# Requirements Engineering for Older Adult Digital Health Software: A Systematic Literature Review

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**Abstract**

Context: Growth of the older adult population has led to an increasing interest in technology-supported aged care. However the area has some challenges such as lack of care givers and limitations in understanding the emotional, social, physical, and mental well-being needs of older adults. Furthermore, there is a gap in the understanding between younger developers and ageing people of their requirements from digital systems. Digital health can play an important role supporting older adults' well-being, emotional requirements, and social needs.
Objective: We carried out a systematic review of the literature on RE for older adult digital health software. This was necessary to show the representatives of the current stage of understanding the needs of older adults in aged care digital health.
Method: Using established guidelines we developed a protocol, followed by the systematic search of eight databases. This resulted in 69 primary studies of high relevance, which were subsequently subjected to data extraction, synthesis, and reporting.
Results: This systematic literature review highlights key RE processes used in digital health software for older people. It explored the key features developed for many digital solutions, utilization of technology for older user well-being and care, and the evaluations of proposed solutions. The review also identified key limitations found in existing primary studies that inspire future research opportunities.
Conclusion: Our results indicate that requirements gathering and understanding have a significant variation between different studies. The differences are in the quality, depth, and techniques adopted for requirement gathering and this reason for these differences is largely due to uneven adoption of RE methods.

*Keywords:* Aged care software, Senior citizens, Elderly Users, Internet Of Things, mHealth, eHealth, Participatory Design

## 1. Introduction

According to the World Population Prospects 2022, the older adult population of the world is growing rapidly [1]. The percentage of the global population aged 65 and above is estimated to increase from 10% in 2022 to 16% in 2050 [2]. Ageing significantly impacts individual health, leading to crucial challenges of physical impairment and mental decline. Aged care, encompassing support services for older individuals' health and well-being, addresses these challenges and rising needs, while accommodating the diverse physical, emotional, and social aspects of individuals [3, 4].

A growing body of literature recognises the importance of software solutions for healthcare problems, including cancer support [5], intensive care monitoring [6], and chronic disease tracking [7]. As aged care needs can be viewed as a combination of several healthcare problems, applying software solutions can address this urgent demand. For example, personalized home care can improve the overall quality of care and enhance the well-being of older individuals with fragility and cognitive decline. Software Engineering for ageing users' digital health software has become a popular area of research and practice. These tend to focus on improving the quality of care for older adults in home or aged care healthcare settings, including adapting to the changing needs of older adults, developing various ageing user Mobile Health (mHealth) applications, smart home, care solutions, and conducting diverse usability testing with older adults.

Requirements engineering (RE) is a critical part of software engineering. This involves obtaining, analysing, recording, implementing, and updating software requirements. In the development of digital health software for older adults, RE can play a crucial role in ensuring that the software is user-centred, accessible, secure, and relevant to the needs of ageing end users and their caregivers [4]. RE is particularly important in medical, health, and welfare software engineering for older end users as they have varying levels of comfort with modern technology, diverse living situations, and diverse physical and mental impacts of ageing.

While several studies have applied RE for their older user-targeted digital health applications, a systematic review has not yet been conducted to identify the key strategies and requirements of diverse software that are developed for ageing users. Several RE frameworks for aged care software solutions have been proposed; however, the analysis of these frameworks remains inadequate to enhance the field's common agreement and mutual learning. Therefore, conducting a systematic literature review (SLR) on requirements engineering for aged care is necessary to ensure that digital health software for older adults meets the specific needs of older adults and is designed to be accessible, secure, and compliant with regulations. The main contributions of this SLR are to 1) highlight the key works that have used RE in older adult digital health; 2) explore how the RE is done in each study; and 3) point out the key benefits, limitations, and recommendations of RE in each study. In our SLR we analyzed 69 studies that were found by filtering studies from eight databases. Our results reveal that the usage and adoption of requirements in older adult digital health software vary by quality and conditions, which is related to the RE techniques used, requirement modelling, and in which stage RE was involved during system building.

This paper is structured as follows: Section 2 provides background and related work. Section 3 presents the review protocol, details about the conduction, and results reporting. Section 4 discusses the advances so far, and Section 5 presents final remarks. This endeavour can ultimately lead to a more successful app that improves the health and well-being of older adults with chronic conditions.

## 2. Related Work

Digital health (or eHealth) leverages technologies to improve healthcare delivery [8, 9, 10], encompassing tools such as electronic health records (EHRs), wearable devices, and health information systems. In older adult digital health, independence preservation is a critical requirement, driving applications like smart homes [11, 12], health management systems [13], fall detection/prevention [14], cognitive health support [15, 16], and social connectivity tools [17]. Another central aim is in enhancing quality of life, which necessitates addressing diverse needs [12, 13], mitigating representation biases [13], and enabling personalization [16]. Reviews proposed that digital health software should offer sufficient training to prevent ageing users from shying away from using complicated systems [12], pay attention to other stakeholders such as caregivers and hospital teams [13], and consider ageing users' changing individual strengths and vulnerabilities [16]. These multifaceted requirements underscore the importance of robust Requirements Engineering (RE) processes. Recent studies [18, 19, 20] acknowledge both the necessity and challenges of RE in digital health, particularly in reconciling clinical and technical specifications while aligning with stakeholder goals.

We review key prior literature relevant to our work. Given the limited existing research on Requirements Engineering (RE) for digital health systems targeting older adults, we synthesize studies from two domains: RE processes and requirements-focused design approaches (e.g., participatory design [PD], user-centered design [UCD], and co-design) applied to digital solutions for older adults; and Requirements in digital health systems for older populations. We identified six key closely relevant review studies: (1) The systematic review by Duque et al [21] on user-centered approaches with older adults highlights risks in software development processes, the time required to establish stakeholder trust, and challenges in designing engagement strategies for older users. (2) The work of Merkel and Kucharski [22] advocates participatory design in gerontechnology (technology for aging populations), emphasizing the importance of involving older adults to enhance technology usability and effectiveness. (3) Fischer et al [23] systematically examines older adults' involvement in technology design, stressing the need for inclusive, context-specific solutions. (4) Machado et al [24] conducts a systematic literature review (SLR) on co-design with older adults, defining and evaluating techniques for collaborative design processes. (5) Zhang [25] proposes a scoping review protocol on co-design in residential aged care, reflecting growing interest in RE-driven methodologies. This review has a very relevant topic but they only developed a review protocol but did not report review findings. (6) Hidellaarachchi et al [26] contributes an SLR on RE with human-centric considerations, included here to compare database selection practices in software engineering (SE) RE reviews. Table 1 summarizes the characteristics of these related works and our study. In this table, "Study", "Year", and "Topic" denote the referenced study, the year of its publication, and the topic it addresses, respectively. "Period" indicates the start and end years employed to screen for primary studies. A blank start year implies that the corresponding study did not specify a start-year in its search protocol. The "Data sources" column indicates the digital libraries utilized by the studies (1: Scopus; 2: IEEE; 3: ACM; 4: Springer; 5: Wiley; 6: Sage; 7: Taylor and Francis; 8: Inspec; 9: Web of Science).

| Study | Year | Topic | Period | Data Source | # Studies |
|---|---|---|---|---|---|
| Merkel et al [22] | 2018 | Participatory Design in Gerontechnology | 2012-2017 | 1/9/specific venues | 26 |
| Duque et al [21] | 2019 | UCD and PD with Older People | 2013-2018 | 2/3/specific venues | 51 |
| Fischer et al [23] | 2020 | User involvement with Older Users | 2014-2018 | 1/9 | 40 |
| Machado et al [24] | 2021 | Co-designing with Ageing people | 2015-2020 | 1/9/specific venues | 146 |
| Zhang et al [25] | 2021 | Co-design for Ageing Digital health (Protocol) | N/A | 1/9/specific venues | N/A |
| Hidellaarachchi et al [26] | 2021 | RE with Human Aspects | 1997-2020 | 2/3/4/5 | 74 |
| This SLR | 2023 | RE for Older Adult Digital health | 2001-2023 | 1/2/3/4/5/6/7/8 | 69 |

Table 1: Comparison to key related review studies

Our study is a cross-domain study inspired by existing review study approaches, but focusing on requirements for ageing user digital health software. We aim to include studies from SE domain that include the RE components in digital health systems design for older adults, the studies from aged care digital health domain that design digital health systems with requirements, and studies from PD domain that studies with include participants to gather the requirements and design the digital health systems. Our study includes a comprehensive range of databases searched for primary studies. These existing review studies collectively recognize the benefits of co-design in enhancing technology and care practices for older adults in aged care facilities, indicating a positive trend towards more person-centred approaches. However, they do not examine the software details of residential or home-based aged care software. To date, there has been little investigation of how RE is carried out in many of these studies. Hence, we wanted to better understand the RE research that has been conducted focusing on aged care digital health by constructing a new systematic review focusing on RE for elderly end user digital health.

## 3. Research Methodology

This Systematic Literature Review (SLR) was conducted to investigate and synthesize the current research findings on Requirements Engineering (RE) for digital health software focusing on senior adults as the end users. To guide our SLR protocol development, we used three guidelines: PRISMA [27]: General systematic review format guidelines; the guidelines for Software Engineering Evidence-based reviews [28]; and PICO [29]: a framework originally for medicine research. We used the Kitchenham and Charters' version of PICOC (population, intervention, comparison, outcomes and context) for SE domain [30].

The process we followed, outlined in Figure 1, has three stages: planning, conducting, and reporting. In the planning stage, we identified the need for the SLR, formulated research questions, defined the protocol,

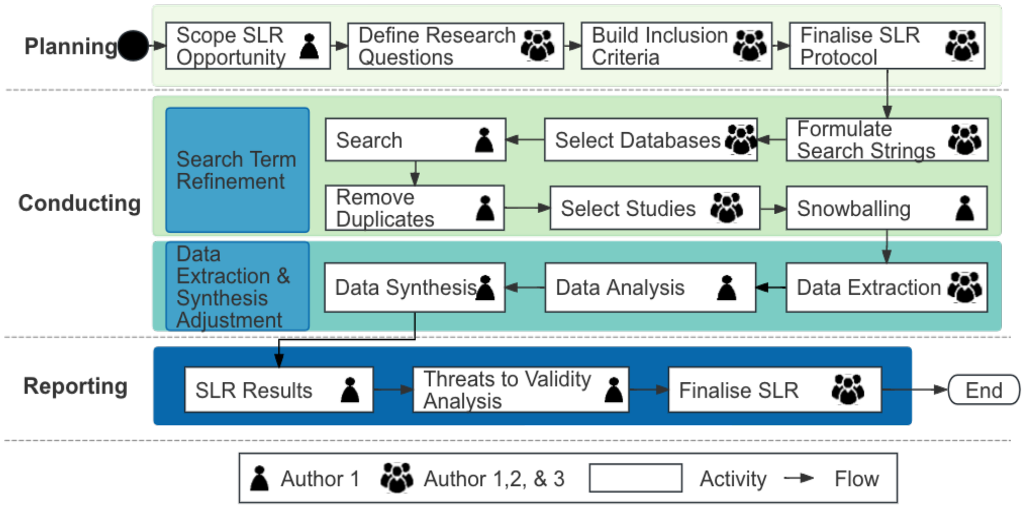


Figure 1: Our Systematic Literature Review Process

and reviewed it. In the conducting stage, we formulated search strings, selected databases, and used the SLR management tool 'Covidence' to remove duplicates and select studies. After snowballing, we ended up with all the studies we wanted and extracted the data. Finally, after the data analysis and synthesis, we reported the SLR results, analysed threats to validity, and finalized the SLR after all authors' reviews.

### *3.1. Research Questions*

The following RQs were developed with the assistance of the PICOC[28] in Table 2:

- **RQ1. What are the key research works carried out to date focusing on Requirements Engineering for digital health for ageing people?** This RQ finds and analyses primary studies that are accessible, in terms of the publication venues, years, users' demographics, application aims, functions and outcomes. We want to answer the following sub-RQs:
  (a) What is the nature and type of studies carried out? $RQ_{1a}$ analyses the industry/academic nature of research the venues of papers, and the publication years.
  (b) What aged healthcare and well-being issues are addressed in each work? $RQ_{1b}$ reviews the key health or mental health aspects that papers focus on.
  (c) What are the demographics of older participants in each study? $RQ_{1c}$ assesses demographics of older participants as mentioned in papers, such as age, gender, and culture.
  (d) What data is captured by the (proposed) software and how is the data used? What technologies did they use? Does the software use any AI solutions? $RQ_{1d}$ investigates AI solutions mentioned and related data methods if mentioned, such as AI algorithm usage for digital health functions and data capture methods for digital health functions, to identify key trends and technology choices.
  (e) What different human aspects (besides age) were considered in the study (if any)? $RQ_{1e}$ examines what other human aspects of older participants than just age as mentioned, such as living alone or not, renting or not, language and culture, and health conditions, to see how these might impact requirements of the digital health solutions.
- **RQ2. How was the RE carried out?** This RQ examines the RE process used and seeks to identify the range of RE techniques, models, and tools each study has used, so that we might identify key

RE choices, recommend best practices to readers, and identify under-researched approaches for future research studies. Key sub-RQs are:

(a) What RE techniques did each study use? $RQ_{2a}$ analyses the RE gathering techniques used in the selected studies.

(b) What tools were used for requirements elicitation and documentation in each study? $RQ_{2b}$ reviews the RE tools for documentation.

(c) How were the requirements modelled in each study? $RQ_{2c}$ assesses the requirements modelling methods like personas, etc.

(d) How were the requirements validated? $RQ_{2d}$ investigates how requirements were validated, for example by users.

(e) Were the requirements used to build an actual system? If so, in which SE stages? $RQ_{2e}$ examines the SE stages that used requirements, if any, reported in the studies e.g. where the gather requirements used to build a prototype solution.

(f) Were the requirements used to evaluate the solution? If so, how is the study evaluated? $RQ_{2f}$ scrutinises the evaluation in papers, and if and how any of the gathered requirements were used for evaluation.

- **RQ3. What are the key Strengths, Limitations, Gaps, and Future work recommendations in the selected studies?** This RQ critically examines the limitations discussed in the selected primary studies and their future directions. This aims to help other researchers further build on top of the current research on the RE for digital health for ageing users. Sub-RQs are:

(a) What are the key benefits/positive outcomes reported? $RQ_{3a}$ analyzes the strengths discussed in the selected primary studies.

(b) What are the key limitations reported? $RQ_{3b}$ reviews the limitations discussed in the selected primary studies.

