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ASSESSMENT OF CHOSEN TECHNOLOGIES IMPROVING SENIORS' QUALITY OF LIFE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Abstract. Sustainable development is a perspective on economic progress that takes into account the equilibrium among social, economic, and environmental elements. This implies that endeavours aimed at development should guarantee the satisfaction of present generations' requirements while safeguarding the capacity of future generations to fulfil their own necessities. In the context of an aging society, sustainable development involves providing solutions, services, and technologies that address the needs of older people while also minimizing negative impacts on the environment and future generations. The aim of this article is to identify, analyse and evaluate technologies that improve the quality of life of older people without compromising the well-being of future generations from ecological, social, ethical and other perspectives. Technologies that enhance the quality of life for older people are often referred to as gerontechnologies in the literature.

The article identifies and then selects 3 gerontechnologies that can improve the quality of life of older people while remaining sustainable. Further, 42 criteria for evaluating gerontechnologies were identified. These gerontechnologies were then evaluated by potential users. A ranking of gerontechnologies was further developed. CAWI and CATI methods were used in the survey. The SAW method was used to build the ranking.

Keywords: older people, gerontechnology, SAW, decision making, ranking, sustainable development.

JEL Classification: C44, O32, O33.

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1. Introduction

Population ageing is widely perceived as a major sustainability challenge affecting the future of science and technology (S&T) policy, economy, and governance in industrialised societies (Chen & Chan, 2014). The older population's proportion in the total population has started to rise and continues growing in many countries. In 2020, 20.6 per cent of the EU population was 65 or older; this was 3.0 percentage points higher than the corresponding percentage a decade earlier. This means that one in five people in the European Union is 65 or older. This represents almost 100 million people, which comes down to roughly three working-age people for every person aged 65 or over. In 2020, Italy had the highest proportion of older people in its population across EU member states at 23.2%, closely followed by Greece and Finland at 22.3% each, Portugal at 22.1%, Germany at 21.8%, and Bulgaria at 21.6%. On the other hand, the lowest shares of older people were observed in Ireland at 14.4% and Luxembourg at 14.5%. At a regional level, Chemnitz in Germany had the highest percentage of older people at 29.3%, followed by Liguria in Italy at 28.7%, Epirus in Greece at 27.3%, Limousin in France at 27.1%, and Saxony-Anhalt in Germany at 27.0%. In contrast, Mayotte and French Guiana, both overseas regions of France, had the lowest percentages of older people at 2.7% and 6.1%, respectively, while the Spanish autonomous region of Melilla had 11.1% (Eurostat, 2021).

Life expectancy in Europe is high. In 2020, life expectancy for the European Union as a whole was 80.4 years. An average EU citizen lives 77.5 years, and a female citizen lives 83.2 years, which comprises a difference of 5.7 years between men and women. The population pyramid shows that these figures can vary from region to region and are slightly higher for women than for men. More than 30% of people over the age of 65 have moderate physical dependence, representing almost 20% of the population. In contrast, 42% have a variety of pathologies, including cardiovascular (65%) or cognitive (43%) conditions that get worse with age. As a result, the phrase "healthy life expectancy" has been coined to encompass not only the number of years lived but also the number of years spent in good health and able to live independently. In Europe, men's healthy life expectancy was 63.5 years in 2020, while women's was 64.5 years, or approximately 77.6% and 81.9% of men's and women's average life expectancy, respectively (Eurostat, 2022).

Addressing the challenges of population aging in the context of sustainable development requires a holistic approach that takes into consideration the healthcare system, infrastructure, social participation, economic opportunities, social protection, and intergenerational solidarity. By promoting active and healthy aging and ensuring the inclusion and well-being of older adults in society, we can strive towards a more sustainable and inclusive future for all age groups.

According to the World Health Organization (WHO), active aging is described as the endeavour to maximize health, engagement, and safety opportunities, aiming to enhance the quality of life as individuals grow older. This effort encompasses not only the individual but also the broader community. Rephrasing, active aging means making use of all of the resources at one's disposal to improve or maintain one's health to its highest possible level as one gets older in order to achieve the highest possible quality of life, which will also have an effect on the community. According to Kalache and Gatti (2002), active aging enables people to realize their potential for physical, social, and mental well-being, participate in society throughout their lives, and ensure adequate protection, safety, and care when necessary. Active, healthy ageing is enabled by innovative technologies to support older people. Technologies that improve the quality of life of older people are often referred to in the literature as gerontechnologies.

The term "gerontechnology" was first used in 1989 by Jan Graafmans (Graafmans et al., 1992) and referred to the relationship between ageing and technology, aiming to contribute to reducing the problems of older people that lead to transformative ageing, supporting compliance with the central strategy (Martínez Ortega et al., 2002). Gerontechnology is perceived as a science, technology and social environment that integrates gerontology and modern scientific and technical measures to support older people (Astasio-Picado et al., 2022). Gerontology and technology are combined in this field to create technologies, products, environments, and services that can: (1) prevent, delay, or compensate for physical and cognitive issues that come with ageing; and (2) offer older people new opportunities in their personal lives in terms of leisure, education, and the like. Thus, gerontechnology's main aim is to improve older people's quality of life (Rodríguez et al., 2016). In 1992, Bouma and Graafmans authored a book titled "Gerontechnology" (Bouma & Graafmans, 1992), which wielded considerable influence in Europe and ultimately popularized the term. In 1997, the International Society for Gerontechnology (ISG) was established to promote culture and scientific exchange among professionals interested in improving the health and well-being of older people.

The report entitled "Technology for Adaptive Aging" identifies six core areas of gerontechnology, also known as the "domains of life": communication, employment, health, learning, living environments, and transportation (National Research Council, 2004). Each of these areas is considered with a view to prevention, compensation and improvement, in line with the principles of universal design, accessibility and usability. Each of these areas is compatible with sustainable development. In contrast, a report prepared by the National Science and Technology Council of the United States identified seven technology areas that support older people's quality of life consistent with the principles of sustainable development (National Science and Technology Council, 2019). These technology groups/areas include:

- Key activities of independent living – technologies that facilitate activities of independent living, including technologies that support proper nutrition, hygiene and medication management;
- Cognitive skills – technologies related to cognitive skills, such as health monitoring and financial security-maintaining technology-based systems for the elderly;
- Communication and social connectivity – Technologies that create easy to use, available and accessible communication and social interaction tools, like video calling and other technologies that help older people connect with friends and family who live far away;
- Personal mobility – technologies that ensure easy and safe tools for people to move around their homes and communities;
- Access to transport – modifications to automobiles and assistance with safely navigating public transportation for the elderly;
- Access to healthcare – enabling adaptations and coordination of healthcare.

