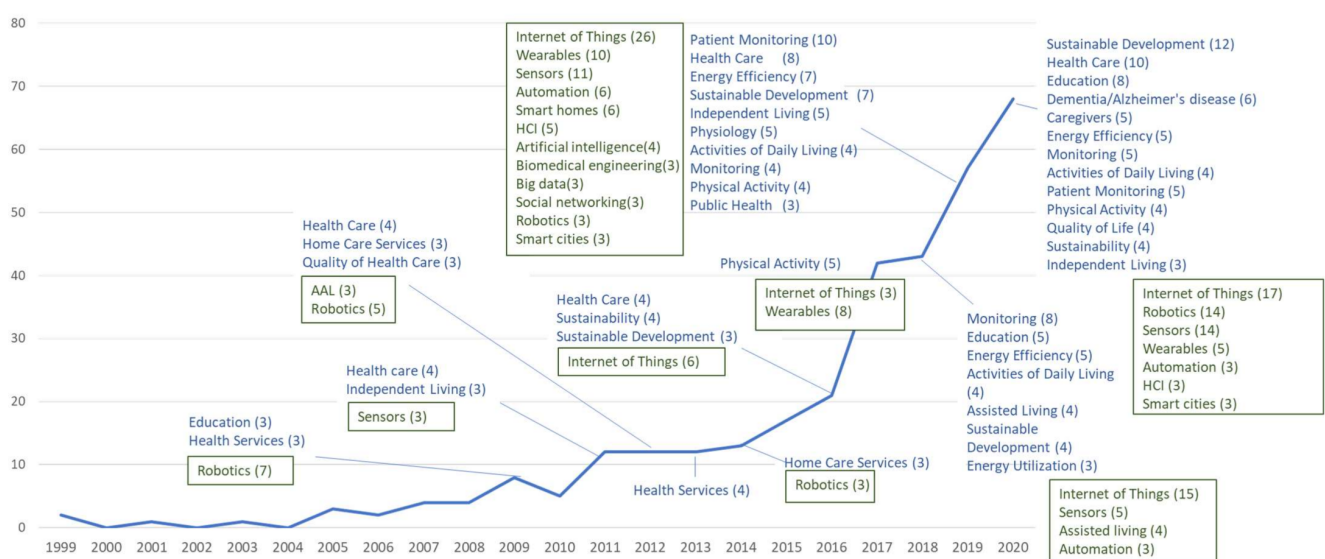
Regarding the organizations funding this research, it is important to mention that not all projects are funded, and that the two repositories (Scopus and WoS) differ in their geographic coverage and their ways of organizing the data. This explains the differences shown in Table 6. The data from Scopus highlight programs funded by the European Union or promoted by European countries. Furthermore, noteworthy is the amount of research carried out under the auspices of the Chinese and Taiwanese governments, the National Health and Medical Research Council of Australia, and the United States. In the WOS database, the main funding programs correspond to the European Union, although institutions from the United States, China, Australia and Japan also play important roles (Table 6).

Table 6. Top funding organizations in Scopus and WoS.

Funding Sponsor—Scopus Corpus	# Scopus	# WoS
Horizon 2020 Framework Programme	7	-
United States Department of Health and Human Services	-	6
European Commission	5	9
National Natural Science Foundation of China	4	5
Engineering and Physical Sciences Research Council	3	3
National Institutes of Health	3	5

3.4. Data Analysis Results: Subjects and Keywords

Analysis of the keywords linked to the scientific documents reflected different research issues or domain applications (in blue and squared in Figure 3) and technologies applied (in blue in Figure 3) in the period 1999–2020. The average number of keywords per paper was 4.94 in WoS and 12.53 in Scopus. Figure 3 shows the keywords and technologies with at least 3 occurrences. Prominent subject trends in research into sustainable technology and older adults included Ambient Assisted Living (AAL), mHealth (Mobile Health), IoT (Internet of Things), BigData, Smart Cities, RFID (Radio-frequency identification), etc. Scopus also included some keywords related to methods, the most cited terms including surveys and questionnaires (12), behavioral research (7), qualitative research (7), decision making (5), treatment outcome (5), randomized controlled trial (5), interview (4), clinical study, (4) and prospective study (4).

**Figure 3.** Main concerns and technology based on keywords in the papers (≥ 3 occurrences) in Scopus.

Network analysis of the keywords showed the relevance of each node. Figure 4 shows the clusters. The font size is larger when the number of inbound links, the degree, is higher. Inbound links are the number of papers that mention the keyword. In the figure, the clusters are identified with a number and labeled with the most relevant keyword in the node.

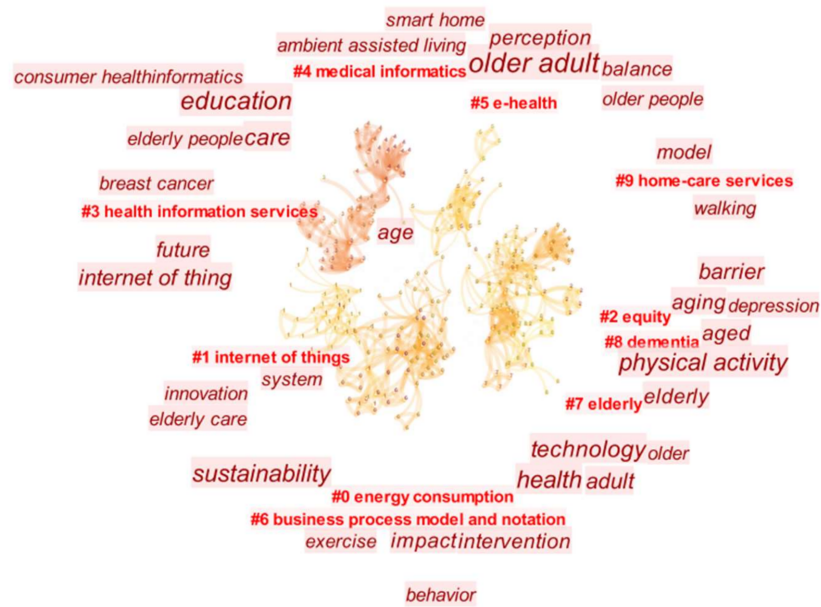


Figure 4. Relevance and clusters of keywords related to sustainability technology and older adults in the WoS collection.

Figure 5 shows the distribution of the documents by subject according to the classification defined in the WoS and Scopus databases. The categories and assignment criteria differ in the two databases, but their organization is similar. In both cases, the main category is Computer Science. They also agree in the Engineering, Environmental Science and Business, but not in other categories. Other categories, such as Science Technology, seem to be underrepresented in Scopus, undoubtedly due to the application of different allocation policies, and other categories of Scopus are underrepresented in WoS, such as Social Sciences.