(c) What are key recommendations for future research? $RQ_{3c}$ assesses the future directions proposed by the authors of the selected primary studies.

| | |
|---|---|
| Population | Digital Health Software for Ageing Users stakeholders (Older Adults, Caregivers, Developers, Researchers) |
| Intervention | Requirements Engineering (RE) |
| Comparison | N/A |
| Outcomes | Applications of Digital Health Software for Ageing Users |
| Context | mHealth/ eHealth/ Digital Health Systems/ Smart Home/Ambient Assisted Living/Assistive Robots |

Table 2: PICOC for our Research Questions

### *3.2. Search Strategy*

We started with a concept map of terms, which can be listed as: Concept 1): Elderly; Older; Ageing; senior; Residential ageing care. Concept 2): Requirement* Engineering; Requirement elicitation; Requirement extraction. Concept 3): Software Engineering; user*; UX; UI; personas; co-design. We used these concepts to formulate our search strings. We searched 8 databases in Oct 2023, including ACM Digital Library, IEEE Xplore, Inspec, Springer, Wiley, Sage Journals Online, Taylor and Francis Online, and Scopus. The use of these databases was motivated by several factors. We incorporated well-known computer science sources such as ACM, IEEE, and Inspec, alongside medical-focused databases like Sage and Taylor & Francis. We didn't use Web of Science as these databases cover all its indexed papers. The key search strings used for different databases are listed in Table3. For each database, we needed to use a different search strategy due to the different search Boolean rules.

| | |
|---|---|
| ACM | [[Full Text: “requirement* engineering”] OR [Full Text: “requirement elicitation”] OR [Full Text: “requirement extraction”] OR [[Full Text: “software engineering”] AND [[Full Text: “ui”] OR [Full Text: “ux”] OR [Full Text: “co-design”]]]] AND NOT [Title: “blockchain”] AND NOT [[Title: “systematic mapping study”] OR [Title: “literature review”] OR [Title: systematic review] OR [Title: “qualitative study”] OR [Title: “vision paper”]] AND [[Full Text: “elderly”] OR [Full Text: “aged care”] OR [Full Text: “ageing care”] OR [Full Text: “elderly adult”] OR [Full Text: “senior adult”] OR [Full Text: “older adult”] OR [Full Text: “ageing residential care”]] |
| IEEE | (“Abstract”:“aged care” OR “Abstract”:“elderly adult” OR “Abstract”:“senior adult” OR “Abstract”:“Older adults” OR “Abstract”: ageing OR “Abstract”:Residential ageing care) AND (”All Metadata”:“Requirement* Engineering” OR “requirements extraction” OR “requirements elicitation” OR (“Software Engineering” AND “stakeholder” OR UI OR UX OR co-design;) NOT (“All Metadata”:“Blockchain”) |
| Inspec | (((“elderly” OR “aged” OR “aged care” OR “ageing care” OR “elderly adult” OR “senior adult” OR “older adult” OR ageing OR “ageing residential care”) WN KY) AND ((”Requirement* Engineering” OR “requirements extraction” OR “requirements elicitation” OR (”Software Engineering” AND (“stakeholder” OR UI OR UX OR co-design))) WN KY)) NOT ((“blockchain”) WN KY)) AND (english WN LA)) |
| Springer | (”aged care” OR “ageing care” OR “elderly adult” OR “senior adult” OR “older adult” OR “aged residential care”) AND (”requirement* engineering” OR “Requirements elicitation” OR “Requirements extraction” OR (”Software Engineering” AND ( “stakeholder” OR “UI” OR “UX” OR “co-design” )))’ within “Computer Science” “English” |
| Wiley | ““elderly” OR “aged” OR “aged care” OR “ageing care” OR “elderly adult” OR “senior adult” OR “older adult” OR “aging” OR “aged residential care”” anywhere and ““requirements engineering” OR “Requirements elicitation”OR “Requirements extraction” OR (”Software Engineering” AND ( “stakeholder” OR “UI” OR “UX” OR “co-design” ))” |
| Sage Journals Online | “elderly” OR “aged” OR “aged care” OR “ageing care” OR “elderly adult” OR “senior adult” OR “older adult” OR “aging” OR “aged residential care”” anywhere and “”requirements engineering” OR “Requirements elicitation”OR “Requirements extraction” OR (“Software Engineering” AND ( “stakeholder” OR “UI” OR “UX” OR “co-design” )) |
| Taylor and Francis online | [[Abstract: “elderly”] OR [Abstract: “aged”] OR [Abstract: “aged care”] OR [Abstract: “ageing care”] OR [Abstract: “elderly adult”] OR [Abstract: “senior adult”] OR [Abstract: “older adult”] OR [Abstract: “aging”] OR [Abstract: “aged residential care”]] AND [[All: “requirement elicitation”] OR [All: “requirement extraction”] OR [All: “requirement engineering”] OR [All: “requirements engineering”] OR [[All: “software engineering”] AND [[All: “co-design”] OR [All: “user*”] OR [All: “ui”] OR [All: “ux”]]]] |
| Scopus | (TITLE-ABS-KEY(“elderly” OR “aged care” OR “aging care” OR “elderly adult” OR “senior adult” OR “older adult” OR “aged residential care”) AND TITLE-ABS-KEY(“requirement* engineering” OR “Requirement elicitation” OR “Requirement extraction” OR ( “Software Engineering” AND ( “stakeholder” OR “UI” OR “UX” OR “co-design” ) )) AND NOT TITLE-ABS-KEY(“blockchain”)) |

Table 3: Table of Search Strings Tailored to Different Database Query Needs

To help us to validate our database searches we constructed a ‘gold set’ of primary studies that comprises a predefined selection of studies serving as a benchmark to evaluate our search strategy. The gold set is composed of high-quality, relevant sources that are known to be accurate and comprehensive in representing the topic under review, and help in refining the search strings [31]. This set was meticulously defined through reviews by all authors after initial searches in key databases like Scopus, ACM, and IEEE, ensuring that the selected articles met the inclusion criteria and were relevant to our research questions. It serves as a comparison or validation tool. For example, a gold set paper from ACM should be included in the search results when using the ACM search string. If the screening process fails to identify a significant portion of the gold set, it indicates that the method may be insufficient or inaccurate. In that case, we refined our search strategy by revising the search string parameters to include additional studies. By having a gold set, we can ensure that the overall quality of the SLR is maintained. It provides a standard against which the entire review process can be measured and refined to improve the accuracy and comprehensiveness of the SLR.

To address potential oversights in the automated search process, a manual search was conducted in accordance with snowballing guidelines outlined by Wohlin [32]. We did forward and backwards snowballing. This process continued over three iterations until no further pertinent papers were identified. As a result, the snowballing yielded 26 additional papers, including 6 duplicate studies that are already in our primary studies set.

### *3.3. Inclusion and Exclusion Criteria*

We defined some key inclusion papers for studies:

1. paper is written in English

2. aged or ageing users are the main stakeholders/end-users of the software system

3. focus or a significant part of the study includes RE for ageing people supporting software systems, including in-home, residential care and institutional care
4. describes a primary study of RE for cognitive or physical support training software
5. is fully peer reviewed study e.g. is not an introduction or review article

We also defined some exclusion criteria:

1. Paper lacks key RE aspects like collection, modelling, documentation, or validation, has no stated requirements at all, or has requirements but less than 15% of its content explaining RE-related activities or requirements.
2. End users are not significantly made up of older adult users, eg. are diverse chronic disease patients, caregivers, clinical staff
3. Studies that talk about "aged software systems"
4. Primary focus is on younger users of a software system
5. Visionary studies (not a primary study) or secondary studies (SLR, SMS, Survey)
6. Primary focus is HCI aspects, the focus is only on human-computer interface components, not RE
7. Short studies, less than 5 pages

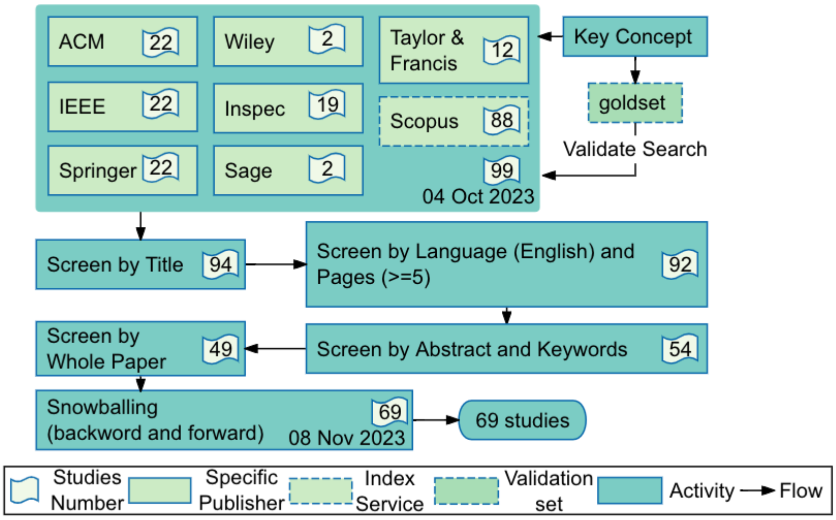


Figure 2: Systematic Literature Review Screen Strategy

### *3.4. Selection Process*

The selection process is depicted in Figure 2. Initially, we identified 99 studies from the 8 databases, reduced to 94 after removing duplicates. After combining database and snowballing results, title screening reduced the list to 94 studies. We excluded 2 studies not in English or shorter than 5 pages, leaving 92. Next, we conducted a screening based on abstract and title, proceeding with studies that at least two authors agreed to include, leading to 54 studies. The snowballing process added 20 more studies. After combined them and screened by whole paper, finally, we resulted in 69 studies. We scored the primary studies based on a quality matrix, both outlined in the Online Appendix. We did not use the paper quality score to remove any of the primary studies found.

## 4. Results

### *4.1. Study Demographics*

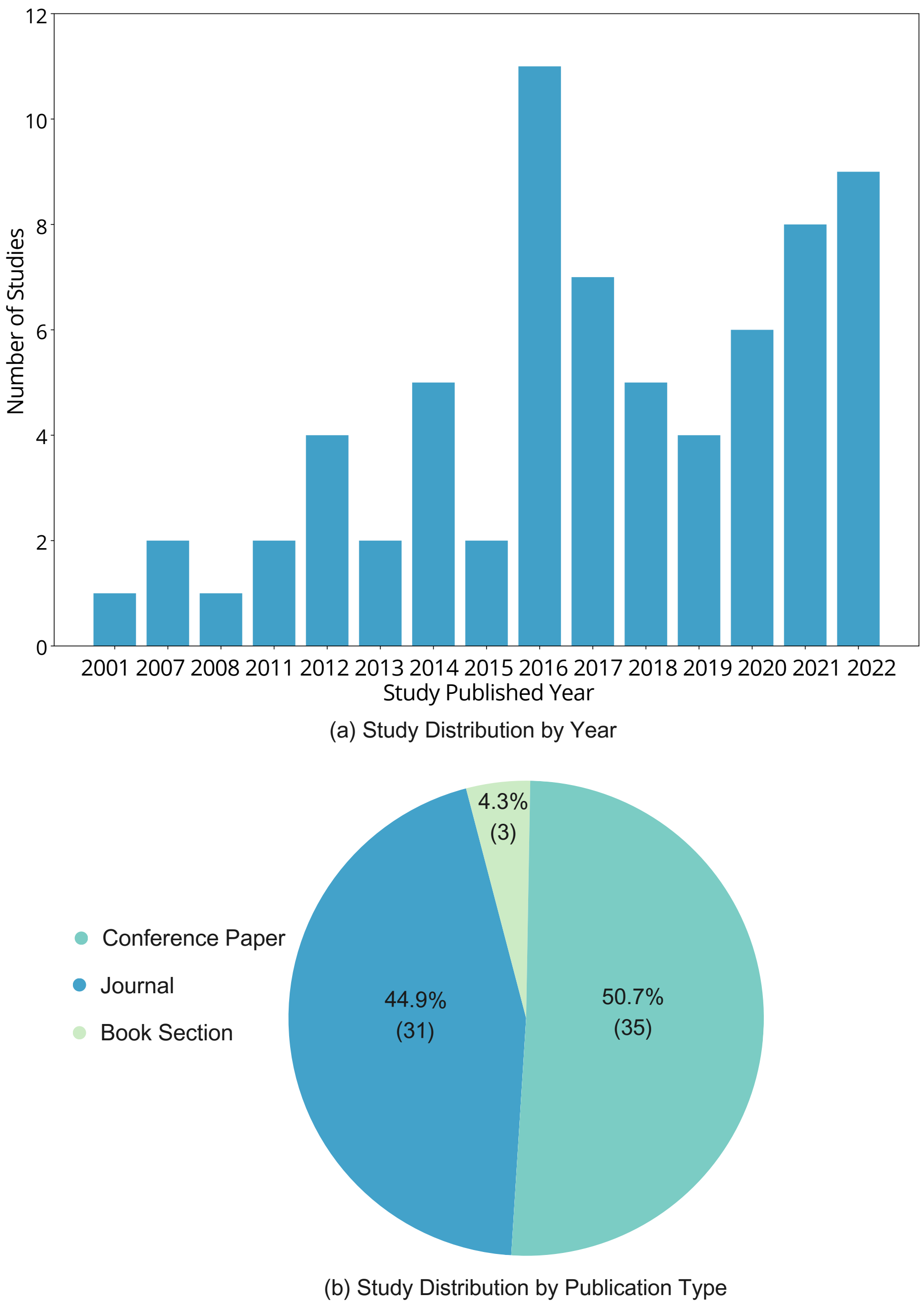


Figure 3: Study Distribution by Year and Type

After our selection process, we identified 69 primary studies published between 2001 and 2024. Figure 3(a) shows a bar graph of study publication years, revealing a significant increase in studies published in

2016 compared to 2015. This might be related to the revolution of Machine learning and AI algorithms around 2016. As some studies have pointed out, after Machine Learning and AI showed their potential in the field of computing, many studies including digital health, HCI, and SE in healthcare have been adopting them [33, 34, 35]. The results suggest rising interest in RE for aged care software systems.