In turn, Halicka identified areas of gerontechnology: interpersonal communication, safety, mobility, care, leisure, housing, and digital accessibility (Halicka & Surel, 2021). Meanwhile, Garcia distinguished three main gerontechnology areas: technology for independent people, assistive technology and technology for communication and leisure (Martín García, 2018). Technologies in the first group include mobile telecare services, accessible interfaces to facilitate TV or Internet navigation, screen readers, virtual keyboard, voice synthesis, home automation and digital smart homes, mobile devices, etc. In contrast, assistive technologies, otherwise called rehabilitation or adaptive, are various types of governance and programmes that function to substitute or enhance the body's capabilities to increase older people's functionality. Such technologies are designed for a wide range of problems: cognitive, language, communication, personal mobility, visual impairment, etc. In contrast, technologies that facilitate communication and leisure enable and improve access to the web. They are screen readers (which read text aloud), screen magnifiers, voice recognition software, and social networking and community programmes specifically designed for older people.

In each of the above-mentioned gerontechnology areas, many technologies can be identified. Since many technologies exist for improving people's quality of life, they should be reviewed and evaluated according to various criteria, such as economic and ecological aspects or expectations, trust and acceptance of future and current users. To date, studies for the evaluation of specific technologies by potential users have been sporadic and concerned with the evaluation of one technology, e.g., smart home-driven digital memory notebook (Dahmen et al., 2018), mHealth app (Hsieh et al., 2018), smartphone (Hsieh et al., 2019), and digital learning game (Nap et al., 2014), The use of the robot by the elderly was presented in the works Sale (2018), Ejdys and Halicka (2018), Ejdys (2020). On the other hand, the mechatronic shoe were discussed by Simsik (2012) and electronic pillbox by Tellier et al. (2020).

An ageing society is a situation in which the proportion of older people in the population increases as the number of people of working age decreases. This creates a number of challenges for society, including rising healthcare and long-term care costs, and the need to provide services and products that meet the needs of older people. In the context of sustainability, an ageing population can mean that investment is needed in the development of sustainable technologies to help reduce the environmental burden and provide access to sustainable energy sources. In conclusion, existing research is not sufficient to fully understand emerging technologies that enhance the quality of life of the older people in the context of sustainable development. Consequently, in order to achieve sustainability and address the challenges of an ageing population, investment is needed to develop sustainable technologies, infrastructure and services that meet the needs of both current and future generations. It is also important that the measures taken take into account the diversity of needs of older people and ensure that they have access to a decent quality of life, while minimising the impact on the environment. As a result, the systematic analysis lacks research: the assessment of geotechnologies in the context of sustainability, which necessitates theoretical and empirical investigation.

The aim of this article is to identify, analyse and evaluate technologies that improve the quality of life of older people without compromising the well-being of future generations from an ecological, social, ethical and other perspectives. The novelty of this article is the evaluation of several specific technologies that meet sustainability principles by potential users. In this paper, based on the literature review, the author has identified examples of technologies facilitating older people's quality of life and at the same time be sustainable (task 1). Based on the literature review, criteria for the evaluation of (sustainable) technologies were identified (task 2). The technologies were then evaluated by people over 40. In this age group, people usually have elderly parents and often care for them, so they know their needs and required technology properties (task 3). In contrast, people over 60 are potential users. The next step was to build a ranking (task 4) using two arbitrarily chosen SAW (Simple Additive Weighting) methods (Halicka & Kacprzak, 2021). SAW method based on a value/utility function using aggregation of preferences based on the values of decision options. A very important advantage of the SAW algorithm is its computational simplicity, ease of interpretation of the obtained result, and the fact that it can be used in a wide range of situations (Roszkowska & Kacprzak, 2016).

2. Literature review

Publications identified in the Scopus Database were reviewed by searching for the phrase: (1) "gerontechnolog*" and "Decision Making"; (2) "gerontechnolog*" and "technology" and "evaluation"; (3)"gerontechnolog*" and "selection"; (4) "gerontechnolog*" and "sustainable development" in the title or abstract, or in the article keywords ((TITLE-ABS-KEY (gerontechnolog*) AND TITLE-ABS-KEY ("Decision Making")); (((TITLE-ABS-KEY (technology AND evaluation) AND TITLE-ABS-KEY (gerontechno*))); ((TITLE-ABS-KEY (gerontechnolog*) AND TITLE-ABS-KEY (selection)); ((TITLE-ABS-KEY (gerontechnolog*) AND TITLE-ABS-KEY ('sustainable development')). In the end, 43 publications were received, with a few repeats. The selected articles were analysed in detail.

In reviewing the literature, it is important to note that technologies improving older people's quality of life can be assessed based on expert experience, bibliometric analysis, text mining analysis, and technical vacancies analysis (Mi et al., 2022). The expert analysis primarily uses the wisdom and experience of experts. Delphi is the most commonly used method. For example, in a publication by Abdi et al. (2021), experts assessed ten new technologies in the context of meeting the needs of older people in five care and support domains, such as (1) mobility, (2) self-care and domestic life, (3) social life and relationships, (4) psychological support, (5) access to healthcare. The Delphi technique was employed, with 21 experts taking part in the first round and 19 in the second. They assessed the following gerontechnologies: self-driving cars, assistive autonomous robots, exoskeletons, mobile apps with AI capabilities, AI-powered wearables, novel drug delivery systems, portable diagnostic tools, voice-activated devices, virtual, augmented, and mixed reality (VR/AR/MR), as well as homes equipped with IoT technology. Expert analysis was also used to evaluate the interactive TV platform +TV4E (Silva et al., 2017). This platform is dedicated to older people and was evaluated by one gerontology specialist and four public policy experts (n=4). In contrast, the Interactive Fuzzy Inference System for Teletherapy of Older People was evaluated by therapists (Rodríguez et al., 2016). Expert-based methods are time-consuming and labour-intensive, and the analysis results are often subjective. Thus, accuracy, efficiency and objectivity are often questioned by researchers.

