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An assessment framework for smart and sustainable housing for older adults using analytic hierarchy process (AHP)

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Introduction: While there is a call for smart and sustainable housing in general and for older adults in particular, little attention is paid to identifying the determinants of such housing and their extent of influence on the quality of life (QoL) of older adults. This study addresses the above gap by re-defining the criteria for house quality assessment, taking into account new needs of older inhabitants, while concerning digital assistive technologies.

Methods: This research uses various methods to identify and validate housing-related criteria and metrics, resulting in a transparent multi-criteria evaluation framework that accounts for the spatial needs of older adults. These include recommendations for multi-criteria decision-making method (MCDM/A), expert workshop to develop new metrics and validate sub-criteria, expert survey to prioritize criteria and sub-criteria and interviews with three employees in the construction-services sector in the Netherlands, to gain knowledge on smart and healthy environments.

Results and Discussion: The results show that age-friendliness of housing function is the most significant criterion, while availability of housing modifications for seniors most important sub-criterion. Our findings can benefit architects in designing improved age- friendly spaces, older adults in evaluating their dwellings and researchers from the field of architecture in selecting most relevant method for their study.

KEYWORDS

housing architecture, perceptual quality, smart and healthy built environment, sustainable housing, community well-being, analytic hierarchy process, multi-criteria decision-making method

1 Introduction

The 21st century has brought about several global challenges, including an aging population (United Nations. Department of Economic and SocialAffairs, 2022), urbanisation (Ritchie and Roser, 2018), and the environmental crisis, including climate change (World Economic Forum, 2022). The three challenges are interconnected and impact on urban quality of life (QoL). Increasing paved

surfaces negatively affect the climate, resulting in a temperature increase and formation of urban heat islands that undermine human health and wellbeing. Moreover, older adults are more vulnerable to climate changes than other age groups (Lee and Kim, 2016). Thus, it is urgent to develop relevant designing and planning support tools, properly adjusted to changing realities and contributing to achieving the UN Sustainable Development Goals (set to address global challenges).

Present and future older adults prefer to age in place (Gawlak, 2022b; Han and Kim, 2017). The quality of the built-up living environment has a strong impact on the wellbeing of its inhabitants (Abousaeidi and Hakimian, 2020; Jabareen, 2006; Mittal et al., 2020). Here, housing is a spatial unit of particular importance which influences the QoL of older adults (Feng et al., 2018; UK Green Building Council, 2016).

The concept of age-proof houses is not new, yet it needs to evolve to respond to new trends and sociodemographic conditions. Interesting concepts of houses include healthy homes, smart homes, and healthy living environments supported by new technologies. These concepts are worth following because they implement solutions that might currently be underappreciated in senior-friendly residential architecture.

Nowadays, a variety of different appraisal instruments for quality of urban life assessment is available. There are urban rankings, guides, as well as surveys measuring citizens' satisfaction and frameworks proposed by researchers, to name a few. Similarly, a host of methods are applied in QoL appraisal instruments. Here, Multi-Criteria Decision Making/Analysis (MCDM/A) method (Ferreira et al., 2019; Roy, 1990), among them an Analytic Hierarchy Process (AHP) (Saaty, 2000), are popular methods used in assessing multi-criteria problems.

The tools that are currently available for the quality of urban life assessment insufficiently address the global challenges of the 21st century (Ptak-Wojciechowska et al., 2003). QoL in a city is often measured only through subjective measures (life satisfaction) or objective measures (living standards) (Gawlak et al., 2021; Mittal et al., 2020), while both measures should be taken into account (Okulicz-Kozaryn, 2011; Rokicka et al., 2014). There is also a lack of transparency in the definition of metrics and methodology (Acuto et al., 2021; Gawlak et al., 2021; Mittal et al., 2020). Moreover, the criteria applied in the tools that are available today are not comprehensive enough to address the varied needs of older adults related to the architectural aspects of housing. Finally, many tools that intend to measure the QoL or the quality of housing disregard or underestimate the opportunities offered by assistive technology (Bridge et al., 2021; O'Brien and Ruairi, 2009). This paper addresses the above gaps by developing recommendations for a transparent multi-criteria evaluation framework that accounts for the spatial needs of older adults, their new abilities and new emerging potentials such as the role of technology in supporting ageing in place.

This study applies one multi-criteria method - Analytic Hierarchy Process (AHP) - to develop an assessment model and prioritize criteria and sub-criteria of housing design quality evaluation, which impacts the QoL of older people. Moreover, it introduces new metrics for measuring quality of architectural aspects of housing and validates a set of sub-criteria during workshops with experts. Interview with stakeholders from construction-services company completes the results with findings on new areas that need to be further investigated. To the best of the authors knowledge there is no other assessment tool that can be used to measure the impact of architectural aspects of housing on the QoL of the older adults in a comparably comprehensive manner.

This study has three main objectives: (i) to analyse state-of-the-art knowledge and tools for the assessment of the quality of (urban) life in view of an ageing society, environmental risks, and architectural aspects of housing; (ii) to identify a comprehensive set of criteria, sub-criteria and metrics for the measuring instruments assessing the quality of housing, which influences the QoL of older adults; (iii) to develop recommendations for an assessment tool that reliably evaluates the quality of senior housing, while taking into account both the objective needs of the ageing inhabitants and their subjective assessment.

The research reviews studies on the QoL of older people and the built environment focused on residential units. The study started with an analysis of the spatial qualities of Polish neighbourhoods, which influence QoL of older people, conducted within another wider research project, and ended with identification of desirable properties of housing in a broader international context, based on examples in the Netherlands. Thus, the selection of methodology and structure of the criteria of the proposed assessment tool is based on research conducted concurrently in Poland.

Consequently, the remainder of this paper is structured as follows. Section 2 describes the background on the relationship between QoL and built environment, and the topics of forms of residences for older adults, healthcare in housing, as well as healthy and smart homes to present varied approaches to designing age-friendly spaces which impact QoL of older people. Moreover, this section discusses the literature about quality of urban life assessment tools and the use of Multi-Criteria Decision Making/Aiding methods in architecture-related research. This is followed by Section 3 with the methodology and Section 4, where results are presented. Section 5 follows with discussion, and finally, Section 6 concludes with insights into the practical implication and directions for future research.

2 Background

2.1 Quality of life and built environment

Quality of life is a broad term that concerns several aspects including nature, health and wellbeing, infrastructure, social environment, development and finally, architecture and urbanism that has an impact on all the above-mentioned aspects (Gawlak et al., 2021). Quality of life and spatial urban structure are interdependent and exert mutual impact on one another (Jabareen, 2006; Mittal et al., 2020). Concepts such as a quality of space, sustainability, liveability, and quality of life often overlap. They all, furthermore, pertain to the relationship between individuals and environmental conditions (van Kamp et al., 2003; Oppio et al., 2022).

10.3389/fbuil.2024.1476249

FIGURE 1
Amsterdam, Amstelring, De Nieuwe Sint Jacob, nursing home for people with dementia; photo by Ptak-Wojciechowska, 2003.

FIGURE 3
WoZoCo in Amsterdam in the Netherlands designed by MVRDV; Photo by Ptak-Wojciechowska, 2003.

FIGURE 2
A complex of residential building wings for the older adults in Stargard Szczeciński, design by DOMINO Grupa Architektoniczna Wojciech Dunaj, photo courtesy of DOMINO Grupa Architektoniczna Wojciech Dunaj.

2.2 Housing and ageing

In the last two decades, we can observe new and interesting spatial solutions designed with an ageing population in mind. Results of our research on contemporary typology of forms of residences for the older adults show that new types of residences (see example in Figure 1), mainly dedicated to health protection and quality of life improvement, have been developed.

The first type of residential development is senior architecture (Figure 2), dedicated strictly to the needs of an ageing population. It has proven to be a highly functional solution, supported with smart technology, but also governed by legislative frameworks and financial instruments. This type of housing is fully accessible and affordable for older adults.

The other type of residential development for older adults is called assisted living housing, which is an alternative solution to living in a nursing home as it provides certain nursing care services. It offers access to healthcare services 24 h a day, 7 days a week for all inhabitants (Rzecznik Praw Obywatelskich, 2012). Its functional scheme typically includes areas dedicated to social integration of older adults, such as gardens, open lobbies or places for professional activities. This type of housing supports independent and safe living for older adults. The third type, known as creative co-housing (Figure 3), which is a shared apartment system, offers access to various types of amenities. The main aim of this solution is to provide social support and foster social bonds between the residents. Feeling part of a community, older adults have a chance to overcome the sense of loneliness and to improve their quality of life.