Figure 3(b) illustrates the publication type distribution of our 69 primary studies. The largest accounting for just over half at 50.7% are conference papers. This is followed by journal articles, which include 31 studies (44.9%). The remaining 4.3% are Book Chapters. Of the total 69 studies, 50 (72.46%) were from academia and 19 (27.54%) were from industry (in collaboration with academia). No study was purely industrial-based research.

| Categories | Studies | Percentage |
|---|---|---|
| **No citation** | S6, S20, S34, S47, S48 | 7.25% |
| **1-50** | S2, S3, S4, S5, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S21, S22, S24, S25, S27, S28, S32, S33, S35, S36, S38, S39, S42, S43, S44, S45, S46, S49, S53, S55, S56, S57, S59, S60, S62, S63, S66, S67, S68 | 65.21% |
| **51-100** | S19, S23, S29, S31, S41, S50, S52, S64, S65, S69 | 14.49% |
| **101-200** | S1, S26, S37, S40, S54, S61 | 8.70% |
| **high citation [201+]** | S30, S51, S58 | 4.35% |

Table 4: Studies Distributed by Citation Numbers

Table 4 shows a summary of our selected primary studies based on their citation numbers. We categorized our studies into five groups: no citations (0), 1-50 citations, 51-100 citations, 101-200 citations, and highly cited (201+ citations). A significant portion of the studies fall into the lower citations category with 65.21% of the total studies cited between 1 and 50 times. 14.49% of the total studies have a moderate citation count, and the 101-200 citations group accounts for only 8.70% of the total studies. The highly cited group, representing just 4.35% of the total studies, includes studies that have significantly influenced the field and have been cited more than 200 times.

### *4.2. RQ1 - What are key research works completed to date focusing on Requirements Engineering for software for care of ageing people?*

#### *4.2.1. RQ1.1 - What is the nature and type of study carried out?*

| Categories | Studies |
|---|---|
| **RE as part of System Development (33)** | S4, S7, S9, S11, S16, S19, S22, S23, S24, S25, S26, S28, S29, S31, S32, S34, S36, S37, S38, S41, S42, S43, S46, S47, S54, S55, S59, S61, S62, S64, S67, S68, S69 |
| **Study focusing only on Requirements Gathering (26)** | S1, S2, S3, S5, S6, S8, S9, S12, S14, S17, S18, S20, S21, S23, S30, S35, S39, S40, S44, S48, S49, S50, S52, S60, S63, S66 |
| **Study Proposing New/Modified RE Methodology (9)** | S10, S13, S15, S27, S51, S53, S56, S57, S58 |
| **Requirements Validation Study (2)** | S24, S45 |
| **RE Guidelines Generation Study (1)** | S65 |
| **RE Exploratory Study (1)** | S33 |

Table 5: What is the focus/type of the study?

We analysed the primary studies in terms of the type of study they present. Table 5 presents a summary of the focus of these primary studies. 94.2% of them focus on RE as a part of overall system development, studies focusing on requirements gathering only, or studies proposing a new or modified RE methodology. Nearly half (33 studies, 47.83%) of the studies conduct RE as part of System Development i.e. that includes RE tasks with associated system design and implementation tasks. For example, study S22 describes the development of a web-based cognitive training tool for senior people called VIRTRAEL. A user-centred development method was applied to gather and extract older adult users' key needs (requirements). Study S46 presents an application for the development of a concrete system, the "Medication Assistant", that allows voice and touch interaction to facilitate older adults' access. This study included older end users in their requirements process to identify needs like forgetting to take medication and to increase the usability and accessibility of their product.

The second-highest percentage (26 studies, 37.68%) are studies that focus only on requirements gathering i.e. studies focusing on RE as the key focus without reporting on using the requirements for system development. For instance, study S1 describes a study investigating factors that influence older adults' intention to use e-health services via a smartphone. It focuses on the process of RE to gather, document, and analyze the key factors in the UTAUT (Unified Theory of Acceptance and Use of Technology) model for older citizens care app. As a result, their study defines that senior citizens are concerned about emotional, social, quality, and price for money when they use the service.

A small (9 studies, 13.04%) percentage of studies focus on proposing a new or modified methodology. These encompass (i) meta-RE studies (e.g., S13, S15, S27), or (ii) new proposed RE design guidelines (e.g., S53, S58). For example, study S13 is a good example of a meta-RE study, which proposes a new ontology-based RE method for well-being, ageing, and health supported by the Internet of Things (IoT). The new ontology RE method in this study makes heart failure patients feel better and cured better as a result. Study S65 presents guidelines for participatory design projects with persons with dementia, benefiting future studies in this area.

A few of the selected primary studies focus on Requirements Validation (2 studies, 2.9%), Guidelines Generation (1 study), and an RE Exploratory study (1 study). Study S33 is the only example of an 'exploratory' RE study. This study discusses the pilot design of a full-scale study to collaborate with older adults but without actual implementation. It highlights the importance of including older stakeholders in the design without any practical design or prototype.

#### *4.2.2. RQ1.2 - What aged healthcare and well-being issues are addressed in each work?*

We analysed the primary studies which targeted health and well-being aspects. Table 6 provides an overview of these aspects that were investigated in each study. We classify these into 3 main types of health aspects – physical challenges (39 studies, 56.52%), mental challenges (14 studies, 20.29%), and ageing in general (21 studies, 30.43%).

The *physical challenges* studies focus on addressing key health challenges related to chronic challenges (7 studies), acute disease (1 study), and long-term care challenges (32 studies). For example, study S36 explored using virtual communities and mobile technology to improve healthcare for older adults with chronic diseases. Study S38 aimed to develop a mobile app prototype for older adults with osteoporosis using a user-centred design.

*Mental challenges* are mainly related to mental health or emotional challenges, including 11 studies on cognitive declines, 1 study on depression, 1 study on loneliness, and 1 study on parent-child relationships. For example, in study S51, the key aim is to utilize participatory design (PD) methods to enable older adults diagnosed with depression to actively participate in the design process of socially assistive robots. In study S41, the key aim is to develop and evaluate a smart home technology, SofiHub, designed to support independent living among older adults with loneliness. S3 aims to gather requirements and develop an older adult caring application (Berbakti) to enhance the parent-child relationship in Indonesia.

*Ageing Challenges (in general)* refers to challenges related to ageing, not specific diseases. For example, study S1 investigated factors influencing older adults' intention to use e-health services via smartphone.

| Main Streams | Health Aspect Major Challenges | Health Aspect Minor Challenges | Studies |
|---|---|---|---|
| Physical challenges (39) | Chronic Disease | No Disease Mentioned | S36, S42 |
| | | Upper Limb Rehabilitation (ULR) | S18 |
| | | Peripheral Arterial Disease | S42 |
| | | Hypertension (Stage 1) | S44 |
| | | Heart Failure | S7, S13 |
| | Acute Disease | Postfracture Acute Pain | S38 |
| | Long-term Care challenges | Living/home Assistance | S1, S2, S5, S9, S14, S16, S19, S20, S21, S23, S25, S26, S31, S33, S35, S40, S41, S48, S56, S57, S61, S62, S63, S68 |
| | | Medication Intake | S39, S46, S64 |
| | | Fall | S67, S69 |
| | | Disability | S59 |
| | | Comorbidity | S47 |
| | | Hearing-aid | S66 |
| Mental challenges (14) | Mental Health or Emotional Challenges | Cognitive Declines | S4, S17, S19, S22, S28, S37, S43, S52, S54, S58, S65 |
| | | Depression | S51 |
| | | Loneliness | S41 |
| | | Parent-Child Relationship | S3 |
| Ageing Challenges (in General) (21) | Geriatric Challenges | Ageing (in general) | S1, S6, S8, S10, S11, S12, S15, S17, S24, S27, S30, S34, S45, S49, S50, S53, S55, S60, S64 |
| | | Inactivity and Sedentary | S32 |
| | | Frailty | S29 |

Table 6: The key aged healthcare and well-being issues are addressed in each work

Study S32 evaluated the usability, user experience, and effectiveness of the GOAL mHealth intervention for inactive, sedentary older adults. Study S29 developed and tested an online community care platform for frail older adults, focusing on supporting their independence through care, health, and communication functions.

*4.2.3. RQ1.3 - What are the demographics of the older adults in each study?*

We collected data on the number of older adult participants, their age group distribution, and the average age of participants. If there were any caregivers or technical experts included, we noted their participation as well. We describe each of these findings in detail below.

***Number of Participants:*** The number of older adult participants in each study is summarized in Figure 4. We divide number groups into six categories: 1-20 participants, 21-60 participants, 61-100 participants, 101+ participants, unclear (no evidence of participant numbers), and none (clearly stated no participants). The most common category is 1-20 participants, accounting for 43.5% of the studies. The next largest group is no participants and 101+ participants, both at 10.1%, followed by 21-60 participants at 8.7%, and no participants at 5.8%. The smallest group is 61-100 participants, representing 2.9%. These variations in sample size can be influenced by factors like the study's target institution size, local population density, funding, etc. Larger participant groups don't necessarily equate to higher participation quality, but they may affect the requirements quality and representation bias.

***Age Range of Participants:*** There is no universal definition of 'older adults', and the age range can

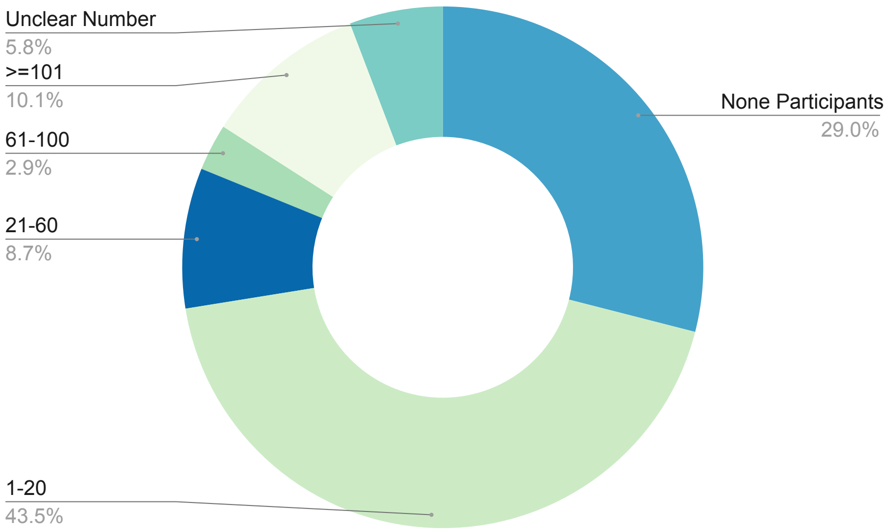


Figure 4: Number of Older Adults Participated in Each Study

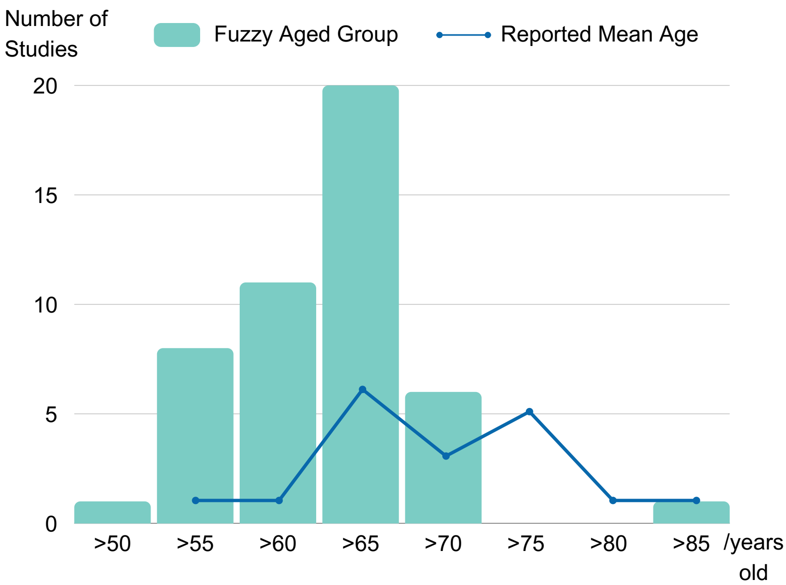


Figure 5: Fuzzy Age Group and Mean Age of Older Adults Participated in Each Study

vary by region or country. For instance, individuals aged 65 are often considered older adults in Australia, the UK, and the US, while in China, Thailand, and Malaysia, the threshold is typically 60. In our review, we use the age specified in each study. If no age is mentioned, we consider the commonly accepted older adult age in the country of the study. If participants' ages are unclear and not specified, we leave it unclear. The age groups and mean ages of older participants in our studies are shown in Figure 5. We classified age bands as >=50 years old, >=55 years old, >=60 years old, >=65 years old, >=70 years old, >=75 years old, >=80 years old, and 85+ years old. We used the reported age range of participants and reported mean age to determine which band it falls into. Most studies involved participants aged >=65, followed by >=60, with no studies reporting age groups of >=75 or >=80. However, the mean age data shows that after the 65-70 group, the 75-80 group is the second largest, and the 80-85 group has 1 study. The discrepancy between age groups and mean ages likely reflects the common senior age in many countries, where most studies have participants with a mean age between 65 and 75. The lower numbers in the 80+ group may relate to availability, health concerns, and assistance needs [36].

***Gender of Participants*** Figure 6 summarises the gender distribution of senior user participants in each study if reported. Figure 6(a) shows that among all the studies we included, there was a higher representation of more female than male participants, comprising 81% of the total sample, compared to male participants, who accounted for 19% of the total sample. Among the studies reporting gender data, there are 17 studies with female-skewed samples, 4 studies with a predominance of male participants, and 48 studies without participant gender information. This gender imbalance with a trend towards greater female participation is aligned with the gender ratio that is commonly observed among the seniors [37, 38].