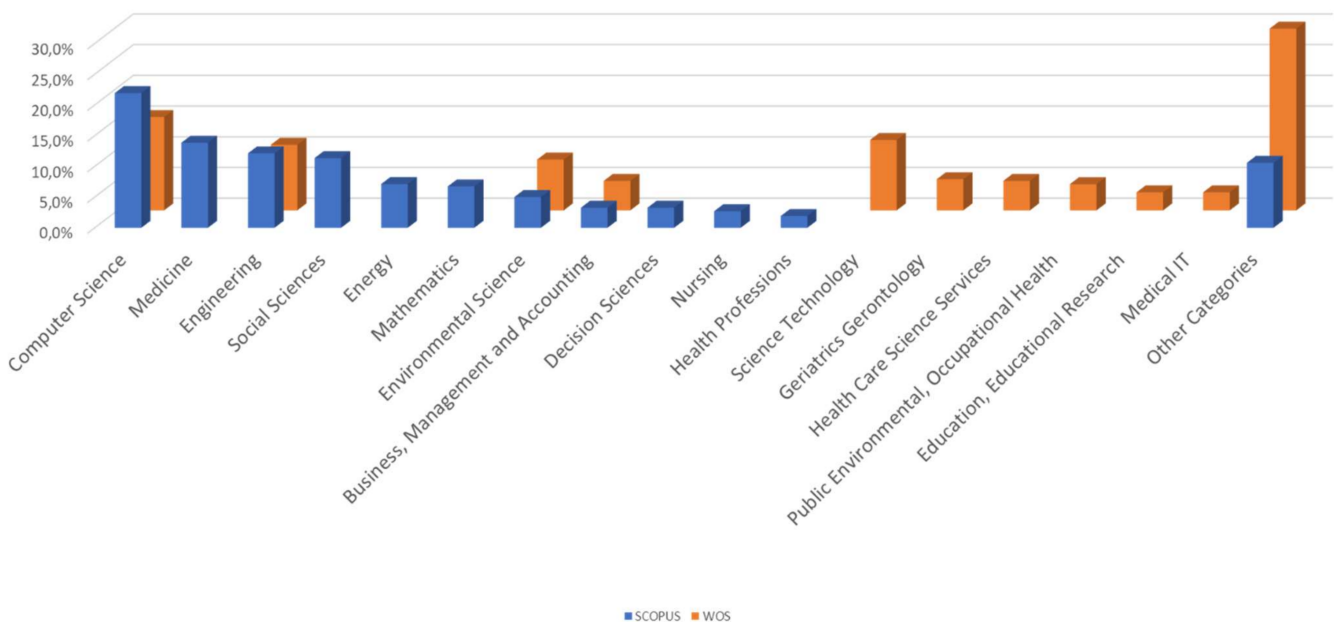


Figure 5. Distribution of the documents by subject in WoS and Scopus.

3.5. Data Analysis Results: Citation Report

Regarding the citation process, 1150 papers were referenced in the documents from the Scopus dataset, while 1156 references were mentioned in the WoS dataset. In Scopus, each document was cited on average 4.63 times, while each document in WoS was mentioned 5.61 times. Both databases have an H-index for these documents of 17. Figure 6 shows the number of citations per year for documents retrieved from Scopus and WoS. The data thus confirm the upward trend in studies related to sustainable technologies for older adults over the last 15 years. The main subjects treated in these documents are summarized in Figure 6.

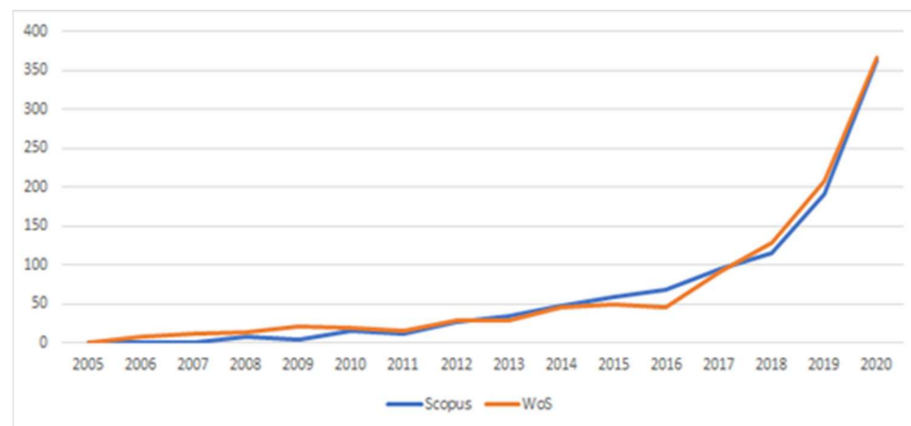


Figure 6. Publication year of the references cited in the documents retrieved from Scopus and WoS.

The references citing the 207 documents in WoS were published in 162 different sources. Table 7 shows the main journals cited. The largest number of papers were published in Sustainability, followed by the International Journal of Environmental Research and Public Health.

Table 7. Main sources in the citation report.

Source Titles	#	%
Sustainability	41	3.53%
International Journal of Environmental Research and Public Health	23	1.98%
Sensors	21	1.81%
IEEE Access	18	1.55%
Journal of Cleaner Production	13	1.12%
Multimedia Tools and Applications	13	1.12%

3.6. Content Analysis Results. Sustainable Technology and Older Adults

The papers analyzed described different sustainable technologies. They could be grouped into three different categories dealing with different aspects of the daily life of older adults: (1) eHealth, which includes papers related to disease prevention, detection and treatment, tele-health and health applications, among other issues; (2) daily activities and wellbeing, which includes different kinds of activities performed by older adults in their daily lives, such as education and training, leisure time, social communication and physical and emotional well-being; (3) policies and strategic plans, which includes technology related to global and systematic strategies affecting older adults, such as environmental or financial sustainability, sustainable living and transport.

There was also a cross-cutting category encompassing different projects such as usability, the study of behavioral patterns in the target population, design methodology and iterations of the different types of actors involved in conducting the projects.

The sustainable technologies applied to each of these categories are summarized below for each category, referencing the main research projects and systems found in the literature

and showing, at the same time, the main trends and strengths of using this technology in a sustainable way. The categorization is based on the main component, as these are not disjoint categories. In fact, the projects have some highly cross-cutting components such as usability design, system accessibility and communication between stakeholders that we summarize in Section 3.6.4. On the other hand, technology is mixed at some points to build sustainable applications for each category. In the sections below, in order to give a structure to the large amount of data, we have organized the information according to the major technology applied in each project, which is the main focus of the article to which it refers.

3.6.1. eHealth

Next, the main research projects and works in eHealth are summarized and organized by the main technology applied. Moreover, Table 8 summarizes the main trends, strengths and weaknesses of using sustainable technology for eHealth and elderly life, answering to the Search Questions (SQ) that the paper defines in Table 3: main research areas addressing older adults, how technology is used and for what purposes, and extent in which technology contributes to sustainability.

eHealth and Information and Communication Technologies

In the field of medicine, Information and Communication Technologies (ICTs) are used to create sustainable conditions aimed at improving the quality of life of older adults and mainly related to illness prevention, detection and treatment. Information and Communication Technologies include mobile or desktop applications. Improvements in healthcare have significantly benefitted the population, above all older adults and their families.

One example of using technology for illness prevention is the initiative to implement immunization triage programs in an emergency department to achieve a sustainable system, reported in [11]. This work examined whether information technology provided a viable, sustainable method for increasing vaccination rates in an adult emergency department. The computerized reminder system produced positive results by increasing vaccination rates.

Along the same lines, Graham's work [12] proposed an integrated digital/clinical approach to reducing tobacco dependence. This was accomplished by leveraging the digitization of clinical information to proactively connect smokers to smoking cessation treatment. The treatment involved digital interventions such as web-based and text messages. The main finding of this study was that when used in lung cancer screening programs digital interventions are a feasible, scalable, sustainable method for engaging more patients in smoking cessation treatment.

In addition, Drobits et al. propose an ICT platform to promote healthy activities for everyone (including older adults) [13]. The platform allowed people to take control of their health, harmonizing medical, care and lifestyle services. It promoted, supported and monitored health related activities, enabling older adults, for example, to monitor exercises prescribed by their doctors.

Other proposals addressed illness detection. A research project carried out by [14] focused on detecting pathologies such as cardiovascular events. Other initiatives were treatment-oriented. For example, Smith's work [15] proposed a method for treating adult thoracolumbar spinal deformity. Another initiative, the Let's Chat project [16], used software development to detect dementia and cognitive impairments in primary care clinical settings.

Table 8. Sustainable Technology in eHealth.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
e-Health Actions related to illness prevention, detection and treatment	Monitor patients to detect clinical conditions or send messages to improve treatment adherence Data mining, ML and LA with different purposes: detect patterns globally or automate alarms and personalized messages to patients in key situations for their health. Medical assistance, emergency support and disability support	IoT to sensor and monitor patients in different situations: (1) monitor specific parameters for detection and control of specific pathologies such as diabetes, heart problems. (2) monitor emergency situations such as falls, heart attacks or stroke. Digitalization of medical records ML and LA to analyze data and provide alarms that trigger services based on data from IoT devices or medical records. Assistive robotics to support physical problems derived from an acquired disability or mobility limitations typical of aging (e.g., wheelchair, exoskeleton or robotics arms).	Big data techniques improve pattern detection and personalization of services and allow the application of ML and LA techniques on a larger scale. Improving communication among professionals from different services allow the attendance of pluri-pathological patients Improving the accessibility and usability of HW and SW (computers, mobile phones and specific devices) allows its application to larger groups with special needs, such as the elderly.	27	[11–38]

With regard to the treatment of illness, Information and Communications Technology is one of the most successful technologies for facilitating home healthcare and telemedicine. The aging population impacts all areas of society, putting pressure on social expenditures and public health services and raising the number of challenges in medical care and rehabilitation. In [17], e-health is presented as a promising concept supporting the idea of independent living for patients with chronic diseases. In regions with older populations that have to travel long distances to hospitals or medical centers, services are improved by technology, but each patient needs personalized treatment.