The bibliometric analysis involves analysing bibliographic data of publications (scientific papers, patent literature, popular science literature, etc.) according to particular characteristics: journal, author, subject classification entry or country, etc. Often, mathematical and statistical methods are used. The method is also used as an introduction to the expert- or text-mining analysis. For example, Noh, Song and Lee constructed a model for the emergence of new technologies facilitating older people's quality of life based on patent indexes and identified 5G technologies (Noh et al., 2016). In turn, the publication (Lee et al., 2015) analysed the characteristics of patent indices and proposed a method for identifying new technologies using machine learning. A bibliometric analysis based on multi-source data reduces the subjectivity of the analysis and does not consider semantic information. Text mining analysis, on the other hand, is oriented towards characterising the content of scientific literature, concertedly analysing semantic information. Of the aforementioned methods, text mining analysis is most commonly used to assess gerontechnology. For example, Astasio-Picado et al. (2022), using initially bibliometric analysis and then text mining analysis, found that communication technologies reduce loneliness among older people, as does virtual reality for exercise, memory training or rehabilitation. The most difficult barrier to overcome is the pre-existing ignorance of older people about technology, which can be overcome by teamwork across the community, especially in the health and education sectors, and within the family. In contrast, Ma, Chan, and Teh (2021) indicated that perceived usefulness, perceived ease of use, and social influence are significantly correlated with older people's willingness to use technologies. Moreover, older individuals are most willing to utilize familiar technologies like smartphones. The ease with which a system can be used, its ability to enhance one's quality of life, and its conformity to social norms all play a role in determining how readily accepted new technologies like healthcare systems and devices are. Conversely, Zhou et al. (2020) established that perceived usefulness and perceived ease of use exert a substantial positive influence on the attitude and behavioral intent of older individuals towards technology adoption. In addition, user behavioral intent is significantly associated with performance expectations, ease of use expectations, self-confidence, technical competence, and subjective norms. Meanwhile, social influence and facilitative conditions exhibit a favorable correlation with user behavioral intent, while anxiety displays a significant adverse relationship with user behavioral intent. In contrast, Abdi et al. (2020), after reviewing 39 research papers, identified pivotal emerging technologies that could address the support and care needs of older individuals. These technologies encompass: autonomous robotic assistants; self-driving vehicles; health-focused smart applications and AI-powered wearable devices; innovative drug delivery mechanisms; portable diagnostic instruments; voice-operated devices; virtual, augmented, and mixed reality; and intelligent residential systems.

In contrast, technical vacancies analysis is mainly based on visualisation techniques (patent matrices and maps). Using this method, current technology gaps, i.e., emerging opportunities with a high potential for older people's use can be analysed and displayed directly (Mi et al., 2022).

The literature also provides dependable publications on particular technology evaluations given by older people (potential users). However, they are mostly focused on one technology. As an illustration, Thilo et al. (2021) investigated the factors, thoughts, motivations, and considerations that shape the utilization or lack thereof of Personal Safety Alerting Devices (PSADs) within the everyday experiences of older individuals living independently in the community. Six focus groups were conducted with 32 older people. On the other hand, Silva et al. (2017) presented an evaluation of the interactive TV platform +TV4E by older people in addition to experts. The survey was completed by eleven seniors. In contrast, Jachan et al. (2021) examined the relationship between the costs and benefits of various embedded smart home solutions to support mobility in older people's housing, as well as usability, user satisfaction, and the correlation between the two. Thirty-seven people took part in the survey. On the other hand, Ejdys and Gulc (2022) confirmed that the willingness to use the analysed Rudy robot for elderly care in the future for one's own needs or the needs of family members was positively influenced by its functionality. The findings proved that robots can be useful as technology to assist the elderly.

The author found no studies analysing, evaluating and comparing several technologies for improving older people's quality of life. Summarising the literature review, it seems reasonable to research, compare and evaluate several specific technologies to facilitate older people's quality of life, engaging potential users. It also makes sense to develop a ranking of these technologies.

3. Research methodology

The research process consisted of four consecutive tasks, as shown in Table 1.

In the first task, the author selected three technologies to facilitate older people's quality of life based on the literature review. The technology selection was guided by the following principles, defining their key attributes: (1) available on the European market or known from media coverage, press and television; (2) easy to use; and (3) versatile, i.e., technologies that can perform different tasks and functions. The author tried to select technologies that covered all areas (technology for independent people, assistive technology and technology for communication and leisure) mentioned by Martín García (2018). In the end, three technologies were arbitrarily selected: the VitalBand, the Robot Rudy, and the wheelchair based on artificial intelligence Wheelie7. Considering the gerontechnology areas listed by van Bronswijk et al. (2002), the selected three technologies can be categorised into the most critical domains for improving older people's quality of life, i.e., health and self-esteem, housing and daily activities, mobility and moving, and work and leisure. Selected technologies align with the principles of sustainable development, i.e., they can improve access to healthcare, reduce the need for physical travel, and enable older individuals to age in place in their homes, thereby reducing the environmental impact of transportation and promoting sustainability. These technologies can assist with activities of daily living, such as mobility, communication, medication management, and fall prevention, enabling older individuals to live more comfortably and sustainably in their homes for a longer period of time.

In the second task, based on the literature review, 42 criteria were selected and sorted into seven groups: (1) innovation; (2) technology demand; (3) social–ethical; (4) ecological; (5) ease of use; (6) functionality; (7) user attitude.

Table 1. Research process for evaluating selected technologies to improve the quality of life of older people in the context of sustainable development

Name of research task	Contractor	Method	Result
Task 1: Choosing technologies to improve older people's quality of life	by the author	literature review	(1) the wheelchair based on artificial intelligence Wheelie7, (2) the Rudy robot, (3) the VitalBand
Task 2: Identification of Technology Assessment Criteria	by the author	literature review	The criteria catalogue (42 criteria)
Task 3: Evaluation of gerontechnologies	people over 40	surveys	Completed technology assessment questionnaires
Task 4: Technology selection	by the author	SAW	Ranking

In the third task, considering the 42 criteria identified in the previous step, respondents evaluated three technologies: the VitalBand, the Robot Rudy, and Wheelie7. A 7-point Likert scale was used, where 1 meant "it definitely means I do not agree with the given statement" and 7 – "I definitely agree". Along with the questionnaire, respondents were also provided with information about the three technologies, their applicability, pictures of the technologies, and links to websites. The survey was directed towards individuals aged 40 and above. This age category was chosen because it encompasses individuals who are presently confronted with gerontechnology matters regarding their parents' utilization of such technology, and they represent potential gerontechnology users themselves in the next 20 to 30 years. The survey was conducted between December 2021 and January 2022 on a representative sample of 1 152 Poles.