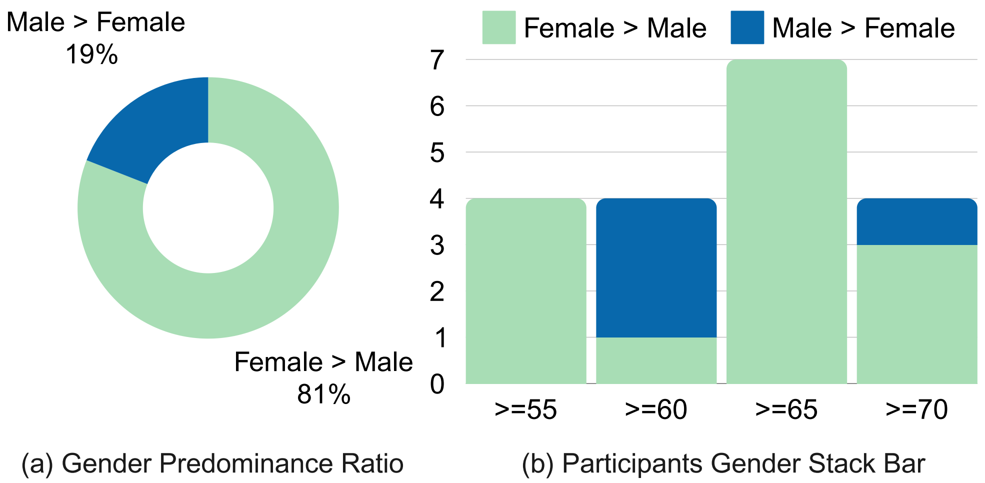


Figure 6: Senior End User Participants Gender Distribution Among Reported Studies

***Caregiver Representation:*** Caregivers in aged care refer to individuals who provide care and support to seniors, including professional caregivers like nurses, clinicians, social workers and informal caregivers like families, volunteers, facility managers, and colleagues. Figure 7(a) provides the number of study participants that include older adult users and caregivers. The results indicate that in the total number of all included studies, the number of older adult participants is similar to that of caregiver participants. Variations in the ratios of seniors to caregiver participants can be observed across studies with differing participant numbers. Studies with few participants, like S42, S4, and S69, normally included more older adult participants than caregivers. Studies with a medium number of participants, like S62, S45, and S27, normally have more caregivers than older adults. Five studies included more than 100 participants, and the extreme values were labelled with stars in Figure 7(a). There are no obvious patterns among studies with high total participant numbers like S2, S28, and S38, with more than 280 older adult participants.In studies S17, S4, and S28, the reason why the caregivers and older adult participants numbers are the same is that they introduced a pair

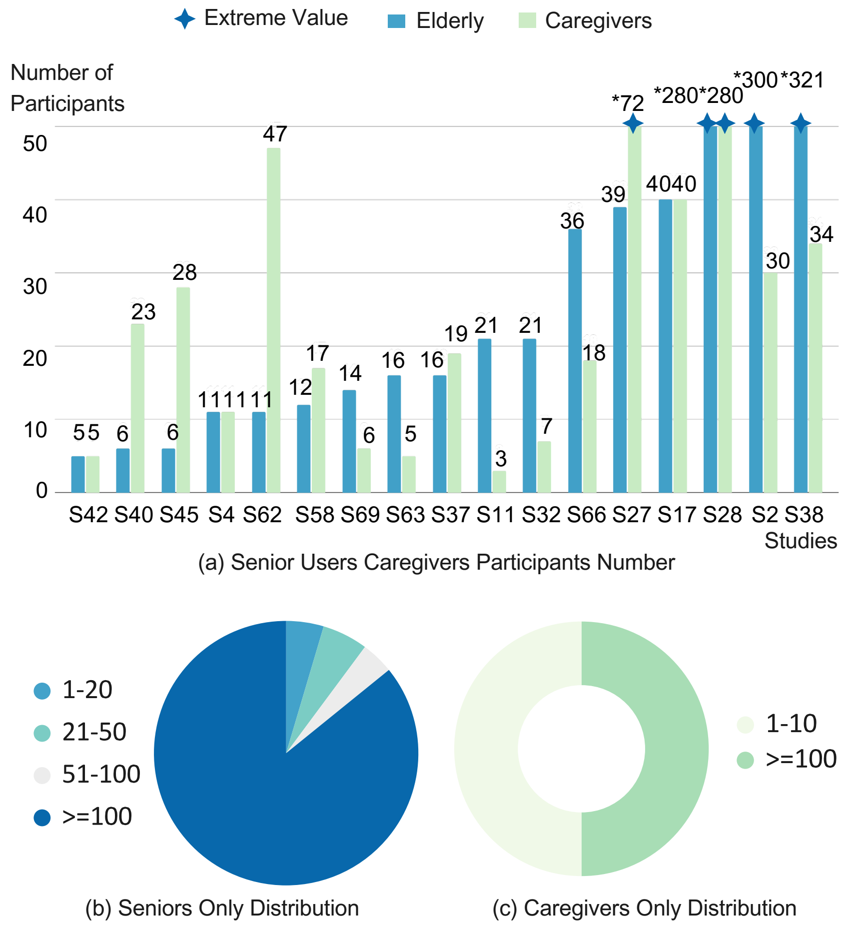


Figure 7: Senior End Users and Caregivers Participated in Each Study

of participants called ‘dyads’, which includes a caregiver and a senior person receiving care to focus on the dynamics of their relationship, the impact of care-giving on both parties and the effectiveness of care-giving strategies. Figure 7(b) Figure 7(c) provides a summary of participants distribution of older adults only and caregivers only in studies. 27 studies included only older adults and 4 studies included only caregivers. In the caregivers-only participants chart, half of the studies have more than 100 participants and the other half have only a few participants. We can see that a significant number of studies focusing solely on the older adult population without considering caregivers.

***Participant Types:*** Figure 8 summarises the different participant types in the primary studies and the studies including single vs multiple types of participants. It can be seen that the most common participant type is general healthcare providers, who are healthcare general practitioners or non-nominate aged caregivers but not clinicians, nurses, and other clinical experts. This suggests the importance of healthcare providers for gathering the needs of older adults in digital health studies. Other significant participant types were families (eg. S25, S3, S42) and clinicians and nurses (eg. S5, S27, S55). In some studies (eg. S52, S55, S2), all types of participants are used to understand older adult needs, while in other studies (eg. S47, S69, S28), they only include healthcare providers and older adults as participants.

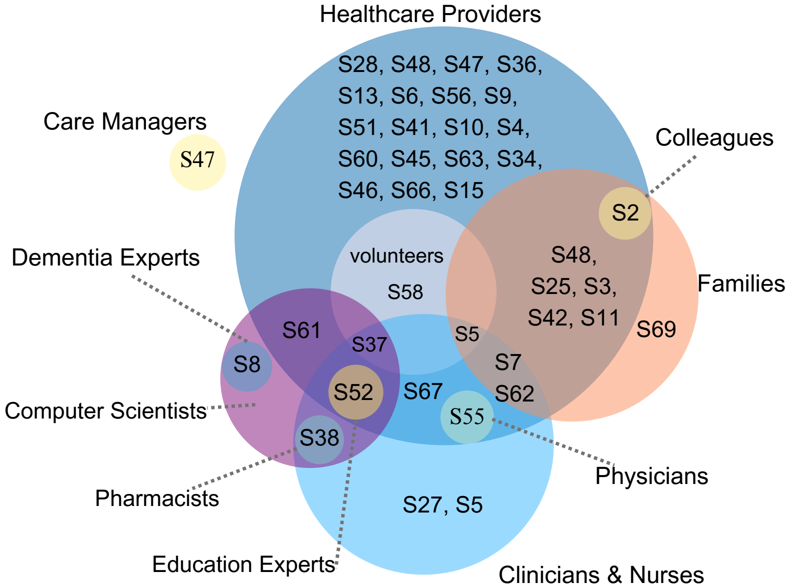


Figure 8: Venn Chart of Participants Types

*4.2.4. RQ1.4 - What data is captured by the (proposed) software, and how is the data used? What technologies did they use? Does the software use any AI solutions?*

Figure 9 is a double bubble chart that displays the relationship between data capture, AI usage, and AI solutions. The size of the bubble is the number of studies. Data capture refers to the data collection methods and data types in our included studies. AI solutions stand for the applications and technologies that applied AI/ML in each study. AI usage means the functions achieved in each study related to AI/ML algorithms. The x-axis showed the data capture and AI solutions, while the y-axis showed the AI usage that is related to them. Each bubble represents a data point, with the x-axis and y-axis determining its position on the chart and the size of the bubble representing the occurrence of such an x-axis and y-axis combination.

Key AI usage and data capture are home data and vital signs data for health monitoring. Health monitoring in our primary studies is the most common application now for aged care applications with AI/ML. For example, study S25 used MEMSS (micro-electro-mechanical sensor system) to develop a smart home to enhance health monitoring and fitness encouragement. Another important finding is that sentiment analysis, social connection, and wellness monitoring interest many studies. These results may be due to the rising popularity of emotional and wellness care in aged care. For example, study S37 applied AI/ML Algorithms in their dementia support to develop a navigator to support older adults with their dementia challenges and help them improve their quality of life. It is interesting to compare the AI health search tools in AI solutions with the voice NLP questions in data capture which shows it is important and common to apply voice in infotainment support instead of text questions.

*4.2.5. RQ1.5 - What different human aspects (besides age) were considered in the study (if any)?*

Table 7 summarises the key human aspects used in RE in our selected primary studies. These are grouped into 3 major categories and 19 minor categories. Out of 69 studies, 5 reported no human factors, 57 used multiple RE techniques, and 7 used only one. Of the studies that reported human factors, 31 studies (44.93%) addressed personal and lifestyle factors, 42 studies (60.87%) covered societal and environmental factors, and 61 studies (88.41%) included health and well-being factors.

***Personal and lifestyle factors*** encompass personal preferences (e.g., food, entertainment, clothing,

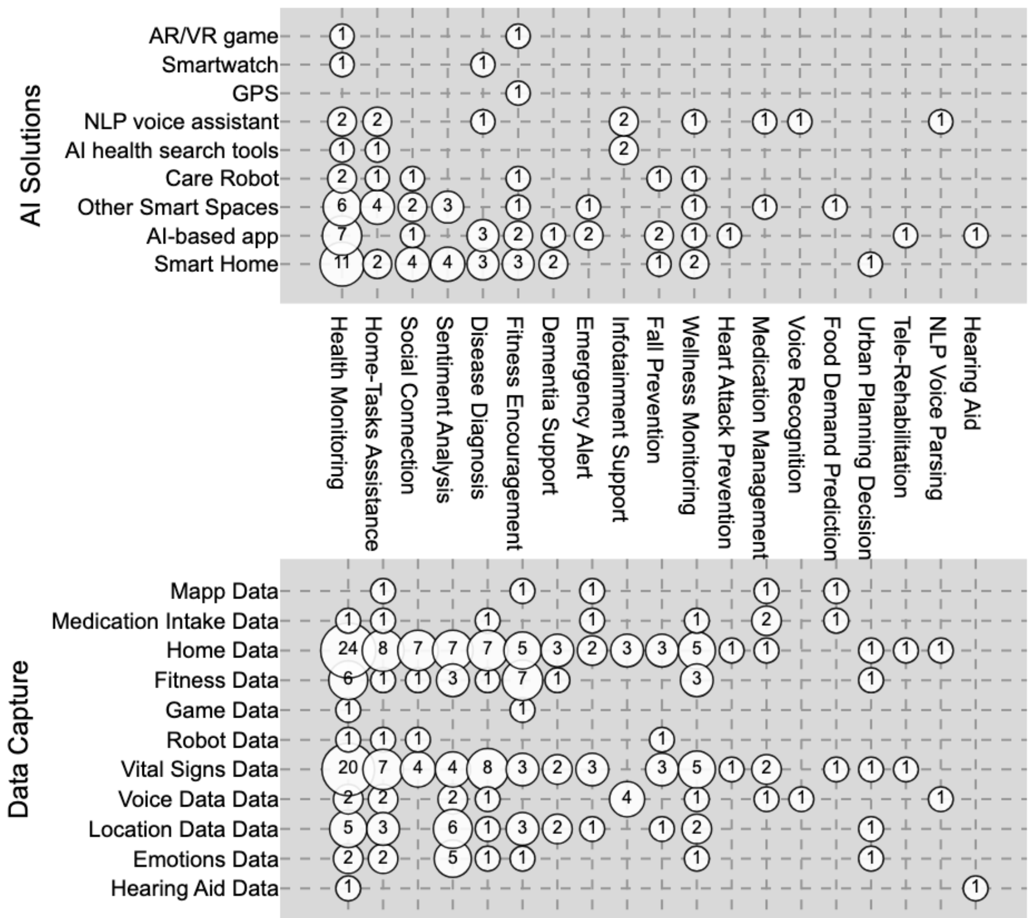


Figure 9: Data Capture Vs AI Usage Vs AI Solutions

| Major Factors | Minor Factors | Papers |
|---|---|---|
| **Personal and Lifestyle (31)** | Personal Preferences (eg. food, hobbies) | S4, S5, S8, S9, S11, S13, S17, S20, S23, S37, S38, S40, S42, S50, S51, S54, S57, S59, S62, S64, S66, S69 |
| | Emotions | S1, S4, S5, S7, S12, S13, S17, S38, S41, S62, S64 |
| | Fitness Lifestyle | S9, S43 |
| | Personality | S8, S10, S44, S64 |
| | Life Experience | S6, S10, S53 |
| **Societal and Environmental (42)** | Living/Family Situation or Societal Influences | S1, S2, S4, S5, S8, S9, S11, S14, S15, S16, S22, S23, S25, S28, S29, S30, S31, S32, S35, S36, S37, S40, S42, S44, S46, S47, S49, S51, S53, S55, S59, S60, S62, S63, S68 |
| | Culture/Ethnicity | S5, S15, S17, S30, S31, S32, S55, S59, S60 |
| | House and Location | S2, S8, S9, S11, S53, S56, S64 |
| | Socio-economic Status | S1, S3, S8, S12, S20, S30, S31, S32, S53 |
| | Parental Status (Living) | S3 |
| | Loneliness | S9, S23 |
| **Health and Well-being (61)** | Physical and Mental Challenges | S3, S5, S6, S7, S8, S9, S11, S12, S13, S14, S15, S16, S17, S20, S21, S22, S24, S25, S26, S27, S28, S29, S33, S34, S35, S36, S37, S38, S39, S40, S41, S42, S44, S46, S47, S50, S51, S52, S53, S54, S59, S60, S62, S63, S64, S65, S66, S69 |
| | Comfort with Technology | S1, S2, S8, S10, S11, S12, S13, S20, S22, S26, S28, S29, S32, S34, S35, S36, S38, S39, S40, S42, S43, S45, S46, S47, S49, S53, S54, S56, S63, S64 |
| | Gender | S20, S22, S28, S29, S30, S31, S32, S35, S40, S42, S44, S50, S53, S55, S59, S60, S62, S63, S66 |
| | Cognitive and Educational Level | S1, S4, S5, S9, S10, S11, S15, S17, S21, S22, S26, S27, S28, S30, S31, S32, S35, S42, S43, S47, S50, S54, S55, S58, S59, S63, S65, S66, S68 |
| | Occupation and Skill Level | S2, S35, S40, S42, S43, S46, S50, S55, S63, S64 |
| | Smoking | S42 |
| **Unclear (5)** | | S18, S19, S48, S61, S67 |

Table 7: Different Human Aspects (Besides Age) Considered In Each Study

hobbies) used in 22 studies, emotions in 11 studies, fitness lifestyle in 2 studies, personality in 4 studies, and life experience in 3 studies. The most commonly investigated factor is personal preferences. However, it is observed that the collection methods for this factor vary across studies and might be influenced by the provided scenarios. Generally, food, entertainment, and hobbies are the most frequently mentioned factors. For instance, studies S11 and S20 collected data on food preferences and hobbies such as sports, highlighting different aspects of life for end users, which could influence the requirements-gathering process. Emotional and fitness lifestyle factors are often considered in studies involving emotional sensors, incorporating these human factors into the participant group as part of the requirement targets, as demonstrated in studies S62, S64, and S4. In study S44, the Bartle Test of Gamer Psychology results indicated the predominant player types in the target group to be explorers and socializers, distinguishing the needs of different elderly individuals in terms of experiencing the game or interacting with friends. Life experience refers to events from the past lives of elderly users, which differ from professional skills or socio-economic status.