Another aspect worthy of consideration is the application of ICTs to communication between different health care providers and the elderly population. The underlying motivation here is the lack of professionals in gerontology, nurses and long-term care professionals—a problem discussed in many papers. In ambulatory care scenarios, it has been proven that facilitating communication between pharmacists and patients and giving the latter an active role in the management of their medication has its benefits [18].

Some of the difficulties posed by chronic disease self-management tools are discussed in [19]. One of the biggest problems is that such tools are usually designed for a single disease and do not take into account the fact that elderly people usually have multiple pathologies. Another issue is usability: most tools have not been designed with the specific needs of the elderly in mind. Kastner presented an eHealth self-management application called 'KeepWell' capable of supporting seniors with complex care needs in their homes and proposed a trial to validate its efficacy, cost and acceptance.

Finally, the COVID-19 pandemic has accelerated the use of ICTs as an alternative form of consultation, especially for elderly people with multimorbidity belonging to high-risk groups for which in-person visits are discouraged. Lee [20] took this opportunity to propose a study into the potential of video consultation and to evaluate the sustainability of such a service after COVID-19. The study used the NASSS (Non-adoption, Abandonment, Scale-up, Spread and Sustainability) framework and its main findings are to be shared with administrators in the healthcare sector to enhance quality and safety in video consultations.

eHealth and the Internet of Things

Sensor-enhanced health information systems play an important role in creating sustainable conditions for self-sufficient and self-determined lifestyles [21]. This section looks at the use of sensors in wearable devices, among other technologies.

Healthcare providers are turning to sustainable technological solutions capable of facilitating information exchange for mobile geriatric care [22]. The use of IoT devices with multiple sensors allows doctors to perform medical check-ups regularly, receiving data directly from the devices and analyzing it accordingly even when they are not in the same building as the patient.

Guo [23] proposed a model for improving the connectivity of personal wearables with community and hospital environments, using an IoT architecture. However, is this technology accepted by everyone? The study carried out by [24] in India examined the factors influencing the adoption of smart wearable devices and IoT in society for health monitoring. Intrusiveness, comfort, perceived usefulness and perceived ease of use were all studied.

One major concern is the early detection of dementia in elderly people living alone. Javed [25] proposed an IoT-based solution involving the monitoring of daily activities to detect early stages of dementia and its evolution. This technique is called Cognitive Assessment of the Smart Home Resident (CA-SHR).

eHealth and Smart Living

Smart living technologies can facilitate interaction between health personnel and older adults. This category of technologies includes things such as Ambient Assisted Living and smart homes or cities. Of particular interest is the development of spoken language-based applications, which provide an intuitive, accessible interface for both the elderly and their

home care providers [26]. In this type of AAL technology, it is recommended that informal caregivers, as experts in the matter, be taken into account when designing such tools [27].

Several studies focused on improving the life quality of older adults in their own homes, avoiding the need to travel to healthcare centers by using different devices to monitor their needs and medical parameters [28]. Some researchers are developing devices using machine learning which can track health parameters through urine tests, measure blood pressure etc. [29,30].

eHealth and Artificial Intelligence and Big Data Technology

Fuzzy-semantic systems have been developed to evaluate the physical state of patients during the rehabilitation process [31]. These kinds of systems are used in mobility/rehabilitation therapies, where the relationship between older adults' mobility and their quality of life is well documented.

eHealth and Robotics and Cybernetics

Robotic solutions are now being designed to provide support for daily activities performed by older adults. Ref. [32] proposed a taxonomy of social robotics, identifying 3 main categories: (i) Assistive Robotics (AR), which gives aid or support to a human user (rehabilitation, wheelchair and other mobility aids, companion robots, manipulator arms for the physically disabled and educational robots). (ii) Socially Interactive Robotics (SIR), the main goal of which is to develop close, effective interactions with a human for the sake of interaction itself. (iii) Socially Assistive Robotics (SAR), which also aims to create close, effective interaction with humans but in this case in order to assist and achieve measurable progress in convalescence, rehabilitation, learning, etc.

Different robots have been successfully used in caring for older adults to prevent dementia. The study carried out by [33], for example, described a robot programmed to play chess to combat brain degeneration.

A complementary analysis related to the treatment of dementia was conducted by [34]. This study, which looked at the engagement and acceptability of people with dementia in residential care for older adults, had older adults interact with a SAR called Matilda for 3 years (from 2010 to 2013). Another project, by [35], evaluated which features enhance patient interaction with robotic pets.

Simonov and Delconte [36] used humanoid robots in rehabilitative exercises, reducing the need for human care. Exercises to rehabilitate COPD patients were coded to program the robot and the human-robot interactions were compared using dynamic time warping (DTW). Other studies have focused specifically on the acceptability of robotic systems among older adults. Ref. [37], For example, analyzed older adults' engagement considering the lack of capacity for socioemotional interactions in the robotics systems then available, and also the price, a big barrier to the more widespread adoption of robots in society.

eHealth and Serious Games and Gamification

Health care associated with leisure time has brought important benefits to the population. One interesting proposal is that of gaming platforms. In 2018, Valenzuela [38] reported how gamification was applied to increase engagement and effectiveness. The author conducted a literature review to show that persistence and participation in the use of fitness games (or exergames) increased when they were more enjoyable.

3.6.2. Daily Activities and Well-Being

Unfortunately, there comes a time when the elderly are no longer able to perform everyday actions on their own. Prior to this situation, long-term care services can use technology to help older adults live independent, safe lives for longer. In this section we will discuss the main innovations that seek to facilitate a more sustainable quality of life for older adults in their daily activities. Table 9 summarizes the main trends, strengths and weaknesses of using sustainable technology for daily activities and wellbeing.

Table 9. Sustainable technology for daily activities and wellbeing.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
Daily activities and wellbeing Actions oriented to facilitate autonomy of elderly helping them to perform every day actions on their own.	Monitor patients in their daily routines: physiological needs, physical activity and nutrition. Mental wellbeing fostering communication, learning and gamification Digital literacy to use personal devices (mobile phones, computers and wearables) to support physical and mental wellbeing	IoT and big data to sensor and monitor patients in different situations to promote active and healthy aging Commercial wearables (wristbands, pedometer, mobile phones) with IoT sensors integrated to monitor patients and send them alarms Socially interactive or assistive robotics for emotional support or to prevent dementia. Even though there are many successful prototypes, the technology is not yet mature for mass and sustainable use Gamification with different purposes: learning, mental activity, physical activity or daily routines.	Interoperability and usability of IoT systems and battery duration still need substantial improvement to make some of these technical solutions sustainable. The maturity of educational platforms (MOOCs, LMS) has made it possible to bring education and serious games to this group despite their mobility problems. Increased use of social networking and videoconferencing tools have allowed elderly to stay connected with family and friends, support networks such as neighborhood centers and health services.	47	[23,37,39–84]

Daily Activities and Information and Communication Technologies

Pasalich [39] established the sustainability of a home-based physical activity and nutrition program, reporting a short-term improvement in diet and in physical activity, albeit with significant gender-related differences and a significant decline in the follow-up phase. In [40] the activity patterns of older adults were monitored with an IoT based system, detecting risky situations and variations in activity metrics. In a pilot study [41], authors analyzed how elderly people may benefit from technology in their daily lives, even though devices have not generally been optimized for their needs (e.g., their physiological or cognitive limitations). This study, which used scenario-based techniques, confirmed that older adults may accept technological artifacts when they perceive them to offer benefits in terms of well-being and health. Regarding daily activities, some technologies are designed to be used by older adults, while others are designed to be employed by their caregivers. Some such projects are summarized below.