In the last task, the classical simple additive weighting SAW method was used to build a ranking of technologies that improve older people's quality of life (MacCrimmon, 1968). SAW is one of the simplest and best-known methods for multi-criteria MCDM decision-making (Bagočius et al., 2014), based on a weighted average, also known as a weighted linear combination (Kacprzak, 2019). It was first applied by Churchman and Ackoff (1954) to solve a portfolio selection problem. The main idea of the SAW method is simple (Medineckiene et al., 2010). The final score for each alternative is calculated by multiplying the normalised value of the criterion alternative by the criterion weight and summing the values for all criteria (Zavadskas et al., 2019; Kozlowska, 2022). Then, according to the decreasing value of the final score, all alternatives are ranked, and the best one is selected (Kacprzak, 2020; Volvačiovas et al., 2013).

The increasing complexity of the analysed decision problems makes it less feasible for a single decision-maker to consider all relevant aspects of the problems. Consequently, group decision-making (GDM) is necessary. Let DM_k (k = 1, 2, ..., K) be a group of decision-makers. From a mathematical perspective, the SAW method for Group Decision Making (GDM) involving the combination of individual judgments can be delineated through the following procedural steps.

Step 1: Assuming that each decision-maker DM_k has to choose one of the m possible alternatives (i.e., gerontechnology in the subject analyses) described by n criteria, the evaluation of alternative A_i (i = 1, ..., m) with respect to criterion C_j (j = 1, ..., n) given by each decision-maker or expert is denoted as x_{ij}. Each decision-maker DM_k gave their decision matrix (individual decision) in the formula:

$$X^k = \left[x_{ij}^k\right]_{m\times n} = \begin{array}{c} DM_k \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^k & x_{m2}^k & \cdots & x_{mn}^k \end{bmatrix} \end{array}. \tag{1}$$

In addition, let:

$$w = \left(w_1, w_2, \ldots, w_n\right) \tag{2}$$

be a vector of criteria weights, where: $w_j \in \mathbb{R}^+$ and $w_1 + w_2 + \ldots + w_n = 1$.

Step 2: To ensure comparability of criteria, the decision matrix X^k (k = 1, 2, ..., K) is normalised using the formula:

$$z_{ij} = \begin{cases} \dfrac{x_{ij}}{\max\limits_i x_{ij}} & \text{if } \ j \in B \\ \dfrac{\min\limits_i x_{ij}}{x_{ij}} & \text{if } \ j \in C \end{cases}. \quad (3)$$

obtaining a matrix of the form:

$$Z^k = \left[z_{ij}^k\right]_{m\times n} = \begin{matrix} DM_k \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} z_{11}^k & z_{12}^k & \cdots & z_{1n}^k \\ z_{21}^k & z_{22}^k & \cdots & z_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ z_{m1}^k & z_{m2}^k & \cdots & z_{mn}^k \end{bmatrix} \end{matrix}. \quad (4)$$

Step 3: Using a vector of criteria weights $w = \left(w_1, w_2, \ldots, w_n\right)$, a weighted normalised decision matrix for each DM_k (k = 1, 2, ..., K) is calculated as follows:

$$V^k = \left[v_{ij}^k\right]_{m\times n} = \begin{matrix} DM_k \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} v_{11}^k & v_{12}^k & \cdots & v_{1n}^k \\ v_{21}^k & v_{22}^k & \cdots & v_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1}^k & v_{m2}^k & \cdots & v_{mn}^k \end{bmatrix} \end{matrix}, \quad (5)$$

where $v_{ij}^k = z_{ij}^k \cdot w_j$.

Step 4: Calculation of the aggregated weighted matrix of the normalised DM decision matrices.

One of the most popular and frequently used SAW methods for GDM is the aggregation of the individual V^k (k = 1, 2, ..., K) normalised matrices into an aggregated collective matrix V according to the formula:

$$V = \left[v_{ij}\right]_{m\times n} = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \end{matrix} \\ \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \end{matrix}. \quad (6)$$

With the most common aggregation methods being (Wang & Chang, 2007):

$$\text{ART – arithmetic mean: } v_{ij} = \frac{1}{K}\sum_{k=1}^{K} v_{ij}^k, \quad (7)$$

$$\text{GEO – geometric mean: } v_{ij} = \left(\prod_{k=1}^{K} v_{ij}^k\right)^{\frac{1}{K}}. \quad (8)$$

Step 5: Alternatives are ranked in descending order of the value of the SAW (A_i), i.e., the larger the value of SAW (A_i), the better the alternative A_i. The best alternative is the one with the largest value of SAW (A_i).

4. Results

Initially, based on the literature review, the author chose three gerontechnologies: the VitalBand smartwatch, the Rudy Robot, and the wheelchair based on artificial intelligence Wheelie7.

VitalBand is a smartwatch dedicated to the elderly containing software that can measure, display, transmit and communicate information on heart rate, respiratory rate, blood pressure, number of steps, movement, and calories burned as well as information about the fitness, vital signs, and physical activity of an older person. They also remind the wearer to take medication. The wristband interface is adapted to the older person's needs and capabilities. Elderly-friendly connectivity to mobile apps allows for viewing data. Vital parameters are collected in real-time and stored. Nutritional data and medication adherence are recorded and streamed to family members and doctors. Relatives can track whether the patient has taken medication, skipped medication and/or read notes entered by the patient.

In the meantime, the AI-powered wheelchair, known as Wheelie7, offers older individuals the ability to command it through voice commands or facial expressions. The Wheelie7 system detects and instantly analyzes the user's facial expressions to direct the wheelchair's motion. Smiling, wrinkling the nose, and raising one's eyebrows are among the ten gestures that the wheelchair can recognize. Adapting this technology to a specific user and teaching them facial expressions is simple and takes several minutes. A smartphone with the appropriate app is required, as well as a helpful person to link the wheelchair's movements to selected facial movements or voice timbre.

The Rudy robot is equipped with a multitude of features that can prove to be beneficial for older adults (INF Robotics, 2020). It offers round-the-clock access to emergency services, can dispense medication and remind individuals to take their doses, and also facilitates remote patient monitoring (RPM). In addition, the robot can assist with finding misplaced items, moving objects that may be too heavy for an older person to lift, and even encourage them to engage in physical and mental activities such as games, music, and dance (Martinez-Martin et al., 2020). Furthermore, the Rudy robot provides a means for social interaction and can also make calls for help if necessary (Halicka & Surel, 2022).