Another type of housing, called controlled social mix, is based on a concept of a diverse user group living in one area, that can arrive at a certain symbiosis of their coexistence. The concept is based on an assumption that mutual interactions between non-homogeneous residents are beneficial for all age groups. Intergenerational relations support active life of the older adults and provide many different stimuli. Synergic habitat - creative partnership of generations - is a concept of compact self-sufficient estates that underlie harmonious social development, integration of older and younger age group members, and, thus, result in socio-economic synergy. This type of housing for older adults also poses a chance for the integration of a variety of local activities and services (Figure 4).

There are also more advanced forms of housing designed with older adults in mind, such as a care farm–a fully self-sufficient organism that guarantees employment, healthcare and inclusion of the elderly. By designing labour-related market mechanisms, such as production, trade, etc., it is also a commercial project with great potential. The above presented types of residential housing for the older adults are just examples and do not exhaust all possible housing types, especially that there are also many other forms of housing, and all concepts are constantly evolving.

2.3 Healthcare and housing

In order to provide older adults with safe living conditions, increasing needs for medical services must be properly addressed. Moreover, future older adults will undoubtedly have different needs regarding housing space. Telehealth systems will require highly functional, supportive and innovative space arrangement. This once

FIGURE 4
Wrocław, Nowe Żerniki Housing Estate, A multigenerational house, by Major Architekci, photo courtesy of Major Architekci (author of the photo - Maciej Lulko).

FIGURE 5
Maanwijk in Leusden in the Netherlands; Photo by Ptak-Wojciechowska, 2003.

revolutionary idea of transferring certain elements of diagnostic tests or therapy into the space of one's own house or apartment has now a chance to become an efficient solution for older adults to enable them to enjoy ageing in place. The fact that older adults in the future will have other skills and competencies than older adults today, especially when it comes to the use of digital devices, cannot be disregarded. In fact, it creates a potential for implementation of certain medical care services like diagnostic tests, treatment or health monitoring in the space of their own home or apartment (Gawlak, 2022b).

2.4 Innovation and technology

Despite houses designed especially for ageing people, there are other types of living environments worth mentioning here, namely, healthy homes and smart homes. The former are defined as homes facilitating both physical and mental wellbeing, that can be characterised by such aspects as: designed in resilience, ensured comfort, built-in security, sound insulation, proper lighting, windows and layouts maximising views out, systems and sensors, matching colour schemes, materials and well-designed ventilation systems. In addition to that a healthy home will have a bedroom promoting healthy sleep, living space and a kitchen facilitating social interaction, storage options and a laundry room. It will be, furthermore, connected to nature and underlie improved wellbeing (van Dijken et al., 2006; Kort, 2017; UK Green Building Council, 2016). All of these design attributes will undoubtedly contribute to the QoL improvement. The latter (smart homes) can be described as homes equipped with relevant independence, comfort and security supporting technologies, which translate without a doubt to improved QoL. At the same time, costs of living and nursing care are reduced (Amiribesheli et al., 2015; Coutaz and Crowley, 2016; Demiris, 2008; Fakhrhosseini, et al., 2020; Stefanov et al., 2004). Smart home technologies may be classified into three main generations: wireless technology and proxy server home automation, electrical devices controlled by artificial intelligence (AI) and robotics integrated with AI (Fakhrhosseini et al., 2020).

Given the significant negative impact of the construction sector on environment, smart homes, incorporating multiple technologies, have the potential to increase the flexibility and adaptability of spaces, which is one way to achieve sustainability (Radha, 2020), while implementing reverse logistics in construction further enhances these efforts by minimizing waste and optimizing the use of materials (Kadaei et al., 2023).

We can also name another type of healthy living environment based on smart technologies (Lan, 2013) that - according to Mourits et al. (2021) - may be defined in view of the following clusters: spatial quality, conducive to exercise, tranquil, clean and accessible, attractive and relaxing, positive effect on climate change, green space, healthy air, soil and noise levels, that encourages healthy choices, conducive to social connections and promotes personal wellbeing. Healthy living environments are also dedicated to the elderly as they support their daily, independent living (Sinoo et al., 2006; Van Hoof and Kort, 2006). Examples of such environments may be found in the Netherlands (Figure 5).

2.5 Assessment tools

Quality of urban life assessment is far from new. Places Rated Almanac - ranking recognised as the first instrument that popularised benchmarking of cities in view of the QoL was published in 1981 (Acuto et al., 2021; Chapman and Pike, 1992; Rogerson, 1999). A few years later, in 1990, the Human Development Index, an index measuring the relationship between economic growth and human development was created (United Nations Development Programme, 1990). From then on, a variety of works on the QoL evaluation have been published and many tools to measure it have been developed. Urban rankings are one QoL measuring instrument. It should be noted that such rankings have been developed by different entities including international organisations, research

and government units, or publishing entities, and businesses (Gawlak et al., 2021; Mittal et al., 2020). Another type of QoL measuring instruments are guides that consist of proposed recommendations, e.g., in the form of the so-called 'checklists' allowing us to measure the QoL in general or to focus on relevant aspects thereof, such as age-friendliness or street sustainability (National Association of City Transportation Officials, 2013; World Health Organization, 2007). Moreover, many QoL assessment instruments are based on opinion polls, questionnaires or surveys that present subjective perception of inhabitants (Centrum Badania Opinii Społecznej, 2020; Eurofound, 2017; Liu et al., 2021; Kemperman et al., 2019; Rokicka et al., 2014; Weijs-Perrée et al., 2019). There are also models of assessment developed by scholars, based on different methodologies and methods, such as multi-criteria decision making/aiding method.

2.6 Multi-criteria decision making/aiding

Multi-Criteria Decision Making/Aiding (MCDM/A) method addresses barriers related to unstructured collaborative decision-making. It allows - with the use of multiple criteria and systematic analysis - to assess variants and select the optimal one (Afshari et al., 2016). This method is often used to assess features of urban environments (Abousaeidi and Hakimian, 2020; Ahmad and Thaheem, 2017; Amin Hosseini et al., 2016; De Toro et al., 2004; Hajduk, 2021). According to the researchers, many methods, such as LEED or BREEAM, that are typically used globally to evaluate green buildings, can be successfully incorporated to form part of more suitable decision-making instruments (Abousaeidi and Hakimian, 2020; Moussaoui et al., 2018).

2.7 Analytic hierarchy proces

What is today known as an Analytic Hierarchy Process (AHP) is a renowned MCDM/A method developed by Saaty (2000). This method is related to decision making process and allows for finding an optimal variant in the complex multi-criteria problems (Ahmad and Thaheem, 2017). AHP excels over other weighting methods with arbitrarily prioritised metrics. Weights and priority index in the AHP are derived from pair-wise comparisons (Abousaeidi and Hakimian, 2020; Sadiq et al., 2003) often with the use of Saaty's scale (see Figure 6). Furthermore, this method is commonly used in architecture-related research (Abousaeidi and Hakimian, 2020; Harputlugil, 2018; Morkunaite et al., 2019). The AHP method allows to prioritise criteria according to the preferences of a given Decision Maker, and finally, to evaluate and rank variants from the best to the worst. Such rankings have a great marketing potential. Thus, they attract the attention of municipalities and communities that can subsequently learn on the basis of the best reference example (Acuto et al., 2021).

3 Material and method

The study approach consists of three main parts reflected in the article structure. Figure 7 shows a diagram depicting an overview of the approach. The first part includes an introduction presenting motivation related to global challenges, and a need of senior-friendly housing assessment, as well as major gaps that the paper is addressing, its aim and methodology. The second part, background, includes topics regarding the quality of life and built environment (2.1), related to housing and ageing (2.2), healthcare and housing (2.3), as well as innovation and technology (2.4), along with appraisal instruments (2.5), MCDM/A (2.6) and selected specific method AHP (2.7). In the next section, methodology (3), both quantitative and qualitative, is presented along with the following methods: literature review (3.1), comparative analysis (3.2), MCDM/A including Analytic Hierarchy Process to recommend appraisal instrument (3.3), experts' workshop (3.4), questionnaire survey (3.5), and stakeholders' interview (3.6). Finally, recommendations for appraisal instrument for assessment of smart and sustainable housing for future older adults are presented in the results section (Figure 7). These are followed by discussion in the fourth section and finally conclusions.