With respect to technology oriented to older adults, Ref. [42] proposed habilitating the home or community environment to enable older adults to remain active and independent for longer through mind stimulation measures that included interactive television and personalized ICT support. This approach proposed the use of open standards, low-cost solutions and interoperable applications.

Carretero [43] demonstrated the benefits of employing ICT-based services for informal caregivers and attendants, in terms of sustainability and savings for the care system. This idea was supported by Leslie et al. [44], whose study focused on how technology can help family caregivers work more sustainably and aid resilience. These authors found that caregivers need improved computer systems capable of connecting them and providing information and support.

Daily Activities and the Internet of Things

Many authors highlight the importance of sensors for monitoring physiological signals and of the Internet of Things (IoT) as an aid to independent aging [23,45–49] compiled several IoT applications, protocols and methods for elderly people and people with special needs. With regard to IoT, the study by [50] addressed digital services for the 60–75 age group by digitally adopting wellness routines. This study found that in this group routines are not maintained over time and concluded that digital coaching can help users create good, effective, sustainable wellness routines. Prominent in this group of articles are those related to fall detection systems for elderly people [51,52]. These systems monitor and detect critical events such as injuries or dangerous environments, triggering immediate action and response.

One interesting work by Wang [47] proposed developing a smart bathroom that uses sensors to monitor physiological signals. Feng [53] suggested using sensor-based posture monitoring. In this regard, perpetual awareness systems [54] are essential for assisted living and healthcare (for instance, fall detection, falls being one of the major public health concerns in older adults [55]). One of the problems with the IoT approach is that there is a need to keep an eye on battery energy status. The study by [56] analyzed the effectiveness of iStoppFalls, an ICT-based prevention system. The same authors also incorporated video games for exercises and mobility monitors adaptable to different subgroups of older adults and their specific characteristics, reducing the risk of falls. Ref. [57] developed a framework to measure gait velocity and prevent falls, minimizing sensor errors caused by thermal noise and the overlapping of different sensors' regions.

The use of sensors to monitor older adults and the data generated require the implementation of techniques that facilitate their analysis. This process needs improved data interoperability and ontologies. Chien [58] studied the application of Fog architecture to a Cloud system intended for elderly care.

Daily Activities and Smart Living

As can be seen in the keyword analysis, smart cities and smart homes account for a large amount of research. Some authors [59,60] have proposed different approaches for implementing smart eldercare and sustainability. Ref. [61] proposed smart senior citizens' communities, using technology as a sustainable method with which to support the aged and incorporating the brand new "green" practice of modern communities. Ref. [62] created VIHO (Efficient Computer Support in Care for the Elderly), a project which explores how information technology could support the development of elderly care projects and improve the efficiency of elderly care work practice in the future. Hu et al. [63] discussed how technologies can help in the sustainability of retirement villages, while the SmartWalk project [64] looked at how smart cities can promote physical activity by doing things such as tracing walking routes in the city.

However, all these technologies do more than simply make it possible to monitor people's lives in order to improve living conditions and prevent problems associated with aging. They also help reduce the effect of adverse events such as falls. Ref. [65], for example, investigated how shock-absorbent flooring in wards for older adults reduces fall-related injuries.

Ambient Assisted Living is a sustainable, affordable solution that allows older adults to lead independent lives. Some studies have tried to identify the main challenges of applying AAL for independent living. In a survey carried out with specialists to learn more about the main problems of this approach, Ref. [66] found problems of reliability, robustness, security and data privacy.

Ambient Intelligence Living (AML) is a paradigm related to AAL. In AML, sensors and wearables are integrated into our everyday environment, the data being processed with Artificial Intelligence (AI). Older adults need constant monitoring to control their health status and quality of life. In this case, the main problem is to find the best way to interconnect devices. The paper by [67] presented a wearable ambient intelligence-based device that continuously monitors the emotional state of older adults in terms of sleepiness and stress. The CARDEA research project [68] included an AAL system, including wearable devices to detect falls, indoor localization and vital sign monitoring, allowing doctors and caregivers to manage the system's functions through their web applications. Other studies focus their efforts on developing tools to recognize older adults' postures, voices and needs in their homes [69,70]. A complementary strategy to those outlined above is to combine biophilia and smart home technology. This provides an optimal context for aging in place, and was the approach followed by Lee [71] to design a sustainable residential-natural environment for smart homes.

Awada [72] presented the results of the CAMI AAL project, which provided a solution consisting of an interface that helps elderly people to self-manage their daily lives and social interactions such as sharing knowledge, working, etc. The application can be customized according to the needs of the user and their social support network (family and friends) and has been partially validated in three different countries: Poland, Romania and Denmark. This project claims to provide flexible, scalable, individualized solutions to support elderly people in their daily lives. Ref. [73] implemented a smart mobile tutoring eco-social laboratory for assisted recreation, applying technologies such as Ambient Intelligent Architectures (AIA) to monitor the power supply, provide professional bio-feedback, etc.

Daily Activities and Artificial Intelligence and Big Data Technology

Human Activity Recognition (HAR) is a well-known problem when using technologies such as ICT or IoT for eldercare and healthcare. Activity is usually detected with the help of sensors, smartphones or imaging devices. However, the data acquired is meaningless if it is not analyzed. Jobanputra and colleagues [74] presented a survey of different operational Artificial Intelligence techniques and methods and compared their results. The technologies studied included Decision Trees (DT), K-nearest Neighbours (KNN),

Support Vector Machines (SVM), Hidden Markov Models (HMM), Neural Networks as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN).

Smart home IoT infrastructures supporting independent living for older adults have been developed in many research projects, as summarized in the previous section. Some of them provide artificial intelligence mechanisms for easy setup and testing of the installed equipment, as well as providing caregivers with advanced data and visual analytics to help them monitor older adults' health and activities efficiently and sustainably [75].

Daily Activities and Robotics and Cybernetics

One way to reduce caregiver dependency is to detect those repetitive daily tasks that can be automated, such as taking medications. Chen [76] designed a smart medication dispenser with a friendly human-computer interaction interface that prevents patients from forgetting their medication and also avoids other errors such as skipping doses. The interesting multidisciplinary project Robot Companions for Citizens [77] proposed an innovative design for more adaptive, behaviorally complex robotic systems capable of assisting older adults with their everyday needs. This initiative combined nanotechnology, biomaterials, neuroscience and human-robot and robot-robot interaction. In the social domain, one equally innovative application of robotics focuses on creating social networks between humans and robots (human-robot social interactions—HRSI). Lee [78] described a theoretical framework for effectively implementing a sociable robot in a healthcare or elderly care facility, promoting healthier, more active lifestyles among the social network members.

One of the key requirements for creating sustainable adult-robot relationships is to improve affective exchanges between humans and robots. Reference [37] proposed introducing a human-robot affective dimension to improve the acceptability of robotic systems. This included non-intrusive sensory interfaces that adapt robot's affective responses to the user's behavior, using verbal and non-verbal communication to enhance the empathic exchange of moods and feelings.

The application of robotics, however, goes beyond merely considering robots as isolated individuals that provide support at specific moments. Studies also exist in which the robot is integrated more closely with the user to provide support in certain activities. Ref. [79], for example, presented a robotic exoskeleton for gait assistance that facilitates active aging by reducing oxygen consumption in comparison with treadmill walking or self-paced overground walking at the same speed. One of the main drawbacks of such gait assistance exoskeletons is that they tend to be large and heavy. Studies such as [80] have worked to make these exoskeletons more wearable by reducing their weight and making them adjustable for different sizes. All of these improvements allow the exoskeleton to be worn under clothing, thereby increasing their social acceptability.

Robots are also used in Smart Green City systems, where artificial intelligence helps physical systems to estimate the risk of environmental pollution, improve the travel time between different parts of the city, increase the quality of social life and ensure a greater degree of independence for older adults or people with disabilities. Pandelea and colleagues [81] proposed integrating anthropomorphic walking robots into Smart Green Systems to detect, monitor and control this process.