***Societal and environmental factors*** include living/family situation or societal influences, used in 35 studies, culture/ethnicity in 9 studies, house and location factors in 7 studies, socio-economic status in 9 studies, parent status in 2 studies, and loneliness in 2 studies. Living/family situations or societal influences refer to any living arrangements, such as living with family or friends or in a residential home with caregivers. These factors can significantly influence the needs of older adults, as evidenced in studies S2, S35, and S36. Study S3 revealed that an elderly individual's parents can be crucial to their emotional, social, physical, and cognitive well-being.

***Health and well-being factors*** include physical and mental challenges used by 48 studies, comfort with technology used by 29 studies, gender used by 19 studies, cognitive and educational level used by 28 studies, occupation and skill level used by 10 studies, and smoking used by 1 study. The physical and mental challenges are the most common and can be related to different clinical goals which is easily noticed, especially in studies published on digital health. For example, study S47 found that the clinical goal is an important human factor in evaluating the patient-centred biopsychosocial blended collaborative care pathway for the treatment of multimorbid elderly patients. In study S58, patients with different levels of dementia were included and their needs were gathered by their dementia clinicians and caregivers.Smoking is used by study S42 as a crucial human factor in a health self-management system for Peripheral Arterial Disease patients and it is shown that smoking can influence their clinical situation and hence influence the needs of patients in the system.

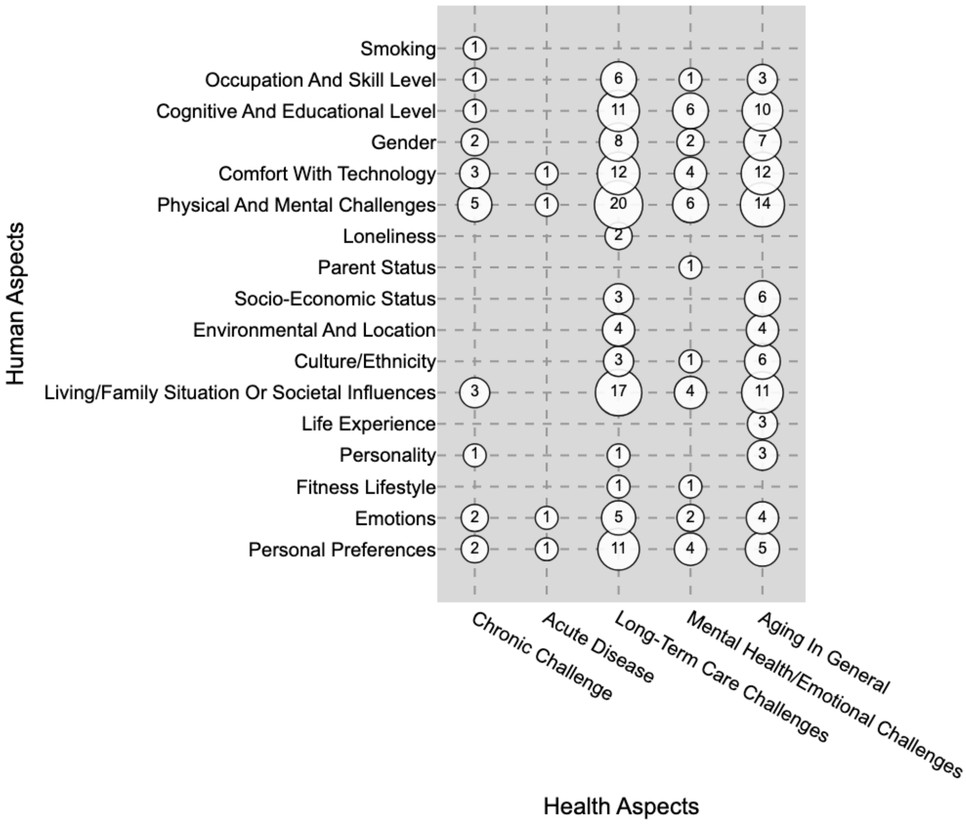


Figure 10: Human Aspects Vs Health Aspects

In Figure 10, we analysed health aspects and corresponding human aspects of each study in the research. The size of each bubble correlates with the number of studies. This reveals a rough trend where more studies are generally associated with popular human aspects (eg. physical and mental challenges, living situations, and personal preference) in all health aspects. the large bubble size for the cognitive and educational levels paired with mental health or emotional challenges highlights the importance of the human factor "cognitive level" in emotional challenge health aspect. For the "ageing in general" category, it is obvious that "societal and environmental" and "health and well-being" are investigated more than "Personal and lifestyle" human factors. This inconsistency may mean that researchers have not yet explored the personal and lifestyle human factors enough for general ageing digital health systems.

**RQ1 Answers**

Half of our selected primary studies are on the development of a digital health system for older adults with a detailed RE process, about one-third propose a method of RE for such systems, and the rest are guidelines for RE in such scenarios. Half of the studies focus on ageing in general or the comorbidity of older adults in the process of ageing. The rest focus on supporting mental health and specific physical challenges of ageing people. The majority of studies included older adults as participants, but the age group of older adults can vary based on the research topic and the country in which the study was conducted. More than half of the studies included caregivers as participants in their study, and a few studies included developers or technical experts as participants. One-third of studies applied AI/ML in their systems to build the system and collect data, especially after 2015. Diverse human aspects have been considered, including common ones like living situations, and cognitive status, and uncommon ones like loneliness and personality.

### *4.3. RQ2 - How was the Requirements Engineering carried out?*

#### *4.3.1. RQ2.1 - What RE techniques did each study use?*

Table 8 summarises the key RE techniques used in our selected primary studies. These are grouped into nine major categories and fourteen minor categories. Of the 69 studies included, 8 reported no RE techniques, 44 used multiple techniques, and 17 focused on a single technique.

| Major Categories | Minor Categories | Studies |
|---|---|---|
| **Interviews (36)** | | S5, S6, S7, S10, S11, S13, S14, S17, S19, S21, S23, S27, S28, S29, S31, S32, S36, S37, S39, S41, S42, S44, S46, S50, S51, S53, S55, S57, S59, S60, S61, S62, S63, S64, S68, S69 |
| **Surveys (26)** | | S2, S3, S8, S11, S12, S20, S22, S24, S27, S28, S30, S31, S32, S34, S35, S38, S39, S41, S44, S50, S52, S53, S57, S60, S64, S69 |
| **Workshops (23)** | | S4, S9, S10, S14, S20, S27, S28, S35, S36, S37, S38, S39, S40, S49, S50, S51, S53, S57, S58, S59, S61, S66, S69 |
| **Observations (21)** | | S5, S7, S10, S11, S13, S17, S19, S22, S28, S29, S46, S51, S54, S57, S58, S61, S62, S64, S66, S68, S69 |
| **Material analysis (11)** | Document analysis | S7, S32, S36, S40, S44, S53, S58, S61, S63, S65 |
| | Video analysis | S28 |
| | audio analysis | S7, S32 |
| | scenario-based user need analysis (SUNA) | S36 |
| **Rapid Prototyping** | | S2, S10, S17, S21, S22, S63, S64, S68, S69 |
| **Innovation process (6)** | Brainstorming | S33, S46, S49, S52, S64 |
| | Design Thinking Process | S47 |
| | Enlisting Allies in Recruitment | S49 |
| **Psychology Test (1)** | Bartle Test of Gamer Psychology | S44 |
| **Reuse existing requirements** | | S1, S17, S34, S43, S45, S52 |
| **Unclear** | | S15, S16, S18, S25, S26, S48, S56, S67 |

Table 8: The RE techniques used in each study

Of the studies that reported their RE techniques (including overlaps), 36 studies (52.17%) used interviews, 26 studies (37.68%) used surveys, 23 studies (33.33%) used workshops, 21 studies (30.43%) used observations, 11 studies (15.94%) used material analysis, 9 studies (13.04%) used rapid prototyping, 6 studies (8.7%) used innovation process, 1 study (1.45%) used a psychological test and 6 studies (8.7%) reused existing requirements. Material analysis included document analysis (10 studies), video analysis (1 study), audio analysis (2 studies), and scenario-based user need analysis (SUNA) (1 study). Innovation processes included brainstorming (5 studies), design thinking (1 study), and enlisting allies in recruitment (1 study). Some studies reused existing requirements. For example, S43 improved a memory game using age-related requirements from previous works by the same authors [39, 40].

#### *4.3.2. RQ2.2 - What tools were used for requirements elicitation and documentation in each study?*

| **Major Categories** | **Minor Categories** | **Studies** |
|---|---|---|
| **RE tools for documentation (32)** | Text/Spreadsheet | S1, S5, S7, S31, S32, S36, S37, S38, S39, S40, S42, S44, S47, S50, S53, S55, S56, S58, S59, S60, S61, S64, S66 |
| | Prototyping Tools | S2, S3, S5, S20, S23, S24, S25, S29, S32, S38, S39, S42, S46, S47, S53, S55, S58, S59, S61, S64, S66, S68 |
| **RE tools for management (17)** | Graphical Specification Language Models (eg.UML models) | S2, S8, S13, S17, S18, S29, S36, S38, S41, S48, S55, S56, S62, S66, S67 |
| | Socio-technical Method | S7, S47, S48, S67 |
| | Application Lifecycle Management | S29, S64 |
| **RE tools for analyzing (5)** | Project Tracking Tools | S30 |
| | Aspect-Oriented RE | S25 |
| | Judgement Call | S14 |
| | Data analysis software | S44, S62 |
| **Unclear (26)** | | S4, S9, S10, S11, S12, S15, S16, S19, S21, S22, S26, S27, S28, S33, S34, S35, S43, S45, S49, S51, S52, S54, S57, S63, S65, S69 |

Table 9: The tools used during requirements elicitation and modelling in each study

Table 9 presents three categories of Requirements Engineering (RE) tools used in the primary studies. These we grouped into requirements documentation (32 studies, 46.38%), management (17 studies, 24.64%), and analysis (5 studies, 7.25%). The category "unclear" includes 26 studies without specific RE tools mentioned. We believe some studies generated user stories likely used RE tools like interviews as well, though they did not specify which ones. Of the 43 studies that reported RE tools, 35 used multiple tools, while 8 used only one.

The dominant category we found was RE tools for documentation. This includes two major subcategories: *Text* and *Tables* tools (23 studies using), and *Prototyping* tools (13 studies using). The second largest category we found was RE management tools, including Abstraction Modelling tools, Application Lifecycle Management (ALM), etc. *Graphical specification language* models (eg. UML model tools, meta models) are used in 15 studies. *Socio-technical methods* is used in 4 studies. For example, in study S48, Work system design is used to represent the needs of older adults and care managers in an evaluation of a patient-centred biopsychosocial blended collaborative care pathway for the treatment of multimorbid elderly patients (ESCAPE). 2 studies used *Application Lifecycle Management* (ALM) tools.

The RE tools for analysis category includes 4 sub-categories of tools, each linked to specific studies where they were utilized. *Issue and Project Tracking Tools* are used by a single study, study S30. Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) are used to analyse the requirements of older adults to understand the end user perspective of smart homes for elderly healthcare. *Aspect-oriented requirements engineering* (AORE) is used by one study, S25. *Judgment Call* was created for industry product teams so that ethical concerns could surface when developing Artificial Intelligence (AI) technology, used in study S14. *Data analysis* software was used in 2 studies.

#### *4.3.3. RQ2.3 - How were the requirements modelled in each study?*

| **Major Categories** | **Minor Categories** | **Studies** |
|---|---|---|
| **user centred Design UCD (59)** | User stories | S2, S3, S4, S5, S7, S9, S12, S13, S14, S16, S19, S21,S22, S24, S25, S27, S28, S29, S32, S34, S36, S37, S38, S41, S43, S44, S46, S48, S49, S51, S53, S54, S58, S59, S61, S62, S63, S64, S66, S68, S69 |
| | Use Case Modelling | S1, S2, S3, S4, S5, S7, S8, S9, S10, S11, S13, S14, S16, S17, S19, S20, S25, S29, S30, S31, S37, S38, S40, S41, S43, S44, S46, S47, S48, S50, S53, S55, S56, S58, S63, S64, S66, S67, S68 |
| | Personas | S5, S7, S9, S15, S26, S35, S42, S46, S48, S55, S59, S62, S64, S68 |
| | Goal Model(e.g. i-Star,KAOS) | S2, S6, S7, S8, S11, S41, S62 |
| | fictional user | S47 |
| **Semantic Model (24)** | Activity Diagram | S2, S9, S15, S17, S26, S41, S42, S58, S61, S67 |
| | Affinity Diagram | S9, S14, S17, S49, S50, S54 |
| | Conceptual Model | S3, S6, S8, S11, S16, S27 |
| | Meta model | S16, S18, S41, S53 |
| | Ontology modelling | S32 |
| | Comprehensive model | S64 |
| **Unclear (7)** | | S23, S33, S39, S45, S52, S57, S60 |

Table 10: How the requirements are modelled

Table 10 provides a categorisation of the main types of Requirements Engineering (RE) models used, including 59 studies (85.51%) that used user-centred design (UCD), 24 studies (34.78%) that used semantic model, and 7 studies (10.14%) did not report a specific RE model they used. Of the 62 reported studies, 44 used multiple RE models, and 18 used a single model.

Of the studies that used some form of user-centred modelling, 41 studies used *user stories*, 39 studies used *use cases* to model requirements, 14 studies used *personas*, 7 studies used *goal modelling*, and 1 study used a *fictional user*. User stories are short, simple descriptions of a feature or functionality from the perspective of an end user. Personas are fictional characters created to represent different user types or user roles that might interact with a system based on real user data. Goal modelling is a technique used in RE to capture and represent the goals and objectives of stakeholders. A fictional user is a character created for the purpose of testing or illustrating a system, but different from personas, they are not based on real data or research but are used to simulate real user interactions and scenarios.