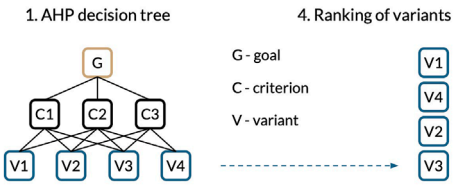
A study is structured as follows: the review of literature on the topics listed above is first made, then follows the comparative analysis of housing metrics and recommendations for a relevant instrument in view of the MCDM/A concept. Next, the subsection moves to the description of the experts' workshop, organised to work up new metrics and validate respective sub-criteria, thereafter, follows prioritisation of criteria and sub-criteria via the AHP-OS method. The section ends with the allocation of weights to relevant criteria and sub-criteria. Next, the subsection moves to the interviews on healthy homes with three stakeholders. Thus, new areas in knowledge that need to be further investigated can be identified. Based on previous steps the article presents recommendations for a reliable assessment instrument. Future step will be to assess single houses, and then compare them and rank them.

3.1 Literature review

In order to develop recommendations for the above-mentioned assessment instrument, a review, labelled as literature review (Grant and Booth, 2009), was conducted on topics related to global challenges, assessment instruments (tools), QoL in cities, ageing in place, new trends in residential environments and healthcare (Cruickshank, 2010; Dentzer, 2018; Gawlak, 2022a; Wilson et al., 2000), importance of technology, both in the area of healthcare provided in one's own house or apartment and in assisted living (the concept was proposed in the early 1960s and is known as "hospital without walls").

To select scientific papers and appraisal instruments, the eligibility criteria have been established in relation to both the scope of the research and the features of metrics. Scope of the research was defined as including the urban QoL assessment, measuring the age-friendliness, and involving urban spatial metrics, while metrics should be influenced by architects and related to housing, have influence on the QoL of older adults, and concern global challenges (see Figure 8).

Records have been identified through the literature search and recommendations of the two experts from the field of age-friendly design. Then, after screening based on keywords: *age-friendly cities;*



	C1	C2	C3
C1	1	3	4
C2	1/3	1	3
C3	1/4	1/3	1

C1	V1	V2	V3	V4
V1	1	2	6	2
V2	1/2	1	3	1/5
V3	1/6	1/3	1	1/5
V4	1/2	5	5	1

Saaty's scale	
Intensity of importance	Definition
1	equal importance
2	weak or slight
3	moderate importance
4	moderate plus
5	strong importance
6	strong plus
7	very strong or demonstrated importance
8	very, very strong
9	extreme importance

FIGURE 6
AHP process overview—pairwise comparisons and Saaty's scale. Authors' own work.

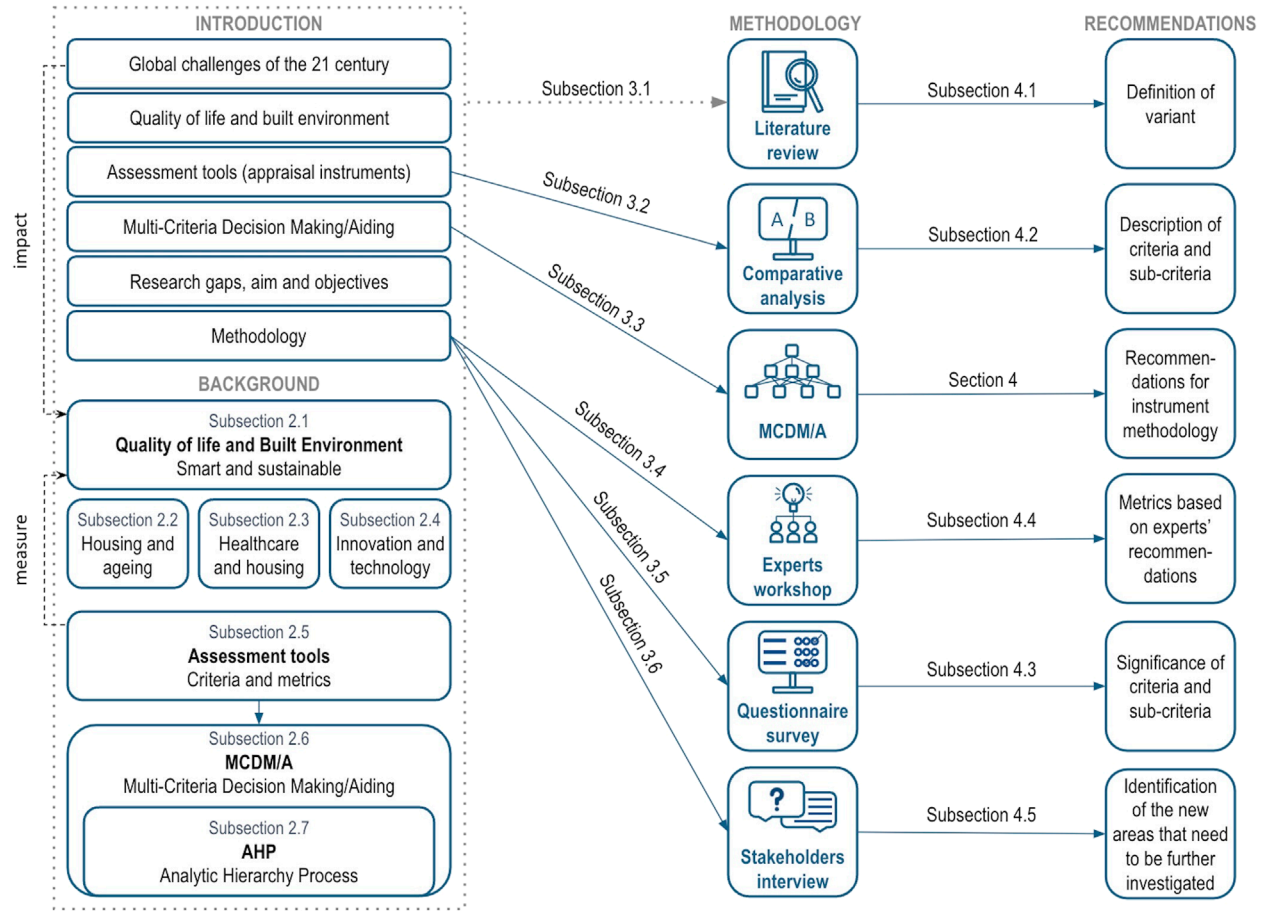


FIGURE 7
Schematic design of the study. Authors' own work.

cities for ageing; instrument; zamieszkiwanie osób starszych; wytyczne; quality of life in city; mierzenie/pomiar jakości życia; ranking jakości życia w polskich miastach, and databases, namely, Scopus and Google Scholar, some papers were excluded.

Subsequently, records were assessed for previously defined eligibility. While some of the records were excluded, some records were later included and assessed for eligibility because the appraisal instruments we analysed recommended new records. Finally,

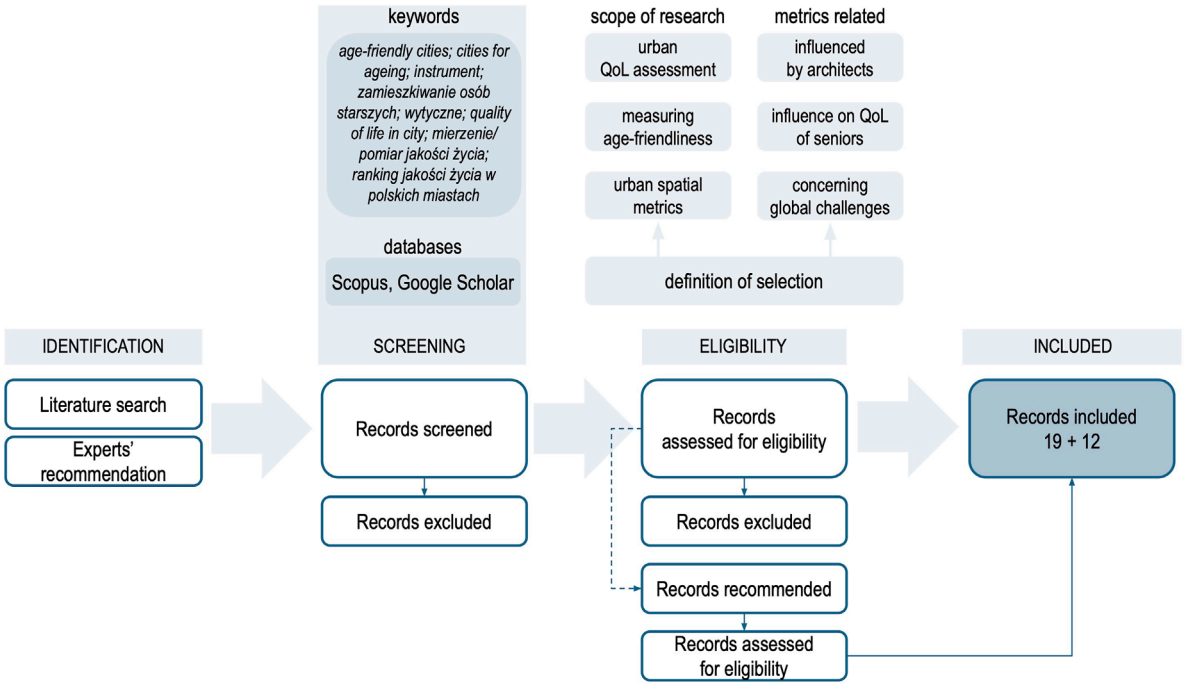


FIGURE 8
Research screening and inclusion process diagram. Authors' own work.