Daily Activities and Serious Games and Gamification

One of the purposes for which serious games have most frequently been applied as a means of enhancing the quality of life in active aging has been to improve cognitive function. Cognitive impairment and dementia are two of the main threats in this area. These types of interventions, referenced using the umbrella term Computerized Cognitive Training (CTT), consist of systematic, repetitive exercises performed on different platforms (computer games, mobile devices, gaming consoles and virtual reality) to improve specific cognitive domains. Even though much research has been carried out in this area, the studies vary greatly and are not very repeatable. Ref. [82] conducted a systematic review of the literature for interventions lasting 12 weeks or more. Among its main findings,

CTT was found to slightly improve global cognitive function compared with other active interventions such as the viewing of educational videos, and there was evidence of a slight improvement in episodic memory compared to inactive control groups. However, no changes in processing speed were detected, nor was there any significant evidence that the cognitive improvements detected persisted over time. It is therefore important to point out that this is an open, active field of research and that more investigation, with more extensive and more in-depth studies, is needed to obtain conclusive results that will scientifically demonstrate the long-term benefits.

Other areas of concern are social welfare and skills management in the workplace. High-level skilled workers are a fundamental asset in organizations, and some studies have therefore analyzed how steps can be taken to promote a feeling of well-being. Gamification techniques have been used to analyze how employees can be helped to acquire experience. For older adults, the feeling of satisfaction is especially valued. The Active @ Work project [83] incorporated intelligent behavior to keep the user aware of their state of well-being, activating notifications to mitigate the risk of fatigue or stress at work.

Gamification has been also used to transfer knowledge from older adults to younger generations. For example, Ref. [84] presented a study in which batik artisans transferred their skills and knowledge using gaming technology as a learning medium, ensuring the sustainability of the industry. The game-based application proposed in the study transposed the physical process of batik production into a digital, interactive, visual space.

3.6.3. Policies and Strategic Plans

The increase in the elderly population has important implications for government policies and strategic plans, above all for the provision of health, wellbeing and care services. Ref. [85] argued that in order to preserve our health system and its sustainability, it is necessary to revise the current work retirement model, teach people to manage their own life, health, economy, etc., change people's activities during their lifetimes and rethink habits regarding the use of health systems. The authors also pointed out that automatic aid devices are needed in homes.

Table 10 shows a summary of the main policies and strategic plans of using sustainable technology for elderly life, similar to previous sections and answering to the Search Questions (SQ) defined in Table 3.

Some authors [86] analyzed the strengths of technology in a cross-European context, establishing that stakeholders should be involved in the definition of future health-care policies and priorities. To ensure a sustainable health-care service, an analysis of the contribution of technological innovation as opposed to that of social reorganization is also needed. Romanopoulou [87] analyzed the challenge posed by the growth of the elderly population in the context of the economic crisis in Greece and proposed the creation of LLM Care (Long Lasting Memories Care), a new health care ecosystem that will provide healthcare specially tailored to the elderly and vulnerable populations. The key to this model is that it is aligned with the European Innovation Partnership on Active and Healthy Ageing (EIP on AHA). Not only does it present the principal considerations governing the establishment of such ecosystems, but it also shows how they interconnect at policy, business, social, technological, organizational and individual levels to improve sustainability and how this exercise in alignment could be analyzed as best practice for similar organizations at European level.

Table 10. Sustainable Technology for Policies and Strategic Plans.

Domain of Application	SQ1 Main Research Areas Addressing Older Adults	SQ2 How Technology Is Used and for What Purposes	SQ3 Extent in Which Technology Contributes to Sustainability	# Papers	References
Policies and Strategic Plans Actions oriented to facilitate the provision of public health, mobility, education and wellbeing services in general and guarantee their sustainability over time.	Create ecosystems with smart facilities and ambient assisted living: smart cities, smart mobility, smart home. Empower users and focus on prevention rather than clinical intervention. Promote individual's autonomy, peer led and social support networks. Considering users, their needs and limitations and involving them in the design of services is key to achieving mass adoption of easy-to-use products and services.	Big data to monitor users, products, services and systems, detect patterns and make predictions. The massive use of cell phones and the increasing penetration of wearables have provided a large part of the population with tools that can be used for monitoring and communication, but it is necessary to make progress in the privacy and security of the data exchanged. One of the main challenges is the interoperability among platforms, devices and data to achieve common infrastructures for the whole ecosystem. It is also important to reduce cost and improve energy efficiency and device's lifetime. to provide low-cost products and services.	It is necessary not to focus on partial solutions to very specific problems but to create a global ecosystem that monitors, connects and informs the needs of different stakeholders: policy makers, healthcare providers, social services, technological industry and individuals using product-service-systems approach. Scale economy and TIC support in in the most disadvantaged areas, such as rural areas or developing countries. New ways of distance product and service delivery that considers usability issues in elderly collective.	46	[27,47,64,85–128]

However, few studies into the needs of the elderly have been carried out which take into account older adults' own points of view. The exceptions include two interesting initiatives in Ireland. The first, conducted by [88] as part of a European Union Northern Periphery Programme (EU NPP), focused more on the specific needs of the rural population, where population aging is even more significant. The second, conducted by [89] as part of the TILDA project, focused more on analyzing the use of formal home care vs. long-term residential care. Since the current situation is not sustainable in the long term, both initiatives were oriented towards collecting evidence to inform policy makers about new ways of improving service delivery. The older adults involved in the first study emphasized the importance of a systemic approach that would take into account an overall vision of different services, not only health but also transport, housing and personal support networks. They valued the closeness of the family mainly for its social and domestic support but considered it important that health, transportation and housing be provided as services to keep them autonomous for as long as possible. The second study revealed instrumental activities in daily life to be decisive factors for adequate health care. The need for residential care in adults with low to moderate levels of dependency can be reduced by providing them with formal home care. In general, older adults valued the existing health services and were concerned that the reorganization of services would prioritize technical efficiency over quality of service. More research and standardized assessment is necessary to support these findings.

For the provision of health services to be sustainable, however, it is necessary not only to focus on the service itself and its target public, but also to develop suitable policies for recruiting and retaining the human resources that provide the service. Ref. [90] discussed this problem in Lebanon, pointing out the importance of developing these kinds of policies at national level in order to make them sustainable. We believe that the use of technology can significantly improve the daily life of health professionals by minimizing travel, facilitating remote monitoring and establishing professional networks to support their work, as indicated in previous sections.

Ramanadhan [91] analyzed hybrid models based on community-clinical partnerships capable of increasing health equity and pointed out the main challenges facing these communities in terms of keeping their services sustainable. The study highlighted the need to take a long-term, infrastructure-oriented approach and emphasized the importance of the partnership's make-up, the alignment of all its members' efforts and a long-term funding structure as keys to success.

Similar conclusions were reached by [92] in a literature review on the Asia-Pacific region which explored the role health technology plays in shaping health care for aging populations. Whereas technology applications do offer a wide range of potential benefits to the elderly population, there are also issues related to surrounding infrastructures, funding and the acceptability of technology. These issues must be approached globally by creating frameworks for the implementation and monitoring of technologies to achieve robust, sustainable development in the long term. The authors [93] advocated using technology to empower older adults and people with disabilities, integrate them back into mainstream society, enhance their capabilities and give them a chance to compete in the real world. Kobayashi and colleagues [94] analyzed recent trends in medical ecology in Japan and proposed the development of high-quality, lightly structured technologies to provide low-cost, easy-to-access healthcare as a basis for safeguarding human dignity.

In addition, Cho [58] examined similar problems in the Caribbean countries, highlighting the need to rethink care models to include more sustainable health systems with new orientations in policy, service delivery, organization, training, technology and funding in response to the growth of the elderly population. As in previous studies, Chou emphasized the importance of interventions to ensure healthy aging, arguing that interventions need to focus on preventive actions that will improve older adults' autonomy in adapted self-care environments. Such policies will improve long-term care and reduce the incidence of the non-communicable diseases that account for 78% of deaths in Caribbean countries.