Semantic models were classified into 6 minor categories. *Activity diagrams* are used by 10 studies, which represent the flow of control or the sequence of activities in a system or process. *Affinity diagrams* are used by 6 studies, which organize a large number of ideas, issues, or information into groups based on their natural relationships. *Conceptual models* are described in 6 studies. These provide a high-level representation of a system to communicate the overall design or structure of a system without implementation details. A *meta-model* defines the structure and semantics of other models used to represent their requirements, which is used by 4 studies. An *ontology model* was used by one study.Finally, a *comprehensive model*, for example, an International Classification of Functioning Disability and Health (ICF) model, was used by one study, S64.

#### *4.3.4. RQ2.4 - How were the requirements validated?*

Table 11 categorises our primary studies into five main validation methods: prototyping (30 studies, 43.48%), reviewing by humans (37 studies, 53.62%), testing by humans (16 studies, 23.19%), automated testing (11 studies, 15.94%) and scoring(2 studies, 2.9%) in the context of software engineering research. The ‘unclear/none’ category (15 studies, 21.74%) includes studies where the specific RE validation tools were unclear or no validation process was mentioned. Of the 54 studies reporting validation methods, 38 used multiple methods, while 16 used only one.

| Validation Major Categories | Validation Minor Categories | Studies |
|---|---|---|
| **Prototyping & Proof of Concept (30)** | | S5, S6, S9, S10, S11, S13, S19, S20, S23, S24, S29, S32, S34, S37, S38, S42, S47, S49, S51, S53, S54, S55, S57, S58, S59, S62, S64, S66, S68, S69 |
| **Reviews by Human (37)** | Stakeholder feedback (eg.workshops) | S5, S6, S11, S12, S17, S19, S21, S22, S27, S29, S32, S36, S37, S38, S40, S41, S43, S44, S45, S46, S49, S51, S54, S58, S60, S64, S66, S69 |
| | Requirements Reviews/Inspections | S5, S7, S9, S10, S13, S21, S24, S31, S35, S51, S54, S55, S64 |
| | External Reviews | S5, S28, S35, S44, S46 |
| **Testing by Human (16)** | Scenario Testing | S20, S28, S36, S38, S42, S47, S48, S59, S61, S62, S64, S68 |
| | Use Cases Validation (eg.input/output) | S7, S16, S26, S48, S67 |
| **Automated Testing (11)** | User Acceptance Testing (UAT) | S10, S22, S27, S28, S30, S31, S32, S34, S38, S54, S64 |
| **Score/Scale system (2)** | | S8, S32 |
| **Unclear (15)** | | S1, S2, S3, S4, S14, S15, S18, S25, S33, S39, S50, S52, S56, S63, S65 |

Table 11: How the requirements were validated in the study

Prototyping and Proof of Concept involves creating experimental software versions to showcase key features and gather stakeholder feedback. For example, study S10 developed a prototype to understand senior users' needs for the SeniorDT RE framework. The largest category, Reviews/Validation by Humans, includes the process of validation by humans checking that the software meets the specified requirements and satisfies the needs of stakeholders, including *stakeholder feedback* (28 studies), *requirements reviews/inspections* (13 studies), and *external reviews* (5 studies).External reviews refer to evaluations or assessments of a product, process, or system conducted by individuals or organizations outside of the entity responsible for the item being reviewed.

Testing by humans involves manually executing test cases to verify the correctness and quality of a software system. Two main approaches described in studies were *scenario testing* (13 studies) and *use case validation* (5 studies). The automated testing category includes studies that conducted automated tests. User acceptance testing (UAT) was used in 11 studies. For example, Study S10 used requirements testing to enhance older participants' engagement and gather insights using the SeniorDT framework.

#### *4.3.5. RQ2.5 - Were the requirements used to build an actual system? If so, in which SE stages?*

Table 12 highlights key SE stages where the requirements were used including preparation (62 studies, 89.86%), development (37 studies, 53.62%), verification (41 studies, 59.42%), and post-production (7 studies, 10.14%). Of 66 studies reporting SE stages, 64 involved multiple stages, while 2 applied them to only one stage. Three studies did not specify any SE stage or activities.

Preparation activities include *elicitation* (51 studies), *documentation* (15 studies), *analysis* (24 studies), and *design* (54 studies). Elicitation involves gathering and prioritizing requirements from stakeholders. For example, S14 elicits requirements from ethical considerations when developing AI technology for older adults in long-term care settings, and S52 prioritizes the needs of older adults using situation-aware mobile devices. Documentation entails creating documents that describe software requirements and design; in S58, notes and audio recordings help extract requirements and update the iterative prototype. Analysis activities include analyzing requirements and system architecture. S33 visualizes biomechanical data on the functional demand of older adults, and S57 analyses the observations and survey data to extract the requirements of stakeholders. Design activities involve conceptualizing software architecture and user interfaces,

The development stage involves implementing the software based on requirements. For example, S53 built a prototype fostering empathy and individualized design to reduce abstract thought, while S68 developed

| Major Stage | Minor Stage | Studies |
|---|---|---|
| **Preparation (62)** | Elicitation | S2, S3, S4, S5, S6, S7, S8, S9, S11, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S27, S31, S32, S34, S36, S37, S38, S39, S41, S42, S43, S44, S45, S46, S47, S48, S49, S50, S51, S52, S53, S54, S55, S58, S59, S60, S62, S66, S69 |
| | Documentation | S2, S5, S6, S8, S21, S32, S35, S45, S49, S55, S58, S60, S63, S64, S66 |
| | Analysis | S2, S5, S8, S15, S26, S27, S32, S35, S36, S42, S48, S49, S50, S51, S52, S57, S58, S60, S61, S63, S64, S66, S67, S68 |
| | Design | S2, S3, S4, S5, S6, S7, S9, S11, S13, S15, S16, S17, S18, S20, S21, S22, S23, S24, S25, S26, S27, S28, S33, S34, S35, S36, S38, S39, S40, S41, S42, S43, S44, S45, S46, S47, S48, S50, S51, S53, S54, S55, S57, S58, S59, S60, S61, S62, S63, S64, S66, S67, S68, S69 |
| **Development (37)** | | S4, S5, S6, S7, S9, S13, S16, S22, S25, S26, S27, S31, S32, S33, S35, S36, S37, S38, S40, S42, S43, S44, S47, S50, S51, S53, S54, S58, S59, S60, S61, S62, S63, S64, S67, S68, S69 |
| **Verification (41)** | Validation | S2, S5, S6, S7, S9, S12, S13, S16, S17, S20, S21, S24, S26, S27, S28, S29, S30, S32, S34, S36, S37, S38, S40, S41, S42, S43, S45, S46, S47, S49, S50, S58, S59, S62, S64, S66, S67, S69 |
| | Testing | S1, S5, S19, S20, S22, S24, S28, S29, S30, S38, S54, S59, S64, S67 |
| **Maintenance (7)** | Updates | S2, S11, S39, S51, S53, S64 |
| | Deployment | S2, S29, S39 |
| **Unclear (3)** | | S10, S56, S65 |

Table 12: In which parts of the process of system building the requirements were used

the telecare app CareMe to improve health monitoring and social connection for older adults.

The Verification stage includes 38 studies that focused on *requirements validation* and 15 studies that focused on *requirements-based testing*. Validation involves ensuring that the software meets the specified requirements and testing activities to ensure that the software functions correctly. For example, S29 developed an online community care platform for frail older adults, using observations and interviews to assess and refine user requirements for platform modifications.

Maintenance includes *software updates* (6 studies) and *deployment* (3 studies). Updates may be made to the software based on user feedback or new requirements. For example, S64 emphasized user testing and feedback from older adults during development, highlighting how feedback improved their medication assistant app. Deployment & Maintenance involve launching the software and ensuring its continued functionality over time. For example, S39 demonstrated how requirements were applied during the maintenance of a home medication adherence assistant.

*4.3.6. RQ2.6 - Were the requirements used to evaluate the solution? If so, how the study is evaluated?*

18 studies (26.09%) did not use their requirements to evaluate a software solution, while the remaining 51 (73.91%)) did with their described requirements. Table 13 categorizes evaluation types: stakeholder requirements (50 studies, 72.46%), domain-specific requirements evaluation (7 studies, 10.14%), quality evaluation (3 studies, 4.35%), and performance evaluation (5 studies, 7.25%). Of the 47 studies using requirements in evaluations, 19 employed multiple methods, and 28 used a single method.

End-user evaluation was conducted in 42 studies. Two used existing user data, and 11 employed user requirements reviews. For example, study S6 involved real-world users testing functional tasks to assess older adults' expectations and evaluate a health management app prototype. Domain-specific evaluation includes 2 studies using *domain testing* and 5 studies using *domain analysis*. For example, study S32 employed the System Usability Scale (SUS) and Technology Acceptance Model (TAM) to evaluate a mHealth app for rewarding healthy behaviour in older adults. In S46, SE engineers and medical experts provided

| Evaluation Method | | Studies |
|---|---|---|
| **End User Evaluation (50)** | Real-world End User Testing | S3, S4, S5, S6, S9, S10, S11, S12, S13, S17, S19, S20, S21, S22, S24, S27, S28, S29, S30, S32, S34, S35, S36, S38, S40, S41, S43, S45, S46, S47, S53, S54, S58, S59, S60, S62, S64, S65, S66, S68, S69 |
| | Existing User Data Evaluation | S39, S61 |
| | User Requirement Reviews | S7, S9, S11, S16, S26, S38, S42, S48, S62, S67, S69 |
| **Domain-Specific Evaluation (7)** | Domain Testing | S29, S32 |
| | Domain Analysis | S24, S44, S46, S51, S53 |
| **Quality Evaluation (3)** | Thematic Analysis | S58 |
| | Reflexive Monitoring | S40, S53 |
| **Performance Evaluation (5)** | Performance Efficiency Metrics | S1, S8, S27, S30 |
| | User Experience (UX) Testing | S1, S31 |
| **No Evaluation (18)** | | S2, S3, S4, S14, S15, S18, S23, S25, S33, S37, S49, S50, S52, S55, S56, S57, S63, S65 |

Table 13: The evaluation method in each study

feedback on a medication assistant system, using patients' clinical and functional requirements for testing. Quality evaluation includes *thematic analysis*, *iterative Verification*, and *reflexive monitoring*, each containing 1 study. Thematic analysis refers to identifying, analyzing, and interpreting patterns or themes within qualitative data collected during software development projects. Study S58 used thematic analysis to help developers and caregivers understand the perspectives of older adults with dementia involved in the project. Statistical method evaluation includes *performance efficiency metrics* and *user experience (UX) Testing*. Performance efficiency metrics involve metrics that evaluate the performance of a system which encompass statistical significance. For example, study S8 proposed a framework of underlying senior citizens' needs in smart-home services, A Balanced Scorecard (BSC) is used in study S8 to evaluate the effectiveness of services provided to the ageing population used evaluation, highlighting the statistical significance of the technology-supported ageing system in S8 for aged people. User experience (UX) hypothesis testing is a statistical test to determine whether a design leads to a higher user satisfaction score.

**RQ2 Answer Summary**

The majority of our primary studies applied classic RE techniques, including interviews, surveys, workshops, and observations. Diverse models were used for RE in the studies. The most common ones are use cases, user stories, and personas. Few studies applied models like ontology models and conceptual models. Different tools were used for requirements elicitation and documentation, including popular prototyping tools (eg. Balsamiq or Axure RP) and UML modelling tools (eg. Enterprise Architect or Lucidchart) and less common ones like text data analysis software (eg. NVivo) and Application Lifecycle Management tools (eg. Tuleap). More than 80% of studies validated their requirements, the most common way to validate it is to include end users in their design process. 75% of the primary studies described the use of their requirements in diverse SE stages, and more than half of the studies have their development stage. Generally, the earlier a SE stage is, the more studies have used requirements in that stage. More than half of studies evaluated their solution with requirements, the most common one using workshops with end users, their caregivers, and technical experts.

| Major Categories | Minor Categories | Studies |
|---|---|---|
| **User-centred Approach Enhancement (59)** | Functional Needs Understanding | S1, S7, S9, S11, S12, S15, S16, S19, S21, S22, S23, S27, S28, S29, S30, S31, S32, S33, S34, S35, S37, S39, S42, S46, S47, S51, S54, S55, S58, S63, S66, S67, S69 |
| | Participatory Design Process Enhancement | S5, S7, S24, S27, S28, S30, S34, S35, S37, S38, S42, S44, S46, S48, S49, S53, S56, S57, S59, S60, S61, S63, S65, S66, S68 |
| | Personalisation & Adaptive Needs | S2, S8, S11, S12, S16, S18, S29, S41, S42, S45, S46, S47, S49, S50, S53, S54, S57, S58, S66 |
| | Mutual Learning Promoting | S4, S11, S12, S26, S28, S37, S38, S51, S57, S59, S61, S63, S68 |
| | Clinical Goals Understanding | S13, S25, S29, S34, S38, S42, S50, S60 |
| | Emotional Needs Identifying | S3, S4, S41, S54, S64 |
| **Automation/AI/ML Enhancement (34)** | AI/ML based System Improvement | S2, S5, S7, S9, S12, S14, S15, S16, S17, S18, S19, S20, S21, S25, S26, S30, S31, S35, S37, S41, S45, S46, S51, S52, S55, S5 |
| | Saving time and effort by Automation | S27, S35, S37, S66 |
| **User Health Improvement (15)** | Maintaining Physical and Mental Health | S17, S19, S36, S37 |
| | Changing Lifestyle for Health Improvement | S17, S18, S19, S24, S26, S29, S30, S36, S47, S49, S50, S59, S62, S66 |
| **System-Building Process Improvement (29)** | Improving/Streamlining Development | S1, S2, S6, S14, S29, S48, S55, S57, S59, S60, S61, S62, S64, S68 |
| | Enhancing Technology Adoption | S1, S3, S6, S22, S26, S27, S28, S39, S52, |
| S60, S62 | | |
| | Enhance User Testing & Feedback | S1, S8, S9, S32, S34, S38, S40, S42, S64 |
| | Improving Usability | S1, S28, S32, S34, S36, S39, S62, S68 |
| **Refinement of RE Methods&Guidelines (9)** | Existing RE methods Improvement | S8, S10, S25, S30, S31, S38, S67 |
| | Guidelines Improvement | S43, S45 |

Table 14: The key reported benefits/positive outcomes

### *4.4. RQ3 - What are the key Strengths, Limitations, Gaps, and Future work recommendations in the selected studies?*

#### *4.4.1. RQ3.1 - What are the key strengths/positive outcomes reported?*

Table 14 summarises the key benefits of the RE approaches, which include enhancing user-centred approaches (59 studies, 85.51%), enhancement of automation/AI/ML approaches (34 studies, 49.28%), improving user's health (15 studies, 21.74%), system-building process improvement (29 studies, 42.03%), and refinement of existing RE methods/guidelines (9 studies, 13.04%). Of the 69 studies, 59 reported multiple benefits, while 9 highlighted only one.