Then, according to the methodology presented in the previous chapter (Table 1), criteria for evaluating these three gerontechnologies were identified. The criteria were formulated as statements and divided into seven groups of technology evaluation criteria:

(1) innovation: I1 – the new capabilities offered by the assessed technology, compared to existing technologies, are of significant importance to users; I2 – the improvement in user convenience offered by the assessed technology, compared to existing technologies, is of significant importance to users; I3 – the use of the assessed technology is a significant improvement on previously known alternatives; I4 – the use of the assessed technology is ground-breaking and has the potential to change the strategies of alternative supplier companies;

(2) technology demand: D1 – there is a demand from institutions responsible for the care of the elderly (e.g., D3 – the evaluated technology is characterised by higher comfort of use and simplicity of operation in comparison to the technologies used so far;

D4 – the use of the assessed technology is compatible with the current habits of the elderly; D5 – potential users are willing to pay a high price for the assessed technology in relation to the prices of the technologies used so far; D6 – it is likely that serious technical problems will arise during the development of the assessed technology; D7 – the common use of the assessed technology depends on the use of materials that are difficult to access; D8 – there is a high potential for further improvement of the assessed technology;

(3) social–ethical: SE1 – the widespread use of the assessed technology will bring tangible benefits in terms of improving the image of the national economy; SE 2 – due to the expected benefits provided by the assessed technology, NGOs may choose to support its dissemination; SE3 – due to the expected benefits provided by the assessed technology, public institutions may choose to support its dissemination; SE4 – the widespread use of the technology under assessment may directly lead to violations of generally applicable moral norms or laws; SE5 – the development and production of the technology under assessment may be a source of disease risk for the users of these technologies; SE6 – the development and production of the technology under assessment may be a source of disease risk for the employees of the organisations producing these technologies;

(4) ecological: E1 – widespread use of the assessed technology will result in measurable environmental benefits; E2 – widespread use of the assessed technology may be a source of environmental problems; E3 – widespread use of the assessed technology may be perceived as an inefficient use of natural resources in the use process; E4 – widespread use of the assessed technology may be perceived as an inefficient use of natural resources in the manufacturing process; E5 – widespread use of the assessed technology may be perceived as an inefficient use of natural resources in the utilisation process; E6 – widespread use of the assessed technology may be perceived as a source of environmentally burdensome emissions and waste from the use process; E7 – widespread use of the assessed technology may be perceived as a source of environmentally burdensome emissions and waste from the utilisation process; E8 – widespread use of the assessed technology will save natural resources in the use process compared to existing technologies;

(5) ease of use: EoU1 – I would have no trouble learning how to use the technology under review; EoU2 – I would need to learn many things before I would plan to use the technology under assessment; EoU3 – I would acquire the ability to use the technology under assessment without the help of others; EoU4 – I would require additional training to master the ability to use the technology under evaluation.

(6) functionality: F1 – if I had to, using the assessed technology would improve my mobility; F2 – if I had to, using the assessed technology would improve my living comfort; F3 – if I had to, using the assessed technology would guarantee my independence and independence from third parties; F4 – if I had to, using the assessed technology would improve my well-being; F5 – if I had to, using the assessed technology would give me the opportunity to realise my dreams, plans;

(7) user attitude: UA1 – in a situation, if I had to, I would be happy to use the assessed technology; UA2 – in a situation, if I had to, I would enjoy using the assessed technology; UA3 – in a situation, if I had to use the assessed technology, I would feel confident and independent; UA4 – in a situation, if I had to use the assessed technology, I would feel safe; UA5 – the development of the indicated technology is the right technology improvement direction for enhancing older people's mobility; UA7 – using the technology gives me a feeling of being competent and able to perform activities that are important to me; UA8 – I would be able to trust the technology assessed.

According to the last research task, the author carried out numerical analyses of the following gerontechnologies: A_1 – the wheelchair based on artificial intelligence Wheelie7, A_2 – the RUDY robot, A_3 – the VitalBand smartwatch/health band. The objective of these quantitative assessments is to prioritize gerontechnologies and pinpoint the most significant one using the SAW (Simple Additive Weighting) method. A group of 1,152 decision-makers, denoted as $\{DM_1, DM_2, \ldots, DM_{1152}\}$, assesses the selected gerontechnologies $\{A_1, A_2, A_3\}$ based on 42 benefit criteria categorized into seven groups. They employ a scoring scale ranging from {1, 2, ..., 7} for their evaluations. They then rank the gerontechnologies in terms of each criterion and assign them a score of "7" as the most important and "1" as the least important. This means that no normalisation is needed in the numerical analyses when the different criteria have the same scale. The weights of the criteria are the same, i.e., $w_j = \frac{1}{42}$ for j = 1, 2, ..., 42.

Table 2 shows the results obtained using the SAW method, where $SAW\ (A_i)$ – the final result of the SAW method for each alternative A_i (i = 1, 2, 3), R – the ranking of the alternatives and J – the normalised (i.e., summed to 1) values of the coefficients $SAW\ (A_i)$, which will allow comparing the rankings obtained by different methods. The arithmetic mean, ART (7), and geometric mean, GEO (8), are used to aggregate the individual matrices provided by the DM into an aggregated summary matrix.

The analysis of Table 2 presents that the final $SAW\ (A_i)$ results obtained for SAW_ART and SAW_GEO differ slightly as a result of different aggregation methods. On the other hand, SAW_ART and SAW_GEO give the same ranking of gerontechnologies regardless of the aggregation methods in the formula (symbol $\prec$ means worse than $A_2 \prec A_3 \prec A_1$.

Thus, it can be concluded that gerontechnology A_1 – the wheelchair based on artificial intelligence Wheelie7 – was rated highest by respondents. Furthermore, considering the J-index, it can be seen that the values obtained vary very little. Figures 1 and 2 show the obtained rankings of the variants using SAW_ART and SAW_GEO based on $SAW\ (A_i)$ and J.