Policies and Information and Communication Technologies

The LivingLab PJAIT project [95] presented a sustainable ICT-based solution to improve senior citizen participation in urban life based on lowering ICT barriers, promoting social inclusion and engaging older adults in the process of developing ICT solutions.

Research into technology aimed at older adults has also explored energy efficient, friendly technologies for mobile and portable devices such as video transmission devices [96]. The aim is to increase such devices' lifetimes. Energy efficiency and user-friendliness are essential in technologies, so reducing power consumption in devices [52] and improving the lifetime and reliability of batteries [97] are key objectives. It is assumed that energy efficiency and resource sustainability will result in improvements in both the service provided by workers and the service received from citizens.

The concept of smart mobility understood as the use of ICTs to organize shared transport adapted to people's individual needs has traditionally been associated mainly with urban environments. However, there are some studies that have analyzed the benefits of adopting this approach also in rural areas. One of these, conducted by [98] in Heinsberg, a rural region in the west of Germany, revealed that smart mobility can help alleviate several disadvantages of rural living, including shortcomings in the provision of public transport supplies and restrictions in older adults' access to different amenities.

The city of Jakarta (Indonesia) was the scenario for a project to implement sustainable e-government (web-based government) and m-government (e-government based on a mobile phone application) and thereby make it a Smart City [99]. Interaction between citizens and the government changed. One of the main results highlighted in the study was that the project enhanced the effectiveness of the public administration. The study also showed that citizens were happy with the applications, which satisfied their sense of self identity, enabled them to pursue their own interests and met their expectations. Senior citizens and conservative communities, however, preferred traditional real-life interaction and the authors concluded that regular training on ICT would be needed for them.

Policies and the Internet of Things

One efficient, sustainable way to help older adults live independently is the use of wearables. A literature review conducted by Godfrey in 2017 [100] on the use of wearables to track older adults' movement (or gait analysis) revealed a great variety of types but threw little light on how they work. Some studies have highlighted the potential energy saving advantages of certain disease prevention measures. Ref. [101], for example studied using the IoT to save energy in lighting while minimizing eye strain in smart homes.

Rich and colleagues [102] described peer-led physical activity interventions with 408 adults in 12 ethnically diverse senior centers in San Diego County. Wearables and sensors (pedometers, wrist activity monitors, blood pressure, GPS devices) were used to monitor individuals and tablets were used by peer health coaches to deliver and track the intervention. One of the main findings was that using a peer-led implementation strategy to deliver technologically monitored physical activities can enhance the adoption, implementation and sustainability of programs.

In Taiwan, the IoT was integrated into the Agricultural and Livestock Production Management System in order to achieve the goal of sustainable agriculture [103]. An agricultural product traceability system made it possible to check compliance with product quality requirements. However, many farmers in Taiwan are small-scale farmers and/or elderly citizens who do not habitually use computers and find it difficult to send the data required to the traceability system. The IoT system allowed the system itself to create real-time production data and send it directly to the traceability system, so the farmers did not need to learn to use computers to upload data to the quality system.

Policies and Smart Living

ICTs applied as part of a multidisciplinary approach to an area of knowledge such as this may have a greater impact, because they make it possible to respond to users'

needs while at the same time providing information on users' daily behavior, thus helping to better manage the sustainability of the system as a whole. In this regard, Ref. [104] proposed a Product-Service-System approach for integrating ergonomics and sustainability competences in the development of Ambient Assisted Living, an initiative based on the research experiences of the Technology and Design for Healthcare (TeDH) research group in the INDACO (Industrial Design, Communication, Arts and Fashion) department at the Polytechnic University of Milan.

In the same field of information service management, Birmingham City Council is running the City4Age pilot project, funded by the Horizon 2020 Program of the European Commission [105]. This project focuses on data collection using wearable devices, outdoor sensors and other smart devices. Its urban system is designed to detect changes in daily life—physical activity and social patterns—early and to develop technology-based interventions to help reduce the risk of frailty.

In response to the difficulty of predicting occupancy, Ref. [106] studied sustainable, efficient living-rooms for residence-homes, or any other large-spaces, finding that the use of low-cost, low-resolution heat sensors allowed lighting, heating and air circulation to be automatized in large areas.

Policies and Artificial Intelligence and Big Data Technology

Urban planning can have both positive and negative effects on the health, well-being and social participation of a city's inhabitants. However, the decisions made by stakeholders involved in public services must be based on firm evidence. Advances in the IoT, LA and big data can contribute significantly to the collection and processing of such evidence. The INTERACT (Interventions, Research and Action in Cities) project [107] involved natural experiments in 4 Canadian cities. This project not only delivered timely evidence about how urban interventions influence health and wellbeing but also took a step forward in this direction by providing methods and tools to facilitate such studies. To address these challenges, the project team plans to collect around 100TB of sensor data on both location and physical activity over 5 years.

With regard to older adult mobility, smart card data from information systems have been used to study bus use patterns [108]. The characteristics analyzed with big data techniques include temporal distribution, the distance, duration and frequency of trips and the spatial distribution of travelers. The information about mobility thus obtained can directly contribute to public transport policy formulation, service and management.

Policies and Robotics and Cybernetics

Twenty years ago, there were great expectations about what ideal multitasking robots for assisting the elderly would appear in the future. Despite much research along these lines, however, their use today remains marginal. Reference [109] pointed out that one of the main reasons for this is the fact that research is carried out on imaginary scenarios or in small-scale trials. She also noted that for robotic solutions to be useful, affordable and sustainable from an ethical, social and ecological point of view, research proposals must be evaluated within the framework of existing care ecosystems, taking into account the real political and economic contexts in which care is provided and the provision of care when resources are limited.

Reference [110] provided a glimpse into the future of elder care, reinforcing Van Aerscot's idea of the need for a more comprehensive approach involving institutions. A transition in the elder care system was predicted, with robots ultimately being embedded in welfare services and society. The authors focused on the future of elder care and how it will be affected by the emergence of care robotics, taking the current use of robots in elder care as a point of departure. The study's results established that there is a shift towards the use of robots in care, but that socio-institutional and technological adaptation is needed. These two areas are highly interrelated and both of them need to be taken into account for the successful integration of robots in society.

3.6.4. Transversal Aspects of Technology

The transversal aspects of technology affect all areas, including: (1) design methodologies; (2) the usability and accessibility of the applications implemented; (3) understanding of behavioral patterns in the target population; (4) interaction between the different stakeholders affected by applications; and (5) training in the use of technology. The main research projects carried out in these areas are summarized below.

1. Design methodology. User-centered, inclusive, co-creative design methodologies are recommended for developing successful, sustainable technologies. Reference [27] recommended engaging informal caregivers, as experts, in the design of AAL-related technologies. In the same vein, Ref. [111] studied how older adults can participate in the software development process, to produce more friendly, useful applications for this population. Reference [112] reported how an IoT for Seniors course led to the design of more suitable applications by developers [111].
2. Usability and accessibility features. To make technology sustainable, it must be developed taking into account characteristics such as usability (including efficiency, effectiveness, easy-of-use, user satisfaction, etc.) and accessibility (creating technologies—including mainstream and assistive solutions—that everyone, including older adults and people with disabilities, can use in a range of different contexts) [113]. The need to develop inclusive ICTs and to employ user-centered methodologies and co-creative methods is explained in [114], where inclusive technologies were designed for and with the help of older adults, balancing ease of use, subtlety and elements of Cognitively Sustainable Design. Human-centered design and methods, which take into account the needs of all the people involved in the care and assistance of the elderly, were also used in the Habitat project [115] to define the most inclusive and less intrusive design solutions for an IoT home assistance platform for elderly users. Co-creative methods are used also in other IoT projects and smart living environments for ageing well, such as the ACTIVAGE project [116]. Digital information and web services are being used increasingly by the population. In particular, the use of Internet to manage bureaucratic procedures (pay taxes, request appointments with the public administration, fill out service request forms, etc.) and access medical information (make medical appointments, consult medical data, etc.) is widespread. Unfortunately, digital barriers exist which impede adequate access by certain groups, such as older adults. This increases the digital divide [117]. Some proposals have been put forward aimed at tailoring health web information services to the needs of elderly and disabled user groups [118]. According to one Ahref report [119], 90.63% of active pages on the web are never visited. This implies a great waste of energy and resources, from the time invested in their creation and indexing to the cost of hosting them on web servers. One reason for the lack of visits is poor readability. This is a factor that especially affects the most vulnerable and isolated groups, such as the elderly. The effort to make effective, sustainable pages can improve such groups' standard of living and their inclusion in society, but there are still limiting factors caused by aging and a lack of computer skills. As a result, when information is required, more time must often be spent searching on the web. Readability can reduce the time spent locating and understanding information. Other studies have focused on analyzing the attitudes of older adults and people with disabilities towards the use of assistive technologies when they are in need of care. Reference [120], for example, helps us to understand the relationship between individuals' perceptions of care and the acceptance of assistive technology by different user groups.
3. Behavioral patterns. As part of the requirements acquisition phase in technology design methodology, it is important to consider users' behavioral patterns. Some papers have described surveys conducted to see how older adults relate to their environment and to technology, to allow the development of more accessible software and devices for use by this group [111,112]. In a project for smart cities, Ref. [105] identified social patterns of seniors in order to avoid accidents. In the same vein, the