Enhancement of User-centred approaches includes *functional needs understanding* (33 studies), *participatory design process enhancement* (25 studies), *personalisation tasks and adaptive needs* (19 studies), *mutual learning promoting* (13 studies), *clinical goals understanding* (8 studies), and *emotional needs identifying* (5 studies). For instance, study S64 found that their patient-centered medication system effectively supported end-user needs including forgetfulness support, medication images, and the expiration date, while study S48 showed how co-design improved personalized experiences and stakeholder involvement. Study S49 revealed participatory design with older adults enhanced personalized health tool development.

Enhancement of Automation/AI/ML approaches includes sub-categories of *AI/ML-based system improvement* (33 studies) and *time-saving automation* (4 studies). In aged care software systems, AI/ML-based systems are very common when it is related to smart places, AI assistants, and accident prediction. For example, in study S45, the RE process helped identify age-related preferences for voice assistants, which are used to develop guidelines and design voice user interfaces that cater to the needs and preferences of older users.

User's health improvement includes *maintaining physical and mental health* (4 studies), and *changing lifestyle for health improvement* (14 studies). For example, the RE approaches used in study S37 contributed to the development of an integrated assistive technology system called Rosetta that is user-centred, customizable for people with dementia, providing information, monitoring daily activities, and encouraging mental health rehabilitation.

System-building process improvement includes *improving/streamlining development* (14 studies), *enhancing technology adoption* (11 studies), *user testing enhancement* (9 studies), and *improving usability* (8 studies). For example, study S14 is one of the first attempts at applying features of Judgement Call in a new context. It was successful as the Judgement Call methodology has found great success at Microsoft and its affiliated partners but has only been used among product designers. Study S26 reports that the RE approaches used, specifically combining Ambient Intelligence (AmI) technology with user-centred design methods, can greatly increase the acceptance of intelligent systems. This approach aims to provide a better quality of life for elderly and disabled individuals, creating a safe and intuitive environment to facilitate household tasks and preserve their independence for a longer period.

Refinement of existing RE methods/guidelines includes *existing RE methods improvement* (7 studies) and *guidelines improvement* (2 studies). For example, in study S67, RE approaches were used to improve an existing requirements modelling approach, combining the strengths of Volere templates, Use Cases, and SysML Requirements diagrams to increase the efficiency and quality of design and implementation results. In study

### *4.4.2. RQ3.2 - What are the key limitations reported?*

| **Major Categories** | **Key Limitations** | **Reported in studies** | **We identified in studies** |
|---|---|---|---|
| **SE Challenges (23)** | System Usability | S5, S6, S8, S15, S21, S23, S24, S29, S30, S32, S36, S39, S50, S52, S60, S61, S62 | |
| | Implementation | S9, S51, S59, S68, S69 | S18, S20, S42, S46, S65 |
| | Personalization Absence | S44 | S64 |
| **RE Limitations (20)** | Representation of Participants Bias | S1, S3, S10, S34, S35, S37, S38, S40, S49, S50, S53 | S16, S31, S33 |
| | RE Process Limitations | S13, S14, S25, S56, S59, S63, S67 | S2, S26 |
| | Participants Engagement | S10, S11, S13, S22 | S19, S48, S57 |
| **Human Aspect Inclusion (5)** | | S10, S28, S43, S58 | S54 |
| **Needs Challenges (9)** | Healthcare Needs | S27, S47, S55, S66 | S12 |
| | User Emotional Concerns | S7, S41, S45, S59, S67 | S4, S65 |
| | User Needs Conflicts | S7, S45 | |

Table 15: The key reported limitations

Table 15 summarises the key limitations reported with the RE approaches used in the selected primary studies. The main issues reported (with overlaps) include SE challenges (23 studies, 33.33%), RE methodological limitations (20 studies, 28.99%), human aspect inclusion (5 studies, 7.25%), and needs challenges (9 studies, 13.04%). Of 52 studies that reported their key limitations, 4 presented more than one limitation, while the remaining 48 reported one key limitation. Studies S2, S4, S12, S16, S17, S18, S19, S20, S26, S31, S33, S42, S44, S46, S48, S57 and S65 did not report specific limitations, but we identified some limitations that we found in these studies in the last column in table 15. SE challenges include *usability/adoption/complexity of system functionalities*, *implementation challenges*, and *lack of AI-based personalized functions*. For example, in study S15, the authors noted that their Independent Living Support (ILS) systems could be enhanced with functionalities catering to users with different skill levels, collaborative interactions, and privacy controls. In study S9, the pattern recognition implementation was hindered by the lack of real user data needed for advanced algorithms, affecting RE extraction.RE methodological limitations include *representation and bias of participants*, *RE process limitations*, and *participants' engagement*. For example, in study S3, the survey questionnaire may not fully represent Indonesia's diverse regions, and participants might struggle to identify their specific ageing group due to the country's cultural diversity. Human aspect inclusion may overlook factors like gender, education level, socio-economic status, and culture/ethnicity. For instance, study S54 shows that seniors can easily interact with the CogniPlay platform, which accounts for age-related needs. However, aspects like motor skill and cognitive decline, perceptual changes, and limitations in spatial cognition and language comprehension should also be considered. Needs challenges include *healthcare needs challenges*, *users needs conflicts*, and *user emotional concerns*. In study S27, the authors reported challenges in balancing technical and clinical requirements, emphasizing the need for effective communication between technical and clinical teams. Study S41 highlights threats to validity related to emotional goals, stressing the importance of addressing emotional concerns in smart home technologies.

#### *4.4.3. RQ3.3 - What are key recommendations for future research?*

| **Categories** | **sub-Categories** | **Papers** | **Percentage** |
|---|---|---|---|
| **System Advancement** | Further Development | S1, S17, S18, S21, S23, S29, S35, S36, S38, S42, S46, S47, S50, S52, S53, S54, S55, S56, S64, S65 | 44.93% |
| | Longitudinal Evaluation | S8, S11, S24, S28, S34, S35, S39, S43, S44, S50, S59, S60, S69 | |
| **RE Enhancement** | Co-design | S3, S9, S19, S20, S25, S28, S39, S48, S49, S50, S51, S57, S63, S68 | 30.43% |
| | Participant Representation and Bias | S14, S24, S30, S31, S32, S37, S58, S63 | |
| | RE models improvement | S7, S10, S13, S16, S26 | |
| **Guideline Improvement** | Improve WBAH Definition | S12 | 1.45% |
| **Focus on Diverse Needs** | Personalised Tasks | S2, S5, S6, S22, S27, S40, S51, S61, S62, S66, S67 | 23.19% |
| | Social-technical requirements | S15 | |
| | Emotional Goals | S41 | |
| | Loneliness | S4 | |
| | Psychological Factors | S33 | |
| | Privacy Protections | S45 | |

Table 16: The key recommendations for future research

Table 16 summarises the key future work that is reported in each primary study. 13 studies did not report any future work recommendations, including S17, S19, S18, S31, S38, S4, S42, S44, S48, S54, S57, S65, S51.

**RQ3 Answer Summary**

Most of the selected primary studies mentioned the key positive outcomes of their studies in enhancing user-centred approach, providing automation/AI/ML, improving user health, and optimizing system development. A smaller number of studies refined existing RE methods and guidelines. More than one-quarter of the studies did not mention any key limitations of their studies. Among those mentioned, limitations included the need for further target system development, RE methodological limitations, lack of human aspect inclusion, and the difficulty of fulfilling diverse user needs. Some key future work recommendations include RE method improvements, new user engagement and representation methods, design and development recommendations, technology usability improvement, further human aspect inclusion, data-driven RE and systems, and integrated holistic support systems.

## 5. Discussion

### *5.1. Key Findings and Recommendations*

Our review analysed primary studies focusing on Requirements Engineering (RE) for digital health (DH) systems for ageing people, including identifying stakeholders, eliciting and analyzing requirements, and documenting them for developers. Though the current adoption of RE methods and techniques in primary studies is not even, the importance of applying better RE practices has been acknowledged and is increasing. The health and human aspects involved are diverse due to the nature of the user diversity in ageing care, but we noticed some common trends and patterns. In this section, we discuss the broader meaning of our results and give suggestions for researchers who are interested in working in this cross-field domain.

| RE Framework | Common Related RE Process | Best Suited For | Key Challenges | Evidence Base |
|---|---|---|---|---|
| Traditional RE | Surveys, Interviews, Document Analysis | High User Diversity, Long-term Projects | Low Flexibility | S6, S8, S11 |
| Human-Centric RE | User Stories, Personas, Observations, Interviews | High User Diversity, Critical Ethical Projects | Time-Intensive, Stakeholder Trust | S14, S24, S27, S46 |
| Formal RE | Goal Models, Semantic Models | High-level Goals, Sensitive Requirements, Clinicians & Developers Communication | Training Cost, Technical Cost | S2, S13, S16, S18, S41 |
| Crowded RE & Emerging RE | Observations, Workshops, Surveys | Abundance data Projects | Lack of Personalisation | S12, S56 |
| AI & Gen-AI RE | Document Analysis, surveys, interviews | Scalability, Technical Teams | Reduced User Engagement | S27 |

Table 17: Key RE Framework Analysis

*5.1.1. Criteria for Selecting an RE Framework for Older Adult Digital Health Solutions*

Table17 summarises the reported RE frameworks with benefits and challenges, as reported in our analysed primary studies. Traditional RE (eg. Scenario-Based RE) utilizes surveys, interviews, and document analysis. It suits high user diversity and long-term projects but can have low flexibility. Human-Centric RE (eg. Co-design) relies on user stories, personas, observations, and interviews. It better handles applications with high user diversity and projects with critical ethical considerations. However, it can be very time-intensive, takes time to win stakeholders' trust, and requires a range of target end user involved throughout the process. Formal RE techniques include goal-driven RE and semantic RE models. It works well for managing high-level goals, complex or sensitive requirements, and can enhance stakeholders communication. Crowd-sourced RE uses observations, workshops, and surveys. This can be more suited for data-abundant, low user diversity projects. Their drawback may be a lack of personalization. Although we did not find many papers that use AI and Gen-AI based RE, studies that use this framework normally combine document analysis, surveys, and interviews with automation. It works best for scalable projects led by technical teams and those with enough structured data, but it might reduce user engagement and have common issues that Gen-AI could involve, like hallucination. It should be noted that our results and recommendations are based on primary studies focusing on older adult digital health solutions. However, some findings may be applied beyond this domain. As the result in Section 4.3.4 and 4.3.6 suggest, RE in older adult digital health focus more on the engagement of stakeholders instead of developers like some existing RE reviews [41, 42]. Overall, we recommend to select RE frameworks that balance stakeholder inclusivity with project scope, ensuring alignment with ethical and regulatory constraints.

*5.1.2. Domain-Specific RE Activities for Older Adult Digital Health Solutions*

In Table 18, we summarize key digital health (DH) solutions, commonly reported RE processes involved from our primary studies, and the contribution and quality of each. The "Strengths" and "Key Challenges" are the common strengths and challenges summarized by the authors after analysis. We have selected some high-quality evidence examples from our primary studies (average quality $\geq 3.5$). The number of studies this column can represent the overall quality of each digital health solution research to a certain degree. Our quality table can be found in the supplementary documents.

As is shown in Table 18, **home-based support** studies normally use human-centric RE framework and have a good understanding of human-centric needs. However, many of them do not have a real system implemented in older adults' homes as it is shown in section 4.3.5. We recommend for home-based DH,

| Digital Health Solutions | Common RE Frameworks | Recommended RE Activities | Strengths | Key Challenges | Evidence Base |
|---|---|---|---|---|---|
| Home-Based Support | Human-centric RE | Longitudinal user testing, Clinical validation workshops | Human-centric Needs Understanding | Person Hour Cost | S4, S5, S13, S14, S21, S31, S37, S41, S42, S48, S57, S62, S67 |
| Cognitive and Mental Health Support | Human-centric RE | Inclusive design workshops, Caregivers opinions | Mental Health Care Gap, User Empathy | Lack of Actual User Data, Representation Bias | S4, S9, S13, S21, S62 |
| mHealth Apps | Agile RE | Prototype Testing with Users | Medical Health Care, User Engagement | Adaptive UI, Personalisation | S2, S18, S52, S56, S66 |
| AI-based Predictive Analysis | Human-centric RE, Goal-Oriented RE | Stakeholder Workshops, Safety Analysis | User Engagement, Robustic Features | Human-centric Needs, Data Privacy | S7, S9, S18, S24, S32, S45, S46, S60 |
| Medication Management | Formal Models | Scenario-Based Modelling, Prototype Testing | Key Value of Dev mApp for Various Domain | Personalisation | S6, S64 |

Table 18: Key Digital Health Solutions Analysis

adopting human-centric RE to engage human-centric needs and bridge the gap of lack real systems by having clinical validation workshops and longitudinal user testing. In **cognitive and mental health support** DH domain, the commonly used RE framework is human-centric RE, resulting in good mental health support and the demonstration of user empathy. The limitation lies in the lack of real user data and representation bias. Although this is a common issue in mental health digital health (DH) due to the sensitivity of mental health data, the results in section 4.2.3 have shown the significance of achieving good representation by involving multiple types of stakeholders. We recommend inclusive design workshops with older adults of diverse backgrounds and caregivers to gain a better understanding and representation. For **mHealth Apps**, the common RE framework used is Agile RE involves interviews and use cases. As it has been shown in section 4.3.5, some mHealth Apps studies lack requirements utilization across the system development stages. The common limitations reported are a lack of an adaptive UI and personalization. We recommend using RE processes that engage users, represent their personalized requirements, and incorporate testing based on users' integration requirements. For **AI-based predictive analysis**, they normally use Human-centric RE and Goal-Oriented RE, which makes their features robust [14]. The common concern is data privacy, which is related to the nature of AI-based algorithms. We suggest using safety analysis with requirements to build trust and follow appropriate guideline to manage the data collection and utilization methods. The AI-algorithms and data tools can be found in section 4.2.5. **Medication management DH** generally use formal models RE. Their benefits reported include the requirements can be reused for the development of other domain apps in the future but reported to be lack of personalisation. We suggest adopting scenario-based models and conducting iterative prototyping with real users.