the search rendered 19 assessment instruments and 12 scientific papers, which have been included in Supplementary Table S1 (Abousaeidi and Hakimian, 2020; Abusaada and Elshater, 2020; Bendowska et al., 2017; Bentley et al., 2005; Błędowski et al., 2016; Brewer et al., 2014; Centrum Badania Opinii Społecznej, 2020; Eurofound, 2017; European Commission. Directorate General for Regional Policy, 2013; Eurostat, 2017; Federal/Provincial/Territorial Ministers Responsible for Seniors, 2007; Feng et al., 2018; Garau and Pavan, 2018; Garcia et al., 2017; Giles-Corti et al., 2016; Kubendran et al., 2017; Mercer, 2019; Monocle, 2019; Oppio et al., 2021; Oppio et al., 2022; Organisation for Economic Cooperation and Development, 2020; Górniczo-Hutnicza, 2018; Reid et al., 2019; Rokicka et al., 2014; The Economist Intelligence Unit, 2019; United Nations Development Programme, 2019; Van der Weijst, 2015; Wałachowski and Król, 2019; Wojnarowska, 2016; World Health Organization, 2007; Yigitcanlar et al., 2015).

3.2 Comparative analysis

Comparative analysis includes collating assessment instruments and metrics incorporated in them. It is important to note that results of comparison of evaluation tools and criteria of the QoL have been published in the previous study (reference to our article), whereas comparison of metrics related specifically to housing quality is presented in this paper.

The records identified in the literature review rendered 1844 metrics, understood here as the smallest dimension, a component of the main criterion. It should be pointed out here that such terms as metrics, indicators and criteria inherent in one analysed instrument may not correspond to those inherent in another instrument. Some of them were unrelated to the scope of our research (determinants of housing providing quality of life for older people, concerning global challenges, influenced by architects) and some were found to be included in more than one instrument. After an in-depth analysis of particular indicators, having eliminated redundancy, we identified 59 metrics. Analysis was executed based on study of entire publications to get acquainted with the context, reading metrics' definitions, as well as looking through the cited references, if description of metrics was not provided. Certain metrics were found to be interrelated, thus they were clustered based on the four-eyes principle method and the literature (Bentley et al., 2005; Feng et al., 2018; Gawlak, 2022b; O'Brien and Ruairi, 2009; World Health Organization, 2007). Regarding the latter, clustering was based on criteria and sub-criteria that were frequently mentioned, proposed by impactful source, or assessed as significant. Finally, metrics were clustered to the following topics: accessibility, function, form, environment, adaptability, affordability, senses and innovation and technology, as shown in Figure 9. It should be noted that during the clustering process, gaps in knowledge were identified.

3.3 Multi-criteria decision making/aiding

In order to develop recommendations for a transparent assessment tool, authors have selected one of the MCDM/A methods, namely, the AHP. In the process of selecting MCDM/A method and defining criteria for the research on the Polish neighbourhoods' assessment, two experts were involved. The

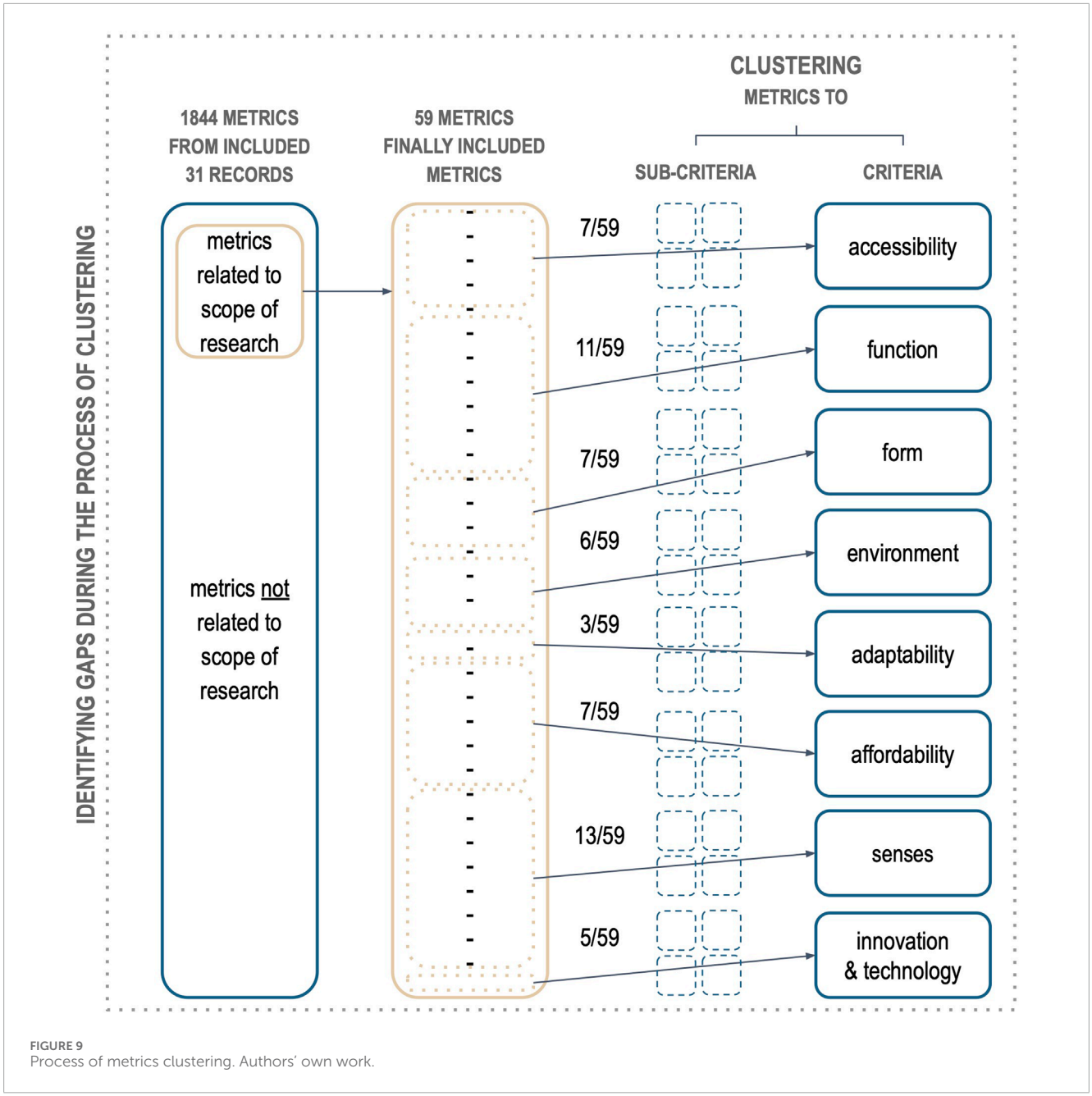


FIGURE 9
Process of metrics clustering. Authors' own work.

first expert specialised in multiple-criteria decision making and the second - in research methods and techniques applied in architecture. For this study the recommendation from MCDM/A was followed, with the focus on the spatial unit of an apartment.