SmartWalk project mentioned earlier identified safe routes in the city [64]. Knowledge of older adults' consumption and living habits is a prerequisite for the design of appropriate technologies. An interesting approach in this regard is the study of energy consumption in relation to elderly people's behavioral patterns, as exemplified in the work carried out by [108,121] on transportation habits. Similarly, Wang [47] analyzed the distribution of the elderly population with cell phones, allowing services to be tailored more sustainably. The study by Godfrey [100] showed that this population is very heterogeneous in its habits.

4. Stakeholder interaction. Interaction and communication between all the different agents involved can contribute to a technology's success. In [122] the design of a multidisciplinary clinical pathway to treat hip fractures reduced mortality rates and shortened hospital stays.
5. Training in the use of technology. ICTs offer many possibilities for improving the daily lives of adults, but the digital divide can also be a factor of social exclusion for them. Ref. [123] highlighted the importance of lifelong learning and, more specifically, digital literacy for improving the social integration of elderly people. As an example, the study reported the effective digital literacy of a group of 96 seniors in the Faculty of Human Sciences at the UABC in Mexico. Ref. [124] analyzed the impact of ICT policies on social inclusion in several regions with the lowest GDP per capita in Spain using the model developed in the IMPOLIS project. The results of this study validated the IMPOLIS model as a monitoring tool for ICT policies that made it possible to design and redirect measures for reducing the digital divide.

However, the elderly population should not be seen only as the recipients of educational actions. In a society where life expectancy is increasing, the contribution of the elderly is a valuable resource that needs to be leveraged. In this avenue of research, Ref. [125] proposed the digital inclusion of elderly groups through a participatory process of digital tool co-creation. This work illustrated the appropriation of digital skills by including older adults as content co-creators in a MOOC (Massive Open Online Course) about how to promote active life for older adults through a collaborative economy. This type of collaboration proved to be effective not only in improving the quality of MOOC content, but also in adapting tools for different groups and improving the autonomy of the groups involved.

Reference [126] reinforced this idea by signaling education as a key strategy for addressing demographic challenges, and lifelong learning as a valuable tool with the social potential to support and empower older adults. This study provided some examples from Bulgaria, where people over 60 constitute one of the fastest growing internet communities.

The European Computer Driving Licence (ECDL) program, also known as the International Computer Driving Licence (ICDL) in non-European countries, is a computer literacy certification. Training is provided in Information and Communications Technology and digital literacy. Qualification enables students to understand and integrate new technologies in the e-society. One particular project, the ECDL PD project, is focused specifically on the needs of elderly people and people with disabilities [127].

Recent studies have proposed recovering other educational approaches, such as intergenerational learning, that can also benefit from new technologies. Reference [128] discussed the physical and psychological benefits of History Alive, a program that promotes the interchange of experiences between senior citizens and college students in a mutual learning process. These initiatives improve learning outcomes, enhance senior citizens' sense of accomplishment and self-worth and allow their stories to live on thanks to the support given by college students via social networks.

3.7. The Process of Technology Adoption in The Elderly

Much research has focused on innovative approaches to achieving sustainable, cost-effective technologies to support aging in place. In this regard, disruptive technological approaches include smart cities, the Internet of Things and healthcare technology, among

others. The cycle of adoption and use of technologies by the elderly has its own particular characteristics. Several in-depth studies have been carried out into different aspects of this process. They are outlined below: technology adoption; training in the use of technology; and Long-term use and limitations to the use of technologies.

3.7.1. Technology Adoption

One of the main limitations when implementing programs for independent living for older adults is their reluctance to use technology. Fields et al. [129] reported that one-third of older adults do not use the internet. This rejection contrasts with the undoubted benefits of the internet for this group: connectivity versus loneliness and a more sustainable health care system. Concern in this regard is aggravated by the shortage of care workers. Basically, the sustainability of health care systems needs technology capable of overcoming these difficulties.

The rejection of technology has been discussed in papers such as [117]. It is an attitude perfectly illustrated in the work carried out by [130] in the field of Information Science. The aforementioned researchers used semi-structured interviews and focus groups to study the impact of information and communication technologies (ICT) in public access venues (PAV) in Botswanan libraries with Internet connections. Their results revealed differences in the acquisition and use of computer skills between users who attend school and users who do not attend school. Older users who do not attend school tend to rely on site staff for information and services, avoiding computing terminals. Another paper worth mentioning is that of [131]. This work, related to the COVID-19 pandemic, studied how centers for the elderly have tried to maintain their services by replacing them with online activities. The study tried to determine whether such online activities are an appropriate substitute for in-person activities. A survey was conducted among 105 older adults. Participants in the activities tended to be very satisfied. Non-participants justified their non-involvement with reasons such as: ignorance of the web-based program, lack of interest in the content and problems. The study concluded that there was a need for web-based activities to counteract issues of boredom and feelings of isolation and for current programs for older adults to be made more accessible.

3.7.2. Training in the Use of Technology

The lack of computer skills is a major challenge for elderly people. To tackle this problem, many projects have been implemented aimed at increasing senior citizens' computer skills. One such project was OASIS [132]. Fields et al. [129] observed a positive effect of providing in-home digital training for older adults in terms of social support and the more confident use of technology. One particularly innovative study was carried out by Ha et al. [133]. Its aim was to detect barriers to the delivery of distance geriatric training between two countries, Singapore and Uganda. Cross-cultural education via videoconferencing was proven to be feasible, although recommendations will need to be designed.

3.7.3. Long-Term Use and Limitations to the Use of Technologies

Another intriguing area of study affecting the development of sustainable technologies for the elderly is the analysis of factors that cause older adults to discontinue their use of these technologies. Here, it is particularly important to study variations in the use of technologies in the medium and long term. Long-term use and older adults' attitudes towards computers were analyzed in the DITUS project [134]. The same results were obtained by Fields et al. [129] and Pasalich et al. [39]. In the same vein, Ref. [135] studied how ICTs can help family members to continue the healthy living practices they engaged in when they lived together. The authors proved that in families which engage in healthy living practices together, all the family members (regardless of age) have a better and higher quality of life. The use of technology to communicate and support members living apart and to cultivate health habits help them to effectively collaborate in healthy living.

4. Discussion

As in the study by [136], it was thought convenient to perform the content analysis in domains and divide them into technologies. This avoided the mixing up of domains with the techniques used. This section discusses the results and their interpretation from the perspective of previous studies, based on the proposed research questions.

4.1. What Are the Main Patterns Observed in the Publication of Research in This Area? (RQ1)

Growth in this area can be seen in both databases. In both cases this growth became more pronounced from 2016 onwards, although this is more evident in Scopus. In the analysis by country, the USA and China stood out, although European—especially the UK, Spain, Italy and Germany—accounted for a large number of papers. The differences in geographical coverage between the two databases were evident in some countries, especially China, illustrating how the two databases can complement each other.