### *5.1.3. RE Processes Reported for Older Adult Digital Health Solution Features*

Figure 11 highlights our key findings of the correlation between RE Process and digital health solution features. Consistent with existing literature [43, 44], our review found that **the most commonly used techniques for requirements collection** in DH systems for ageing people are interviews, workshops/observations, and surveys. Interviews and surveys are widely applicable across various studies for DH systems due to their effectiveness in gathering qualitative and qualitative insights and understanding user needs. Compared researcher in DH domain, workshops are more commonly used by RE and SE domain researchers as they enhance the collection of participants' perspectives [12, 45]. Observation studies are more common in ageing care digital health RE, which is possibly related to the accessibility of collecting data with ageing participants in that way. As shown in Figure 11, the use of interviews, workshops/observations, and surveys are by far the most commonly used techniques in our selected primary studies, especially for applications that require high - level interactions with older adults, suggesting a growing trend towards participant - prioritized techniques in RE. Very limited use has been made of video analysis, rapid prototyping, and document analysis, suggesting these may be less relevant techniques to use in this domain.

Most existing digital health studies **still focus on the requirements that are brainstormed or proposed based on clinicians' experience** with patients or patients' medical records, rather than elicited from patients' own qualitative input like interviews and workshops [46, 47, 48]. Additionally, audio and video analysis techniques are particularly prevalent in requirements prioritization for classic AI-based digital health systems, such as smart homes, care robots, and natural language processing (NLP) voice assistants. This is

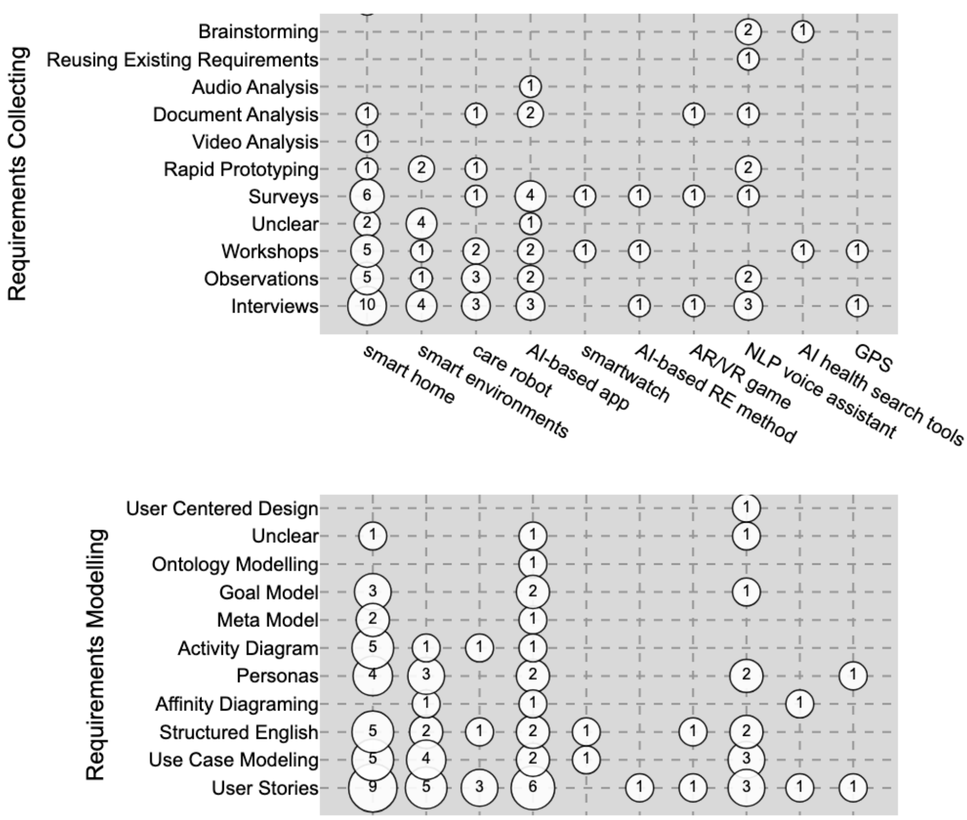


Figure 11: RE processes VS Ageing care Digital Health Domain

consistent with data obtained in existing research on digital health design [20, 49, 50]. This can be attributed to the abundance of existing multimedia data, which supports these methods. As can be noticed in Figure 11, generally, the more a system requires software engineering (SE) knowledge, the more participant-based RE techniques and multiple RE techniques are used. In contrast, the more a system relies on health knowledge, the more analysis-based RE techniques are used and the fewer RE techniques are employed overall. This trend in RE research shows a sequential pattern. Initially, digital health domain researchers have recognized the importance of applying RE techniques, and gradually, with the assistance of SE domain researchers, the field is moving towards more comprehensive requirements management and verification processes. When developing AI-, VR-, NLP- and GPS-based systems, we found higher prevlance in use of brainstorming, prototyping, and observation-based techniques.

The **most common RE models used** include user personas [51], user stories [52], use cases [52], and various semantic models [53]. Heyn et al. have mentioned that using RE conceptual models can improve contextual definitions, data attributes, performance definition and monitoring, and the impact of human factors on system acceptance and success [18]. Nazir et al. and Ahmed et al. have verified that NLP - based and Large Language Model (LLM) - based requirements engineering can greatly reduce the amount of rework and improve the quality of the system [54, 55]. Our results corroborate the findings of previous work in user requirements modelling [51, 52]. Some previous studies have suggested that personas can also be more useful than user stories for understanding the user as a whole, while user stories can help developers understand and empathize with the users emotionally, and use cases focus on specific tasks and requirements [56, 57, 58]. As is shown in Figure 11, compared to other RE models, user stories and other description-based RE models remain the most popular choice for most older adult digital health studies, suggesting these more user-centred and human-centred RE modelling techniques are good choices in this domain.

Our review found that **more complex and technical approaches, such as meta-modeling or ontology modeling**, are less frequently utilized for RE for older adult digital health solutions. Semantic models, including ontology models, conceptual models, and meta-models, represent the meaning of requirements in a formal or semi-formal way. They help to clarify and specify requirements in a way that is more precise and unambiguous [59]. In Figure 11, the low adoption of such models in our primary studies can be explained in part by the time and resource availability in RE processes for older adults' digital health systems. It may also be related to the nature of the digital health domain, where users' needs are diverse and software design teams are smaller than those in large-scale, distributed projects. However, we also think the use of complex and technical approaches is an emerging trend that shows great potential. As adoption of AI-powered technology increases, it may become more practice in the coming years. It is important to adopt such models in studies because by creating a common semantic vocabulary and ontology, which can enhance knowledge reusability, enabling different stakeholders to better communicate and understand the requirements.

### *5.2. Recommendations for Future Research*

**System Advancement:** Approximately 45% of the studies reviewed have emphasized the importance of advancing the state of current system design using better requirements. Studies S38 and S55 specifically highlighted the potential benefits of further developing the system into a multi-platform solution to accommodate more diverse users and adding functionalities such as recovery and early mobility information. Several studies (eg. S11, S28, S34) have identified inadequacies in using longitudinal studies for understanding the evolving behaviours and needs of senior end users over time. Future research should examine system adaptability for seniors with diverse needs, including vision, hearing, mobility impairments, pain, and dementia.

**RE Enhancement & Guideline Improvement:** Fourteen studies suggest improving co-design to better understand true needs, and real-time adaptive telecare functionalities, and enhance the interoperability of software agents. Study S50 specifically focuses on addressing the needs of different generations of older adults. Participant bias has been highlighted by eight studies, including S58, which proposes the use of empathy to understand different groups in participatory design, and S30, which recommends improving the balance of participant data to consider a comprehensive user group in RE. Five studies have mentioned the need for RE model improvements, such as incorporating user stories for non-English speakers as noted in study S7. Additionally, study S12 emphasizes the need for guideline improvement to understand better the trade-offs between needs, technical limitations, and costs.Future studies should aim to: 1) evaluate the effectiveness of formalized RE processes in software development; 2) propose guidelines for RE in agent-based digital health systems for disease diagnosis, health monitoring, and promoting healthy fitness and lifestyle; and 3) explore the dynamics of relationships through qualitative research, including interviews and focus groups with senior users and their caregivers or clinicians. Defining, understanding, and modelling these conflicts can guide the design of technologies that support not only the functional and clinical needs but also the emotional and social well-being of senior users. The relationships between users, particularly caregivers and families, and their influence on senior users are also of interest.

**Focus on Diverse Human Needs:** Incorporating diverse human aspects is crucial for effective digital health software for older adults. Classic studies have highlighted the importance of socio-technical factors, including emotional and psychological impacts. Eleven studies, including S6 and S67, suggested that adding personalized tips, such as drug information, meals, beauty tips, and clinical goals, can be beneficial. Studies S15, S41, S4, S33, and S45 each proposed diverse needs that should be better considered in future work. Additionally, the current studies that have applied human aspects have left a significant space for future exploration due to the limited types of human aspects they adopted and their uneven application across different studies. Future research should thus focus on 1) further development of human aspects in aged care digital health software, especially for clinical goals, emotional goals, psychological factors, and loneliness. Human aspects such as culture, age, language, mild mental health conditions, and education level significantly influence technology adoption and usage. They should also 2) investigate different methods for capturing these diverse factors and integrating them into the design of healthcare technologies. For instance, cultural considerations can impact the acceptance of smart home devices, while language and educational differences can affect the usability of health management applications. 3) utilize advanced statistical methods and machine learning algorithms to analyze the data, identifying trends and patterns that can inform the development of adaptive and responsive AI solutions.

**Data-driven RE:** A further suggestion from our synthesis of current study gaps is to focus on data-driven RE modelling in developing adaptive personas and RE models that are specifically tailored to local and target aged care groups. This involves addressing 2 main research topics: 1) generating personas and RE models based on published studies and making them adaptive for specific aged care groups, and 2) the understanding and development of the data-driven personalized needs of senior users. To generate personas and RE models based on published studies, future studies should explore methodologies for mining existing literature and data sources to construct initial personas. These personas should then be validated and adapted through local user studies, ensuring that they accurately reflect the needs and behaviours of the target population.

**Data-driven Health Solutions:** Understanding the personalized needs of senior users requires comprehensive data collection and analysis. Future research should focus on identifying key data sources, such as electronic health records (EHRs), surveys, and observational studies, to capture a wide range of user preferences and requirements. Specific areas of interest could include personalized meals and beauty tips, which can significantly enhance the quality of life for senior users. By leveraging data analytics and user feedback, researchers can develop tailored recommendations that meet the unique needs of individuals.

**Integrated solutions for multiple health and wellness challenges:** Many proposed solutions target a single or small number of health and wellness challenges that ageing people face. This means multiple, sometimes incompatible, and very differently designed and realised solutions result from multiple RE exercises. Future work should explore capturing diverse, related health and wellness challenges ageing people face and the requirements for integrated, holistic supporting applications. These will need personalisation to diverse human aspects of different people, including living conditions, background, physical and mental challenges, and preferences.

## 6. Threats to Validity

Although this systematic literature review (SLR) strictly followed the recognized methodology for performing SLRs within the software engineering domain [28, 60], it is crucial to admit that our review indeed has multiple limitations mainly associated with our search strategy and the data extraction process. In this section, we will investigate the potential elements that could impact the credibility of our research.

Even though we conducted a comprehensive search across eight relevant databases using automated and manual strategies, our review still has the construct validity in the search and study-selection process, as other SLRs stated [61]. A noteworthy limitation is that the inconsistent terminology used in the search can lead to potential suboptimal inclusion. To address this risk, we identified and addressed multiple terms for "aged care" and "geriatric syndromes," as well as "needs" and "requirements," by searching across terms used by researchers from various fields, highlighting the gaps between SE, digital health, and medicine. Additionally, we followed the PICO criteria and searched for the key terminologies in the full text to increase the inclusion scope.

To mitigate internal validity threats, we developed a detailed SLR protocol, reviewed by all authors, which guided the search process. We optimized the search string across multiple databases, using the systematic literature review tool "Covidence" for several filtering rounds to minimize selection bias, starting from titles and abstracts to full paper reviews. We developed a data extraction form aligned with our RQs and conducted a pilot test. All authors performed data extraction for a subset of studies, and results were compared for consistency. Deliberative discussions ensured accurate categorization and presentation, reducing bias in our analysis.

All authors reviewed and refined all the attributes until they reached a consensus. To present the data extraction outcomes, we utilized a combination of different graphical representations and textual explanations. This approach serves to enhance the connection between the data we extracted and the conclusions we drew, thereby strengthening the overall integrity of our study.

## 7. Conclusion

We conducted a systematic literature review of requirements engineering for digital health software targeting senior users. After searching and filtering, we identified 69 primary studies. We identified various types of studies, health and well-being issues, a range of senior participants, and human aspects studied. We analysed the RE techniques, requirements modelling and validation approaches, and whether the requirements were used to build a system. We identify a range of strengths, limitations and gaps in the primary studies and potential future research directions.

## 8. Declaration of generative AI and AI-assisted technologies in the writing process

During preparation, Yuqing Xiao used ChatGPT and Grammarly for grammar correction, then reviewed and edited the content and takes full responsibility for the content of the published article. Xiao and Grundy are supported by ARC Laureate Fellowship FL190100035.

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## Appendix A. List of Selected Primary Studies

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**S16** A. Koshima, V. Englebert, M. Amani, A. Debieche, A. Wakjira, A Model-Driven Engineering Approach for the Well-Being of Ageing People, in: Advances in Conceptual Modeling. ER 2016 Workshops AHA, MoBiD, MORE-BI, MReBA, QMMQ, SCME and WM2SP. Proceedings: LNCS 9975, 2016, pp. 21 – 9

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**S34** T. K. C. Umm e Mariya Shah, Y. Mehmood, A Usability Evaluation Instrument for Pain Management Mobile Applications: An Elderly's Perspective, International Journal of Human–Computer Interaction (2022) 1–17

**S35** K. Schäfer, P. Rasche, C. Bröhl, S. Theis, L. Barton, C. Brandl, M. Wille, V. Nitsch, A. Mertens, Survey-based personas for a target-group-specific consideration of elderly end users of information and communication systems in the German health-care sector, International Journal of Medical Informatics (2019)

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