Table 2. Rankings of gerontechnologies with the use of SAW_ART and SAW_GEO

		SAW_ART			SAW_GEO		
Gerontechnology	Alt.	$SAW\ (A_i)$	R	J	$SAW\ (A_i)$	R	J
The wheelchair based on artificial intelligence Wheelie7	A_1	5.0515	1	0.3457	4.6937	1	0.3503
The Rudy robot	A_2	4.7078	3	0.3222	4.2688	3	0.3186
The VitalBand	A_3	4.8539	2	0.3322	4.4349	2	0.3310

Then a sensitivity analysis (SA) based on SAW_ART was carried out. It was checked how a change in the value of the single weighting of a selected criterion affects the ranking of gerontechnology (CR). It was also analysed how a change in the value of the criteria weights affects the best gerontechnology (CB). The weights of the individual criteria were changed and their impact on the ranking result was checked. The following equations were used:

$$w_h^{mod} = \frac{1 - w_j^{mod}}{1 - w_j} \cdot w_h,$$

where w_j^{mod} – denote the modified weight w_j of the jth criterion (j = 1, 2, ..., 42).

The results of the sensitivity analysis based on the SAW_ART method are presented in Table 3 and Figure 3, Figure 4. All criteria were assumed to have the same significance. The weights of the criteria are the same, i.e., $w_j = \frac{1}{42}$ for j = 1, 2, ..., 42. Besides, CR – ranges of changes in the criteria weights that do not affect the ranking of the gerontechnology and CB – ranges of changes in the criteria weights that do not affect the best gerontechnology.

Table 3. The final result of sensitivity analysis based on SAW_ART: CR and CB

C_j	CR	CB	C_j	CR	CB
1	[0.0000;1.0000]	[0.0000;1.0000]	22	[0.0000;1.0000]	[0.0000;1.0000]
2	[0.0000;1.0000]	[0.0000;1.0000]	23	[0.0000;1.0000]	[0.0000;1.0000]
3	[0.0000;1.0000]	[0.0000;1.0000]	24	[0.0000;1.0000]	[0.0000;1.0000]
4	[0.0000;0.6096]	[0.0000;0.6096]	25	[0.0000;1.0000]	[0.0000;1.0000]
5	[0.0000;1.0000]	[0.0000;1.0000]	26	[0.0000;1.0000]	[0.0000;1.0000]
6	[0.0000;1.0000]	[0.0000;1.0000]	27	[0.0000;0.6709]	[0.0000;0.6709]
7	[0.0000;1.0000]	[0.0000;1.0000]	28	[0.0000;0.3722]	[0.0000;0.3722]
8	[0.0000;0.5174]	[0.0000;0.5174]	29	[0.0000;0.5581]	[0.0000;0.5581]
9	[0.0000;0.6004]	[0.0000;0.6004]	30	[0.0000;0.2878]	[0.0000;0.2878]
10	[0.0000;0.3308]	[0.0000;0.3308]	31	[0.0000;1.0000]	[0.0000;1.0000]
11	[0.0000;0.3182]	[0.0000;0.3182]	32	[0.0000;1.0000]	[0.0000;1.0000]
12	[0.0000;1.0000]	[0.0000;1.0000]	33	[0.0000;0.8956]	[0.0000;0.8956]
13	[0.0000;1.0000]	[0.0000;1.0000]	34	[0.0000;1.0000]	[0.0000;1.0000]
14	[0.0000;1.0000]	[0.0000;1.0000]	35	[0.0000;0.5355]	[0.0000;0.5355]
15	[0.0000;1.0000]	[0.0000;1.0000]	36	[0.0000;1.0000]	[0.0000;1.0000]
16	[0.0000;1.0000]	[0.0000;1.0000]	37	[0.0000;1.0000]	[0.0000;1.0000]
17	[0.0000;1.0000]	[0.0000;1.0000]	38	[0.0000;1.0000]	[0.0000;1.0000]
18	[0.0000;1.0000]	[0.0000;1.0000]	39	[0.0000;1.0000]	[0.0000;1.0000]
19	[0.0000;1.0000]	[0.0000;1.0000]	40	[0.0000;1.0000]	[0.0000;1.0000]
20	[0.0000;1.0000]	[0.0000;1.0000]	41	[0.0000;1.0000]	[0.0000;1.0000]
21	[0.0000;1.0000]	[0.0000;1.0000]	42	[0.0000;1.0000]	[0.0000;1.0000]

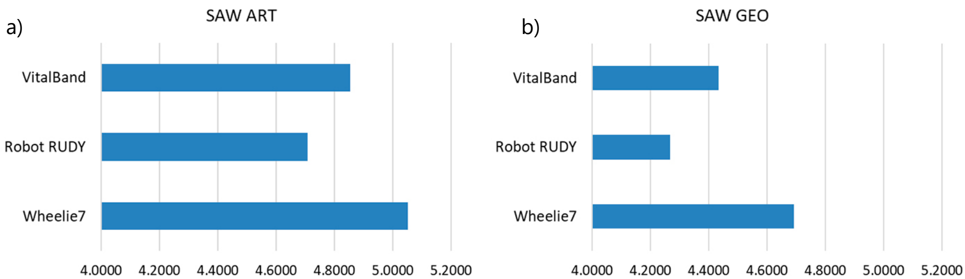

Figure 1. Rankings of gerontechnologies with the use of SAW_ART a) and SAW_GEO b) based on *SAW* (A_i)

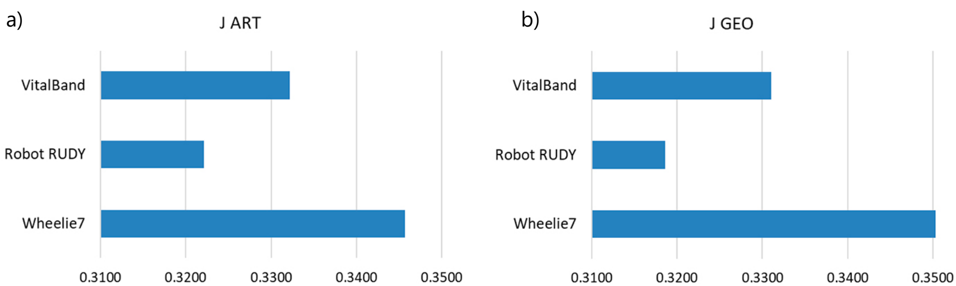

Figure 2. Rankings of gerontechnologies with the use of SAW_ART (a) and SAW_GEO (b) based on *J*

Analysing Table 3 and Figure 3, it can be seen that the developed ranking is quite stable. Changing the weight of eleven criteria C_4, C_8, C_9, C_{10}, C_{11}, C_{27}, C_{28}, C_{29}, C_{30}, C_{33}, C_{35} gives a new ranking. For example, if the weight of criterion C_4 is greater than 0.6096 or the weight of criterion C_{11} is greater than 0.3182 then the ranking will change. Other changes in criteria do not change the ranking. In turn, by analysing the Figure 4 and Table 3, it can be seen that changing the weights of seven criteria such as C_8, C_9, C_{10}, C_{11}, C_{27}, C_{29}, C_{35} may result in a new best gerontechnology. For example increasing the weight of criterion C_8 or C_{10} by more then 0.5174 or 0.3308 changes the leader of the ranking. Other changes in the criteria weights do not affect the selection of the best gerontechnology.