Regarding the publication medium, the journals *Sustainability* and, to a lesser extent, *BMC Geriatrics* were prominent in both databases, while *Lecture Notes in Computer Science* was relevant in WoS. With respect to authors' affiliations, some Italian institutions, such as the CNR or the University of Pisa, and institutions from the countries mentioned, such as the University of California (San Francisco), also stood out. European interest in the subject was funded mainly by the H2020 program and the European Commission. In the US, the most prominent sources of funding were the National Institutes of Health (NIH) and the US Department of Health Human Services.

4.2. What Topics and Areas of Research Are Addressing Older Adults? (RQ2)

According to the studies about sustainable technologies for older adults appearing in WoS and Scopus, interest in this area grew between 2000 and 2020. In this twenty-year period, the increase was first gradual, but intensified significantly in the last five years. It should be noted that as the elderly population grows and more emphasis is placed on sustainability objectives, interest in this field and the areas it covers is expanding. There is therefore a growing interest in a more nature-oriented, independent living at home and in smart cities, with a more preventive approach to health.

On the one hand, it should be taken into account that most of the projects and research analyzed were related to areas defined in the sustainable development goals, more specifically:

- Goal 3. Good Health and Well-Being
- Goal 8. Decent work and economic growth
- Goal 11. Sustainable cities and communities

As an unprotected group, however, older adults are also affected by other objectives such as: 5. Gender Equality and 10. Reduced inequalities.

On the other hand, the older research papers had a higher degree of medical content. In the more recent papers, there was evidently an evolution towards the domestic domain and independent living. In general, the keywords and themes reflected growing concern about the situation of elderly people living independently in their homes and communities, the attendant energy consumption, older adults' connectivity with health professionals, relatives, care workers, etc. They also reflected growing interest in the creation of programs to promote occupational therapies and social networks, as a means of increasing older adults' independence and well-being as much as possible.

4.3. How Have Sustainable Technologies for Older Adults Evolved?(RQ3)

Table 11 shows mentions of the main technologies in the period 2000–2021 and the percentage of works published from 2016 to the first term of 2021. In the technological keywords indicated by the authors, IoT was the most mentioned technology (1.6% of occurrences). All mentions of this term correspond to the period 2016–2021. Next came robotics (0.7%), sensors (0.6%), artificial intelligence and wearables (0.5%), health monitoring, big data, medical IT and HCI, each accounting for 0.3%, and a group comprising intelligent buildings, assistive technology, wearables, independent living systems, ambient

intelligence, smart city, telemedicine, assistive technology or AAL, with 0.2% each. This count can be chronologically misleading, because all mentions of smart cities, smart homes, big data, telehealth, smart communities or wearables belong to the period 2016–2021 in both databases. It should be noted that these keywords were taken from the articles in the database, not compiled by the authors of the present study. From a 2021 perspective, some papers may therefore be associated with other keywords, but the only processing carried out in this study was to formally normalize the keywords to represent how the terminology used in the two databases had evolved. No subsequent thematic attribution was made.

Table 11. The most common technological keywords in the two databases, with the total number of mentions in the period 2000–2021 and the percentage of them published in the period 2016–2021.

Keyword	WoS Total	% WoS 2016–2021	Scopus Total	% Scopus 2016–2021
Internet of Things (IoT)	25	100	73	98
Robotics	19	74	44	45
Sensors	16	88	38	71
Wearables	7	100	26	100
Artificial Intelligence (AI)	3	100	17	64
Big data	5	100	8	100
Automation	1	100	17	82
Human Computer Interaction	0	0	12	83
Assisted living	1	100	11	82
Medical informatics	3	0	5	0
Smart city	4	100	9	100
Telemedicine	5	60	8	62
Ambient Assisted Living	7	43	10	30

As can be seen, robotics, sensors and computational medicine have been a constant over the last 20 years, although in recent years the presence of wearables, smart living and Internet connectivity has increased.

Standardization of keywords is often scarce. For example, between 2018 and 2020, there was an increase in the study of energy efficiency, but different keywords were used associated with this area of research. Terms used included “energy efficient”, “low energy consumption”, “high energy efficiency”, “sustainable energy sources”, “energy optimization” and references to associated topics such as “energy conservation” and “energy management”. Something similar occurred with terms such as “smart communities” and “smart cities”, and the relationship between “eHealth”, “Telehealth” or “Telemedicine”.

4.4. What Research Topics Require Further Attention? (RQ4)

Older adults are often affected by one or several age-related disabilities, either moderate or severe. System features such as usability, accessibility or readability have a more pronounced effect on this type of user, influencing their acceptance or rejection of systems. It is therefore necessary right from the initial planning stage to implement a user-centered design that will result in sustainable, inclusive technology [27,111]. It is also necessary to encourage developers to adopt this type of methodology [137] to create inclusive resources.

One often overlooked aspect is how older adults can improve technology. Even though older adults play an active role in evaluating applications, user-centered design is seldom applied. This problem is worse when research does not take advantage of one of the greatest strengths of the aging population, their knowledge and experience. Some projects have attempted to incorporate and codify this experience to mitigate disasters such as food shortages. Lunga’s thesis [138] is that this knowledge can be incorporated into more sustainable techniques related to the environment.

Another aspect rarely taken into account is the affordability of technology. On the one hand, future society faces a lack of funding for the health care and public pension systems. Older adults tend to have more ailments and physical and cognitive limitations. On the other hand, the impact of lower incomes and purchasing power, especially among women

(Table 2), forebodes difficulties in acquiring, installing and maintaining technologies. The proposals discussed in this paper rarely address the costs of their application or who is to assume those costs, and therefore run the risk of not being generically applicable.

Neither do any studies exist showing the extent to which these technologies have been implemented—for example, detailing the number of older adults using them, the degree of implementation, the results obtained, their benefits in terms of efficiency and sustainability (i.e., savings for the public health care system or energy savings) or their scalability to benefit a larger proportion of older adults. However, the proposal for an EU regulation on Artificial Intelligence [139] does warn of the issues that will have to be considered in the future implementation of these technologies, with experts drawing attention to the privacy of older adults' personal data, the risk that their behavior may be manipulated by artificial intelligence programs and the need to detect risks and ensure the traceability of results.

Finally, most of the research projects presented in this paper are short term projects or programs to train older adults in the use of new technology, so it would be advisable to promote the real use of these technologies in the medium and long term.

5. Conclusions

Technology offers smart, sustainable solutions to enable older adults to live in better conditions. These solutions must cover not only healthcare, but also social and emotional needs in people's daily lives. Smart homes and cities, the IoT, ICT, robotic systems, artificial intelligence and other technologies can offer efficient, scalable, cost-effective and sustainable solutions. These solutions are not only accurate once cognitive or physical decline has become apparent but are also of great interest for the prevention and early detection of age-related decline.

Throughout this paper it can be seen how technology has facilitated aging in place for the elderly population, either by studying the development of older adults' daily lives or by improving their connectivity with community and health professionals. Technology thus improves social inclusion and promotes a life with greater wellbeing, treating health preventively and enabling the early detection of risks and diseases.

It is important to note that the search strategy on which this article is based prescribed that terms associated with sustainability must be expressly included in the abstracts of the articles by the authors. That is to say, the ultimate object of study was the researchers' own perception of these technologies for older adults as vehicles through which to meet sustainability goals. The large number of authors with just one or two papers over a 20-year period suggests a low degree of specialization. This contrasts with the growth in interest in this area in the last five years. The underlying reason is that the technologies were previously in an immature state, and it is only in recent years, due to growing interest in sustainability and awareness of the challenge posed by the aging population, that their degree of applicability to this field has been raised. Given such recent interest and the technologies involved, a low degree of specialization is to be expected.

There is a clear need to study the feasibility of applying these measures from two different perspectives: on the one hand, the extent to which the target population engages with and adopts technology, and how this increases with the implementation of user-centered, inclusive designs and specific training; and on the other, the cost of installing, maintaining and using these technologies for older adults and whether the elderly population will be able to afford them.

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