Application of the AHP method requires the identification of the main goal and a set of measurement criteria, sub-criteria and variants. In this study, sub-criteria have been divided into objective and subjective, former to be measured by experts in the field of architecture, and latter to be assessed in the form of a perception of older people, both with the use of the questionnaire surveys. Following the recommendation from MCDM/A, criteria have been defined as nouns, and their number did not exceed the Miller Number, which is 7 ± 2. This is a concept related to multicriteria problems. According to Miller, people are able to perceive and distinguish only a limited number of elements in one moment (Miller, 1956; Saaty and Ozdemir, 2003). The process of clustering the metrics identified certain gaps in knowledge. Roles of accessibility and technology were limited to the selected aspects only. Metrics related to accessibility accounted only for three principles of universal design. Metrics that defined innovation and technology were narrowed down to such aspects as event driven systems, walking aids, telehealth and telecare, and excluded such aspects as significance of communication, cognitive training, environmental control and object location. Moreover, almost all criteria failed to assess the importance of perceived quality. On the basis of literature and authors' expert knowledge, the list of sub-criteria related to accessibility (Table 1) and technology was extended with other universal design principles and technology-related sub-criteria found to be missing.

TABLE 1 Part of the table (Supplementary Table S2) showing the C1 criterion, with its sub-criteria and metrics based on the review of literature.

C1. Accessibility of housing for the ageing population	C1.1 equitable use	Accessible circulation (even surfaces, passages wide enough for wheelchairs)
		accessible entrance to the building
	C1.2 flexibility in use	
	C1.3 simple and intuitive	
	C1.4 perceptible information	
	C1.5 tolerance for error	skid resistance of floors
		rationality and accessibility of space (eliminated impediments)
	C1.6 low physical effort	
	C1.7 size and space for approach and use	accessible facilities (e.g., handrails, railings)
		convenience of facilities for living (independence in daily activities)
		appropriately designed bathroom, toilet, kitchen
	C1.8 seniors' perception of accessibility	

3.4 Experts' workshop for the validation of sub-criteria

The workshop was executed to validate sub-criteria with the multicultural group of experts. It was preceded by the pilot workshop with a group of experts with a background in architecture, including three separate experts–one of which took part in both pilot and final workshop.

In the final workshop, the set of relevant sub-criteria was validated by a group of eight experts, in this in the field of architecture (both researchers and practitioners specialising in such areas of architecture (n = 7) as health and the ageing population, sustainable design or interior design), as well as in the field of gerontechnology (n = 1). The experts had to meet the following conditions to be considered in this category: they were required to have at least a master's degree in a related discipline and demonstrate advanced research activities, evidenced by completed PhDs, ongoing doctoral studies, or equivalent scholarly contributions in professional research settings. For the purpose of the validation of the said sub-criteria, the experts used two tools, namely, Miro[1] (white board) and Mentimeter[2]. In the brainstorming session with the use of Miro, the experts recommended new sub-criteria and metrics. Whereas the voting system as prescribed via the Mentimeter tool allowed the group of experts to decide which sub-criteria shall be finally included in the assessment tool. The workshop commenced with a multimedia presentation and a short introduction, which included an overview of the study, background information, rationale, purpose and methodology. The workshop was structured into two principal sections: the initial identification of housing design qualities and a subsequent voting process on the sub-criteria. Firstly, experts were requested to identify the sub-criteria that should be considered in order to measure age-friendly housing. These were then written on sticky notes and placed on the selected sub-criterion, which was visible on the Miro board. The experts then proceeded to fill in the board in a similar way with sticky notes containing the proposed adequate metrics. Subsequently, the authors of the study [APW, AG] revised the set of sub-criteria prepared earlier in Mentimeter and presented the results to the experts. Eventually, the experts were requested to cast their votes on the sub-criteria that should ultimately be included.

The final set of sub-criteria was based on 50% of experts' votes. Participants voted on additional sub-criterion no sharp corner or edges that was named after that *Architecture without sharp corners or edges*. They also proposed to extend the existing sub-criterion of *Affordability of property maintenance* with the rented property aspect. Consequently, the sub-criterion was named as the *Affordability of property and rented property*.

3.5 Questionnaire survey

Furthermore, the group of eight multiculturally diverse experts, including six that took part in the workshop and two new experts, prioritized the criteria and sub-criteria in a hierarchical structure in a software package called the AHP online system

1 Online software allowing to conduct brainstorming sessions on-line together with a team on a digital whiteboard.

2 Software allowing for the presentation of interactive on-line polls, word clouds and quizzes, where results of voting are immediately visible on the screen.

- AHP-OS, developed by Goepel (2018). This tool consists of a table where relevant hierarchy is assigned under a three level structure: the main goal, criteria and sub-criteria. The experts used the software individually to make pair-wise comparisons of all the criteria and sub-criteria and calculate their weights. Having attributed weights to the criteria and sub-criteria, the said experts verified them for consistency using the Consistency Ratio CR as provided by the software. The acceptable CR rate was below 10% (Liu et al., 2018; Saaty, 1987). Subsequently, weights were averaged to obtain one normalised weight for each criterion and sub-criterion. Afterwards, global priorities that show the importance of particular sub-criteria as a product of weight of a main criterion and weight of a sub-criterion has been computed. All calculations were made by the software. Results will be presented in a tabular form, according to the prioritisation of criteria and sub-criteria made by the experts.

3.6 Interviews with stakeholders

Interviews with three employees in the construction services sector in the Netherlands, who were senior executives and specialist, were validated via data coding. At first, the audio recordings were transcribed by the first author [APW] with the use of ATLAS.ti software[3] that assures safety of the collected data. After reading the data, the first author applied codes to particular excerpts, and having repeated the procedure for several times, topic-grouped codes created a network of codes (as shown in Supplementary Figure S1) assigned to quotes. The second round of the coding procedure involved one of the co-authors [AG], and the third - another co-author [HK]. Finally, transcripts with proposed codes were sent to all the interviewees for their acceptance. After implementing minor changes based on the interviewees' recommendation, the codes were interpreted. Based on the stakeholders' interview on their view on living environments that influence the quality of life of inhabitants, new areas that need to be further investigated were identified. On the basis of previous results, recommendations for appraisal instruments were developed. In a further step, prioritized criteria and sub-criteria could be used as coefficients for the evaluation of houses for older people that then, might be compared and subsequently ranked.

4 Results

As a result of the research, the set of criteria and sub-criteria were developed based on the experts' workshop, weights (Wt) of particular criteria were assigned by experts, and finally the global priorities were calculated automatically by the AHP-OS software, as shown in Table 2.

All criteria include objective sub-criteria to be evaluated by the experts and subjective sub-criteria, related to perceptual quality of older adults. The set of criteria and sub-criteria may be used in the form of a first screening list to evaluate individual dwellings in view of their age-friendliness (as shown in Supplementary Table S3). It is recommended to use the AHP method to rank variants, which mean different houses, in the further step as shown in Figure 10.

4.1 Definition of a variant

In this study, variants are defined as residential units for ageing people who live alone in different configurations, as singles, pairs, or in a group. Architectural form may represent an apartment in the tenement, block of flats, etc., single-family home and different forms of co-housing.

4.2 Description of criteria and sub-criteria

C1. Accessibility of housing for ageing population. This criterion consists of sub-criteria based on seven Universal Design Principles and one based on the perception of accessibility by the older adults, namely,: *C1.1 equitable use*, which means design that can be used by all people despite their diverse abilities, *C1.2 flexibility in use*, which refers to design that takes into account a broad spectrum of individual abilities, but also individual preferences, *C1.3 simple and intuitive use*, which implies the easily understandable design for everyone, at any rate of knowledge, concentration or cognitive skills, *C1.4 perceptible information*, which shows that design successfully conveys the required information, for instance, different surfaces can be distinguished as a result of the application of different colours and finishing materials, *C1.5 tolerance for error*, which intends to minimise risk of an accident through eliminating impediments, *C1.6 low physical effort*, which describes designs that can be effectively used without any forcible strength, for instance, doors should not be too heavy for the user, *C1.7 size and space for approach and use*, which suggests architecture designed in a way that can be easily accessible and used, where furniture can be easily reached in spite of the user's limitations, such as mobility, height, etc. and finally, *C1.8 perception of seniors on accessibility*, which will be measured as a level of satisfaction.

C2. Age-friendliness of housing function relates to an intended purpose and functional program of a given work of architecture. This criterion is further sub-divided into the following sub-criteria: *C2.1 robustness of space*, which means its adaptability and flexibility of use, *C2.2 availability of socialising space*, which designates space that fosters social interactions, *C2.3 protection*, which means assurance of safety in view of meteorological conditions, *C2.4 non-interference of private space*, which ensures privacy in residential spaces, *C2.5 household appliances and furniture*, which includes fundamental fit-out and relevant appliances and electronic devices, *C2.6 installations and sanitary facilities*, which incorporates availability of basic sanitary facilities and connections to the sewage system in the flat, and lastly, *C2.7 perception of seniors on function*, which aims to verify the degree of satisfaction.