5. Discussion

As a result of the numerical analyses, it should be stated that the methods used gave the same ranking. The highest-ranked technology was Wheelie7. This wheelchair is equipped with artificial intelligence, enabling older people to steer it using facial expressions or voice. In contrast, the robot was rated the lowest. Also, research by Abdi et al. (2021) concluded that voice-activated devices and applications using artificial intelligence would play an increasingly important role in the care and support of older people in the near future. The publication (Abdi et al., 2021) also notes that other technologies, such as robotics, face several technical and acceptability issues that may hinder their adoption by older people in the near future.

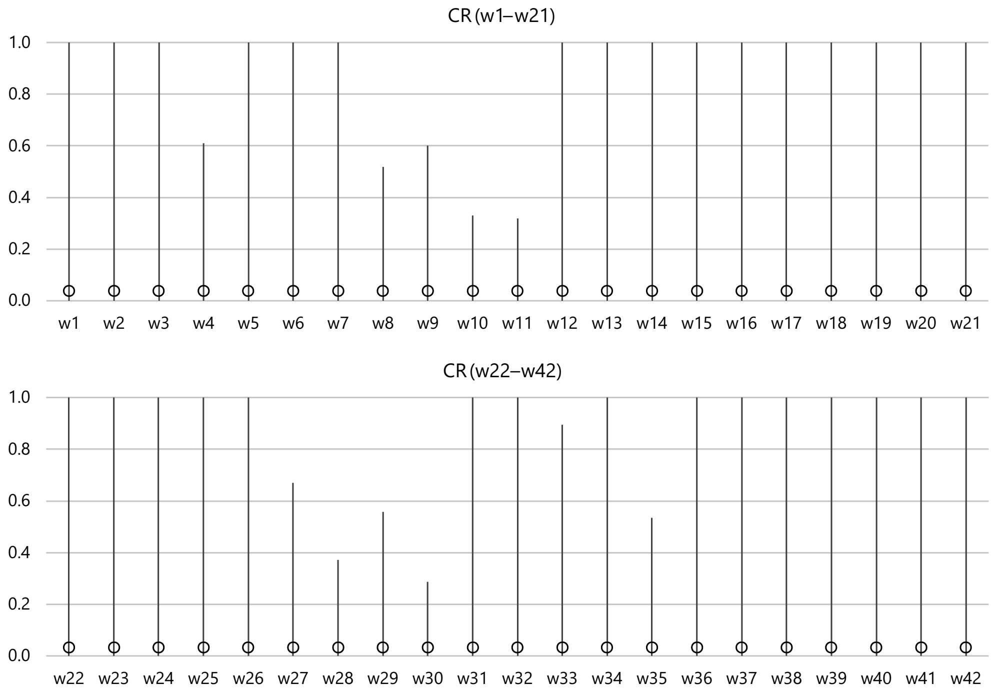

Figure 3. The final result of SA based on SAW_ART: CR

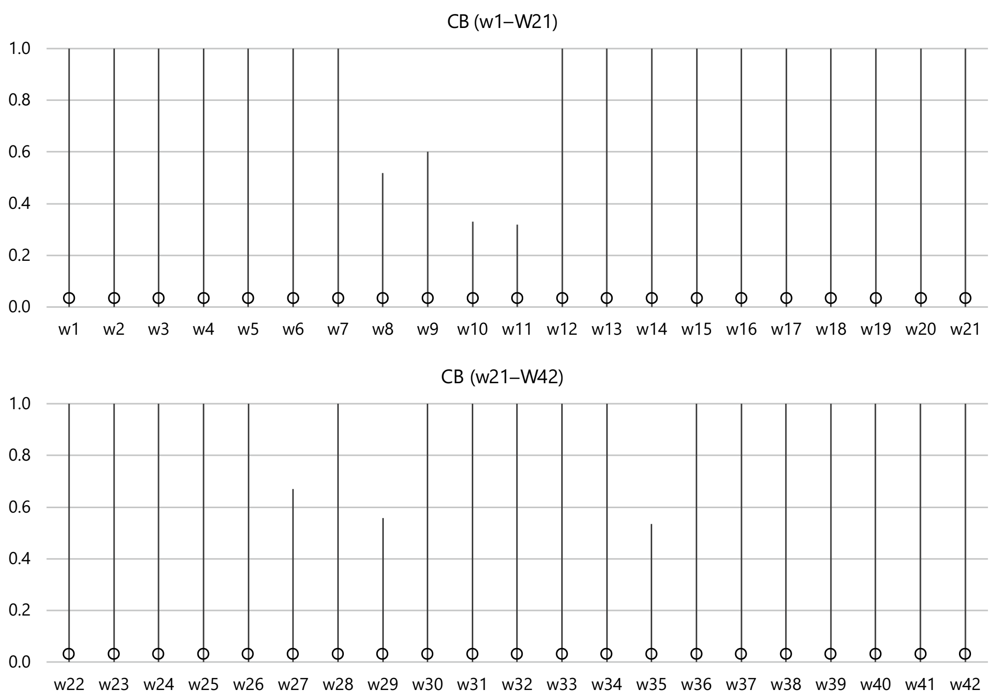

Figure 4. The final result of SA based on SAW_ART: CB

According to a study that was conducted as part of this article, Wheelie7 was rated the highest on criteria related to ease of use, functionality and innovation. This was also confirmed in a study by Ma et al. (2021). They found a strong correlation between older people's willingness to use technology and their perceptions of its usefulness and ease of use (Ma et al., 2021).

Also, Zhou et al. (2020) demonstrated that perceived usefulness and perceived ease of use have a significant positive impact on the attitude and behavioural intention of an older person using technology.

However, it should be emphasised that so far the literature has not analysed and compared several specific, life-enhancing technologies for older people simultaneously. Nor has a ranking of such technologies been carried out. Instead, aspects of the acceptance of technologies dedicated to the elderly will often appear in the literature. For example, Huang and Oteng (2023) provided a holistic perspective of older people and their carers through a systematic literature review on the acceptance of gerontechnologies. The findings underscore that the adoption of gerontechnology among older individuals and their caregivers is significantly influenced by specific personal, physical, socio-cultural, and technological factors. Conversely, Zainal et al. (2023) conducted a comprehensive review of existing literature to explore usability metrics aimed at enhancing the user experience with digital health technologies among older individuals. The study's outcomes reveal that the design, functionality, and overall structure of emerging digital health technologies serve as the primary obstacles to widespread adoption. In contrast, Tan et al. (2023) switched the acceptance and quality of interactions between the Japanese social robot LOVOT and lonely older people in Hong Kong and Singapore.

The novelty of this article is the evaluation of several specific gerontechnologies that meet the principles of sustainability by potential users. As mentioned in the introduction of the article, gerontechnology is a field that focuses on the use of technology to improve the quality of life of older people. In the context of sustainability, the 3 gerontechnologies identified, transferred and evaluated (RUDY Robot, VitalBand, the wheelchair based on artificial intelligence Wheelie7) can play an important role in several aspects, for example: (1) *Healthcare*: selected gerontechnologies (e.g. VitalBand, and RUDY Robot) can help monitor the health of the elderly, controlling the correct use of medication, which can lead to earlier detection and treatment of diseases. This can reduce healthcare costs and the burden on the healthcare system. (2) *Telemedicine:* thanks to gerontechnology (e.g. VitalBand, and RUDY Robot), older people can benefit from telemedicine, which eliminates the need to travel to hospitals and clinics. This, in turn, contributes to reducing transport-related greenhouse gas emissions. (3) *Independence:* gerotechnology (e.g. RUDY Robot, VitalBand, the wheelchair based on artificial intelligence Wheelie7) can support older people to remain independent and self-reliant, which can delay the need to move to care institutions. This may reduce the construction of new care homes, which has an environmental impact. (4) *Mobility*: gerontechnology (e.g. the wheelchair based on artificial intelligence Wheelie7) can support older people to access transport. (5) *Community:* access to communication technology (e.g. the RUDY Robot can act as a communal technology) can help maintain contact with family and friends, which affects the wellbeing and quality of life of older people. Reducing the sense of isolation and promoting mental wellbeing is in line with the sustainability goals related to social inclusion.

All these aspects of gerontechnology, when integrated with the principles of sustainable development, can contribute to a more sustainable future in which older people can enjoy a better quality of life while reducing negative environmental impacts.

6. Conclusions and future research directions

This article addressed the very important issue of identifying, analysing and also evaluating technology that improves people's quality of life in the context of sustainable development. The following research questions were answered in the conducted research: (1) Which technologies can improve the quality of life for older people while being compatible with sustainable development? (2) What criteria should be used to evaluate gerontechnologies in the context of sustainable development? (3) How did potential users evaluate the technologies based on different criteria? (4) Which of the selected gerontechnologies received the highest rating from potential users in terms of sustainability? To date, this type of research has not been conducted.

This paper proposes the application of the SAW method to evaluate and select the highest-rated gerontechnologies, such as the VitalBand smartwatch, the Rudy Robot, and the wheelchair based on artificial intelligence Wheelie7. The selected gerontechnologies have the potential to greatly improve the quality of life of older persons while also promoting sustainability. These technologies (VitalBand, Rudy Robot) enable remote healthcare services, including virtual consultations, remote monitoring, and telemedicine. They can enhance access to healthcare for older persons, particularly those living in rural or remote areas, reduce the need for unnecessary travel, and promote sustainable healthcare practices by reducing the carbon footprint associated with transportation. Wearable devices, such as smartwatches (VitalBand, Rudy Robot), fitness trackers, and medical alert systems, can help older persons monitor their health, track physical activity, and receive emergency assistance when needed. These technologies can promote healthy aging, enable early detection of health issues, and enhance safety, while also promoting sustainability by reducing the need for unnecessary medical visits and interventions. Transportation technologies (Wheelie7) can enhance mobility, reduce social isolation, and promote active engagement in the community, while also contributing to sustainability by reducing the reliance on individual car ownership and promoting more efficient transportation options. Social connectivity technologies (Rudy Robot) can reduce social isolation, promote mental well-being, and enable participation in social and cultural activities, while also promoting sustainability by reducing the need for physical travel and promoting virtual social interactions. Technology can play a significant role in improving the quality of life of older persons in the context of sustainability. By leveraging technological advancements, we can create solutions that enhance health, well-being, social connectivity, and independence for older persons, while also promoting sustainability by reducing environmental impact and promoting resource efficiency. It is crucial to ensure that these technologies are accessible, affordable, and inclusive, so that they can benefit all older persons, including those with diverse needs and backgrounds. Initially, gerontechnologies were reviewed in the literature, and three exemplary technologies were selected. Then, 42 technology evaluation criteria (in line with the principles of sustainable development) were identified considering the following aspects: (1) innovation; (2) technology demand; (3) social-ethical; (4) ecological; (5) ease of use; (6) functionality; and (7) user attitude. Potential users rated the technologies according to the identified criteria. A ranking of the highest-rated technologies was then drawn up using the SAW method. As a result of the numerical analyses, it should be stated that the methods used gave the same ranking. The highest-ranked technology was Wheelie7.

Thus, considering various criteria, the most desirable for current users is the gerontechnology based on artificial intelligence, especially voice-activated or facial expression-activated. Developers and manufacturers should focus on this technology type.

In the author's opinion, the study's exceptional value is in its novelty, as no such research has been yet presented in the available literature. However, it has some limitations. First, it was conducted only in Poland. Also, only three selected gerontechnologies were evaluated. To build the ranking, one of the simplest methods from among the numerous MCDM methods was selected. It was also assumed that all criteria have the same importance and the same weights.

In the forthcoming studies, the viewpoints of decision-makers regarding the basic principles of the criteria will be given due attention in the process of creating the rankings. Furthermore, there are plans to broaden the scope of research to include other European countries and additional technologies to compare the rankings of gerontechnologies across different nations. In addition, there are intentions to expand the catalogue of criteria and formulate rankings using alternative approaches. The author also aims to incorporate other technology assessment data formats, such as fuzzy numbers and interval counts. The author also plans to use other, more advanced MCDM methods to build ranking of gerontechnology.

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Author contributions

The author is responsible for the entire article. She independently developed the concept and design of the study, performed the calculations and analysis, interpreted the data, and discussed the results.

Disclosure statement

The author declares that she has no competing financial, professional or personal interests with other parties.

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