C3. Age-friendliness of housing form evaluates such sub-criteria as: *C3.1 space in the dwelling,* understood as average surface area per person in the apartment, *C3.2 quality of architecture, C3.3 quality of materials,* assesses their durability and maintenance options, *C3.4 quality of structure,* which also means good condition of windows, doors or floors (no rotten structures), and no damp stains or leaks appearing on walls and roofs, *C3.5 architecture without sharp corners*

3 Software allowing to make transcripts of the audio files as well as to code the interviews.

TABLE 2 Significance of relevant criteria and sub-criteria regarding global priorities.

Wt	Criteria	Sub-criteria	Wt	Global priorities (%)
0.227	C2. Age-friendliness of housing function	C2.3 protection	0.183	**4.2**
		C2.1 robustness of space	0.177	**4.0**
		C2.2 availability of socializing space	0.139	**3.2**
		C2.7 perception of seniors on function	0.131	**3.0**
		C2.5 household appliances and furniture	0.128	**2.9**
		C2.4 non-interference of private space	0.121	**2.7**
		C2.6 installations and sanitary facilities	0.121	**2.7**
0.226	C1. Accessibility of housing for ageing population	C1.3 simple and intuitive	0.185	**4.2**
		C1.6 low physical effort	0.174	**3.9**
		C1.1 equitable use	0.132	**3.0**
		C1.2 flexibility in use	0.129	**2.9**
		C1.7 size and space for approach and use	0.114	**2.6**
		C1.5 tolerance for error	0.106	**2.4**
		C1.4 perceptible information	0.085	**1.9**
		C1.8 perception of seniors on accessibility	0.076	**1.7**
0.145	C5. Adaptability for seniors ageing in place	C5.1 availability of housing modifications for seniors	0.520	**7.5**
		C5.2 availability of personalization	0.298	**4.3**
		C5.3 perception of seniors on housing adaptability	0.182	**2.6**
0.112	C6. Affordability of housing for older people	C6.2 affordability of property or rental property maintenance	0.334	**3.8**
		C6.1 affordability of property	0.282	**3.2**
		C6.3 affordability of housing modifications and repair	0.207	**2.3**
		C6.4 perception of seniors on housing affordability	0.177	**2.0**
0.103	C3. Age-friendliness of housing form	C3.3 quality of materials	0.242	**2.5**
		C3.2 quality of architecture	0.197	**2.0**
		C3.4 quality of structure	0.176	**1.8**
		C3.6 perception of seniors on housing form	0.131	**1.4**
		C3.5 architecture without sharp corners or edges	0.129	**1.3**
		C3.1 space in the dwelling	0.124	**1.3**
0.066	C8. Innovation and technology for ageing in place	C8.3 communication	0.167	**1.1**
		C8.2 walking aids	0.165	**1.1**
		C8.7 telehealth and telecare	0.138	**0.9**
		C8.1 event driven systems: fall detection, fire, security	0.134	**0.9**

(Continued on the following page)

TABLE 2 (*Continued*) Significance of relevant criteria and sub-criteria regarding global priorities.

Wt	Criteria	Sub-criteria	Wt	Global priorities (%)
		C8.5 environmental control	0.112	**0.7**
		C8.6 object locator	0.097	**0.6**
		C8.4 cognitive training	0.096	**0.6**
		C8.8 perception of seniors on innovation and technology	0.091	**0.6**
0.061	C7. Quality of multisensory experience of housing	C7.2 adequate natural light	0.210	**1.3**
		C7.6 adequate temperature	0.179	**1.1**
		C7.3 noise quality	0.154	**0.9**
		C7.1 adequate illumination	0.138	**0.8**
		C7.5 adequate insulation and aeration	0.131	**0.8**
		C7.4 sensual experience	0.104	**0.6**
		C7.7 perception of seniors on multisensory experience	0.083	**0.5**
0.059	C4. Environmental friendliness of housing	C4.1 emission level of harmful substances	0.390	**2.3**
		C4.4 access to nature	0.240	**1.4**
		C4.3 share of environmentally friendly technologies	0.147	**0.9**
		C4.2 share of recyclable materials and pro-environmental materials	0.133	**0.8**
		C4.5 perception of seniors on environmental friendliness of housing	0.091	**0.5**
				100

Global priority represents the overall importance of each lowest-level element (subcriteria) relative to the hierarchy's goal. It is calculated by multiplying the weights of the criterion and its corresponding subcriterion.

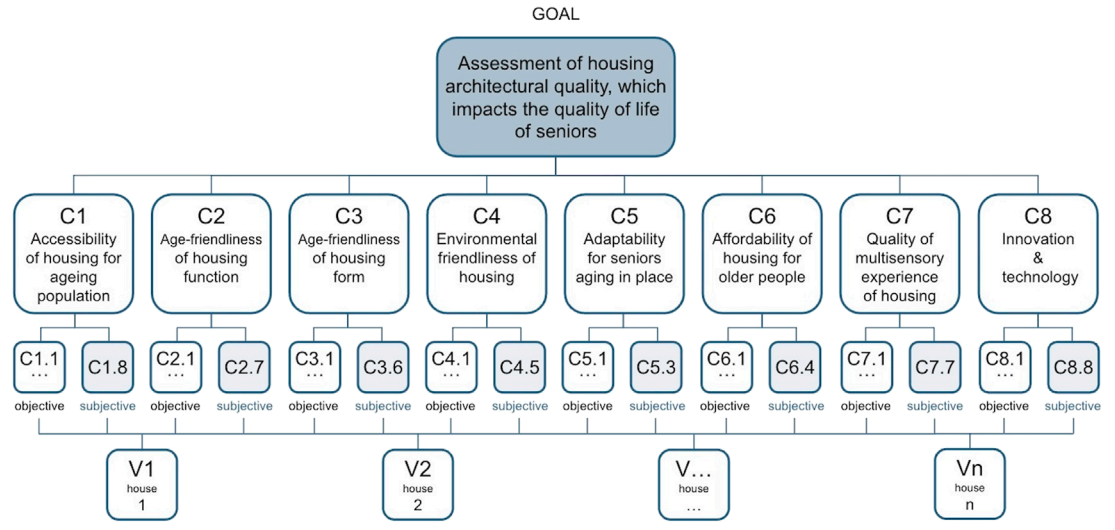


FIGURE 10
The AHP decision tree indicating the goal, criteria, sub-criteria and variants. Authors' own work.

or edges, which refers to satisfaction with aesthetically pleasing curvilinear forms and interiors, which underlie many positive emotions, such as the feeling of calmness and relaxation, and are, thus, more friendly than the rectilinear forms and interiors (Dazkir and Read, 2012), and increase physical safety of the users. The final sub-criterion contained is *C3.6 perception of seniors on housing form,* which is to identify the satisfaction of the elderly with all the aforementioned aspects of the housing form.

C4. Environmental friendliness of housing is assessed through the following sub-criteria: *C4.1 emission level of harmful substances,* which verifies air pollution/air quality, *C4.2 share of recyclable materials and pro-environmental materials,* which refers to the low emission buildings and carbon neutrality, *C4.3 share of environmentally friendly technologies,* which focuses on energy saving solutions and renewable energy sources, *C4.4 access to nature,* which highlights the significance of greenery, i.e., plants, flowers and possibly green walls in interiors, and finally, *C4.5 perception of seniors on environmental friendliness of housing,* which accounts for positive perception of the use of devices and materials and the presence of greenery.

C5. Adaptability for seniors ageing in place is composed of the following sub-criteria: *C5.1 availability of housing modifications for seniors,* which refers to installation of additional technological facilities supporting independence of the elderly in their daily lives, *C5.2 availability of personalisation,* which simply means that older adults can adapt the housing via individualised designs to their own tastes, *C5.3 perception of seniors on housing adaptability,* which allows them to express their attitude towards possible changes.

C6. Affordability of housing for older people comprises such sub-criteria as: *C6.1 affordability of property,* which is measured by average price of 1 square meter of an apartment to average salary, *C6.2 affordability of property or rental property maintenance,* which includes affordability of general maintenance services, taking into account of cost-efficient construction materials, *C6.3 affordability of housing modifications and repairs,* which refers also to fixed income, *C6.4 perception of seniors on housing affordability,* which allows to compare numbers with personal feelings.

C7. Quality of multisensory experience of housing concerns relations between housing and different senses of its inhabitants, and in particular, *C7.1 adequate illumination* sub-criterion refers to sufficient amount of light in view of a relevant situation, *C7.2 adequate natural light* assess sufficiency of daylight, *C7.3 noise quality* measures sound-proofness of an interior and delimits loud and silent zones, *C7.4 sensual experience* relates to a wide range of sensations felt owing to the application of different design components evoking a variety of sensual experiences, such as images, sounds, tactile feelings, smells, *C7.5 adequate insulation and aeration* represents, e.g., good ventilation, *C7.6 adequate temperature* designates facilities installed to maintain comfortable room temperature, and finally, *C7.7 perception of seniors on multisensory experience* represents assessment by the older adults of multisensory comfort of the housing space.

C8. Innovation and technology for ageing in place stresses the opportunities for the elderly posed by new technologies and devices in the field of assisted living. The criterion is composed of the following eight sub-criteria: *C8.1 event driven systems: fall detection, fire, security,* which verifies alerting technologies that notify caregivers of risks, *C8.2 walking aids,* which assesses technologies protecting the elderly against falls, *C8.3 communication,* which includes special on-line platforms where the elderly can keep in contact with family and friends, *C8.4 cognitive training,* which improves retrospective memory, *C8.5 environmental control,* which concerns, e.g., maintaining comfortable temperature and controlling vacuum cleaning, *C8.6 object locator,* which helps finding lost items, e.g., keys, with the use of a network of smart cameras, *C8.7 telehealth and telecare* sub-criterion, which involves general monitoring, health monitoring (vital signs, medication, food intake), as well as location tracking, and finally, *C8.8 perception of seniors on innovation and technology,* which enables to find out what the older adults think of the applied new technologies and what is their level of satisfaction with the use of such new technologies.

4.3 Significance of criteria and sub-criteria

The experts prioritised the criteria in the order of significance. They deemed *C2. Age-friendliness of housing function* as the most important, followed sequentially by: *C1. Accessibility of housing, C5. Adaptability for seniors ageing in place, C6. Affordability, C3. Housing form, C8. Innovation and technology*, *C7. Quality of multisensory experience and finally C4. Environmental friendliness of housing*.

The most important sub-criterion - in view of global priorities - is *C5.1 availability of housing modifications,* which is followed by *C5.2 availability of personalisation*. The sub-criteria which ranked at the same third position were *C1.3 simple and intuitive use* and *C1.3 protection* (see Table 2).

4.4 Metrics based on experts' recommendations

The experts participating in the workshop proposed new metrics for the quality of senior housing assessment based on such aspects as accessibility, form and function, affordability, sustainability, multisensory experience, and technologies, as shown in Supplementary Table S4.

4.5 Results from the interviews

During the process of coding the interviews, new areas that need to be further investigated, other than those identified in the introduction, were found in relation to the measurement of housing quality and in relation to such aspects as:

- *climate adaptation,*
- *local biodiversity and local nature values,*
- *circularity of materials,*
- *indoor climate and indoor air quality monitoring,*
- *housing design that allows adaptation by predicted space for stair elevator or lift,*
- *healthy location of housing,*
- *housing design with less installations as a response to current too complex dwelling design,*
- *windows design versus energy efficiency and affordability,*

- *innovation and technology for optimizing use of energy,*
- *connecting technology to installations and heat pumps,*
- *transition from fossil towards renewable energy,*
- *sustainability of building process,*
- *making housing interactive* (allowing a company and a customer to automate maintenance questions),
- *platform as a way of contacting inhabitants by municipalities.*

Moreover, the interviews revealed new interesting aspects related to life cycles of the buildings:

- design in response to *loss of biodiversity*, as well as *overusing Earth's resources*,
- *inhabitants' footprint*,
- considering investment as a part of ecosystem, but also having commercial reasons for environmental friendliness,
- investment affordability and reduced cost due to industrialization,
- *platform as a way of contacting customers* by the company and *automated maintenance solutions*,
- affordability and long-term adaptability in view of *water-related risks*, as well as *removable houses* as a response to a local Dutch challenge,
- *long-term management* and *lifelong learning*,
- and finally, *legislation and regulation* having impact on every design quality criterion, from *affordability*, via *form, function, sustainability, adaptability, multisensory experience* to *innovation and technology.*

5 Discussion

5.1 Appraisal instrument recommendations

The aim of the study was to address the gaps by developing recommendations that include transparent methodology and comprehensive set of criteria, embracing importance of the role of innovation and technology, in supporting daily living and ageing in place. In effect, a proposed set of prioritised criteria and sub-criteria may be used by architects as guidelines for improved age-friendly design. The tool, developed based on recommendations, allows for verification of the present condition of housing via the first screening list. Whereas, with the use of the interview or a questionnaire measuring perception of older people, a questionnaire for experts, and finally AHP method, potentially it could allow to compare them between one another to learn on the basis of good examples. After a further validation process, metrics based on a literature review, as well as an experts' recommendation might be used in the form of practical guidelines for architects. Nonetheless, architects, implementing the idea of ageing in place in their designs, should always comply with the prevailing local laws and specific regulations.

5.2 Findings based on interviews

Interviews rendered a number of interesting findings, in this those related to energy efficiency of the building structure and access of natural light to the interior. It cannot be denied that we need natural light in our houses, yet, architects should also remember that too large windows undermine energy performance, environmental friendliness of the building, and also translate into higher energy costs. Considering the topic of sustainability, aspects often omitted in the assessment instruments but recognised by stakeholders are circularity of materials, innovation and technology for optimizing use of energy, and sustainability of building process. Among other vital aspects, health-related housing aspects were named, i.e., healthy location of the living environment and monitoring of indoor climate and air quality. The two latter aspects were confirmed in our research to be significant from the perspective of designing an efficient quality assessment tool, they had, however, already been studied. Whereas the interviews identified a gap in the current state of designing, namely, the designed houses are provided with too many systems, which often leads to new problems solved by means of other technological devices. Thus, the need has been identified to simplify housing designs. The interviewees also raised another issue that is worth considering, namely, predicted space for stair elevator or lift. Their observation can be correlated with the expert's proposal to include a metric called (Preparing for) sandwich generation–taking into account the phenomenon of a group of middle-aged adults who provide care not only for their children, but also for their aging parents. As this phenomenon can affect anyone, it is worth predicting effective spatial solutions that can be applied in future housing designs. Furthermore, the interviewees also indicated long-term management and lifelong learning as a part of their employer strategy. It is extremely significant to evaluate the already built investment, so as to optimize some solutions and make improvements if needed. Such an approach is also beneficial for the construction services company, as it supports constant progress. Affordability of housing is another important aspect underlying the quality of architecture and predetermining solutions used by developers. Furthermore, life cycle of the building has been brought to our attention. To be able to respond to current challenges such as loss of biodiversity and depletion of natural resources, we need to change our perception of the living environment and to see it as part of the ecosystem, affected by the inhabitants' footprint. Because the stakeholders who participated in our interviews worked for a Dutch company, local water-related challenges turned out to be of high priority for them, especially in view of affordability and adaptability. The affordability challenge is related to rising loan rates in high-risk areas. Adaptability poses a question about the need of building houses that allow further adaptations, while it is predicted that the house may be removed due to a raise of water level. Considering affordability of houses in general, it should be noted that the Netherlands faces a particular challenge that calls for an urgent solution.

According to the interviewees, the strategy of the company regarding the healthy living environment focuses on the following aspects: area/place attachment, sustainability, healthiness, social connectedness, and smartness. What is crucial is the fact that the company responds to the main local challenges found in the neighbourhood, regarding nature, spatial and social domains. Technologies and innovations can play an important role. Whether in a form of a platform, connecting inhabitants with one another, or with company and municipalities, or system monitoring air-quality. It should be, however, noted that implementing technologies typical for healthy living environments, and the overall ease of doing that in

a given neighbourhood, may be affiliated with the smart city policy. The local policy and the approach of the municipalities that want to boost the image of the city can play a key role.

5.3 Innovation and technology

Despite the undeniable potential of smart homes to contribute to assisted living of older adults, they are usually designed to address a particular issue, while they should offer adaptability to inhabitants' changing needs over time. This is an obvious gap and in response thereto, Sumi Helal and Christopher Bull developed a programmable assistive environment that can support the ageing people by means of the Internet of Things (IoT). Advantages of such solutions, i.e., possibility of personalisation and dynamic changes of applications and interfaces were demonstrated in The Gator Tech Smart House (GTSH). Among GTSH integrated technologies are smart blinds, beds, closets, laundry rooms, bathroom mirrors, bathroom sinks, displays, microwaves, kitchen, floors, plugs as well as smart front doors, smart mailboxes, security monitoring systems, emergency calls and cognitive assistants. Furthermore, Artificial Intelligence [AI] and machine learning techniques were used for the identification of behaviour types, activities, situations and phenomena (Helal and Bull, 2019). It should be noted that at present many studies are pending on opportunities offered by new technologies as regards improvement of the living environments for people with dementia. They are still at their pilot stage; thus, the area of large-scale implementation remains undeveloped (Bowes et al., 2019).

5.4 Strengths and limitations

Studying the selected research problem, authors had to face certain limitations. First, the conception of measuring the quality of housing for the older adults originated in Poland, where the subject of the study are entire neighbourhoods, rather than single houses. Thus, the assessment tools and publications which were analysed and compared, concerned various spatial scales, from an entire city via neighbourhoods to single dwelling units. If the analyses were related only to the smallest spatial unit, which is a single house, the set of developed metrics would be different. Therefore, it is necessary to verify if the recommended criteria, sub-criteria and metrics developed based on the Polish context could be implemented for the assessment of housing in the Netherlands and if the results of the study could be generalised to form universal guidelines.

Moreover, cultural and policy differences were not analysed, thus, the research concerned only a homogeneous context, which may pose a limitation for the developed assessment tool. Co-housing may be used here as an example. Dutch houses often do not offer sufficient area for sharing space with parents and/or grandparents, while in Poland, multi-generational families commonly live in one household, where extra space is foreseen in advance. Finally, the sample of interviewees was limited to only three stakeholders, therefore, it cannot be perceived as a representative sample of the entire construction-services sector. Furthermore, all the interviewees were Dutch and lived in the Netherlands, hence, the number of identified areas that need to be further investigated is notably limited.

The methodology developed as part of this research includes a transparent calculation procedure of Analytic Hierarchy Process. The utilisation of Saaty's 1-9 scale may have resulted in certain challenges for experts using this scale, as it necessitates consistent and precise judgments, which can prove challenging when comparing sub-criteria that are similar in preference. Moreover, the subjective nature of assigning numerical values to qualitative comparisons can result in errors or inconsistencies, particularly when experts' comprehension of the criteria or their individual judgement strategies diverge. However, experts received legend with definitions of all criteria and sub-criteria. Furthermore, the AHP-OS system was able to discern instances of inconsistency in expert responses and provide experts with the necessary information.

To develop the set of criteria, sub-criteria and metrics we have used the results of the analysis of existing studies on housing evaluation, among them widely recognised publications and international tools and rankings. The involvement of experts from both the field of architecture and gerontechnology was necessary, to check whether the already prepared set of criteria and metrics was complete, and accurate. The workshops allowed us to incorporate missing aspects and thus improve the set.

Despite the aforementioned limitations, the study came to interesting and vital conclusions. The study created a new set of criteria and sub-criteria for the quality assessment of housing intended for the older adults and prioritised the proposed criteria and sub-criteria following the experts' opinions. The high number of experts involved in the research is without a doubt its strength. Moreover, experts, participating in the pilot study, workshop and prioritisation of criteria in the AHP-OS questionnaire, represented culturally diverse backgrounds.

Research presented in this article contributes to solving the needs of an aging urban population in Europe in the context of climate change and to achieve the UN Sustainable Development Goals:

- by offering recommendations for designing healthy homes that support wellbeing of elderly (*3. Good health and wellbeing);*
- by fostering innovation, like building smart homes and using newest technologies to facilitate ageing in place. Our recommendations involve aspects such as the use of environmentally friendly materials (9. *Industry, innovation and infrastructure);*
- by highlighting the importance of housing design for most vulnerable groups, that simultaneously supports design for all, and thus reduces inequalities (10. R*educed inequalities);*
- by developing metrics supporting design of inclusive, safe and resilient human settlements (11. S*ustainable cities and communities);*
- by directing readers' and architects' attention to the aspects related to combating climate change through responsible building design that is reflected in criterion C4 Environmental friendliness of housing, as well as in the findings from the interviews (13. C*limate action).*

A comprehensive first screening list can serve as a valuable reference for architects, outlining the key elements to be considered in their design process. Additionally, insights collected from

interviews with professionals can inform the incorporation of sustainable solutions and advanced technologies in housing design.

The findings of this study can be utilised by architects in the following manner. Since the weight (significance) of a given sub-criterion has been determined, it becomes possible to identify which aspects warrant particular attention. For instance, the accessibility of modifications was assigned the highest rating. Therefore, architects should ensure that they have considered the future accessibility of modifications to the apartment, for example, by providing enough space for the installation of a handrail in the bathroom. Furthermore, the use of a set of criteria and metrics proposed in this study, in conjunction with the first screening list, enables the verification of whether specific elements that enhance the quality of life for older people have been duly considered. This may entail the incorporation of a designated space for social interaction, the provision of adjustable lighting, the incorporation of sensory experiences through the utilisation of diverse textures and materials that enrich the architectural experience.

5.5 Future research

On the basis of the experts' workshop, new metrics for the assessment of senior-friendly housing were developed. They shall be next validated via experts and thereafter, relevant questionnaire surveys shall be worked up to question the older adults both in Poland and in the Netherlands to assess their perception. This shall also allow to verify ecological validity and compare housing, both in the Netherlands and in Poland. The clarity and legibility of the questionnaire form should be validated by the older adults as well. Only after all the validation stages have been completed can relevant metrics be included in the assessment tool, being the scope of our research. In the course of experts' pair-wise comparisons, it is interesting to note that sub-criterion of seniors' perception was most often the least important, according to experts' assessment. This opens up opportunities for further research on an alternative set of indicators, actively involving the older adults in the decision-making process and criteria formulation. Such an approach was not adopted here, as the Decision Maker was a group of architects–either practitioners or academics, while a group of older people were only a stakeholder whose needs were taken into account. Nonetheless, the authors hereof are aware of the importance of the users' perception, therefore, in their opinion, correlations that shall be diagnosed by comparing both sets of metrics (subjective and objective ones) might prove a highly effective approach in developing the final assessment instrument.

6 Conclusion

The authors of this paper were successful in addressing many current gaps by developing relevant recommendations for an appropriate quality assessment instrument. Taking into account global challenges related to the quality of life and built environment, they have analysed currently available assessment instruments and reviewed scientific papers, in order to consequently come up with a set of proposed assessment criteria. Their preliminary selection was then verified by adopting a multicultural approach and conducting an experts' workshop. By combining the workshop formula with the AHP questionnaire, authors developed a comprehensive set of relevant and prioritized criteria and sub-criteria. It should be noted that experts ranked *C2. Age-friendliness of housing function,* with weight 0.227, as the most important criterion and *C5.1 availability of housing modifications for the seniors* as the most vital sub-criterion with 7.5% score according to global priorities. Using relevant metrics and the AHP algorithm, the authors hereof have formulated final recommendations for the tool intended to assess senior-friendly housing architecture.

Recommendations for architects, worked up in the form of a very extensive first screening list, shall be viewed as valuable part of the research results. Without doubt, they will make an added value for architects, who may regard them as a set of design principles, as well as for the ageing societies, who can utilise the criteria and metrics to assess the suitability of their current living environment or, to inform their decision-making regarding potential future accommodation. Authors see opportunities for further research on the assumption of including older participants in the process of developing relevant criteria and metrics for the quality assessment of senior housing. A comparative analysis of results of the studies in which the older adults would play an active role with those in which they were not directly involved may render interesting results.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for these studies involving human participants because experts were invited to participate voluntarily and anonymously. They completed questionnaires using the AHP-OS system and collaborated during workshops to recommend research sub-criteria and metrics, including anonymously voting on evaluation sub-criteria. Participation in the survey and workshops was voluntary, and the questions posed did not involve sensitive data. Three stakeholders who agreed to be interviewed, provided written informed consent by completing consent forms. The studies were conducted in accordance with local legislation and institutional requirements. All information that could identify participants was anonymized.

Author contributions

AP-W: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing–original draft, Writing–review and editing. HK: Conceptualization, Formal Analysis, Methodology, Resources, Visualization, Writing–review and editing. DK: Conceptualization, Formal Analysis, Methodology, Resources,

Visualization, Writing–review and editing. AG: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Resources, Supervision, Visualization, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2024.1476249/full#supplementary-material

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