Empowering Older Adults through Smart Home Automation for Better Quality of Life

Antonio Jorge Oliveira Pereira
Univ. Federal de São João del-Rei
São João del-Rei, Minas Gerais, Brazil
ajop19@gmail.com

Franciele Alessandra de Paula
Univ. Federal de São João del-Rei
São João del-Rei, Minas Gerais, Brazil
franciele.depaula07@gmail.com

Thalia Bianca da Silva Melo
Univ. Federal de São João del-Rei
São João del-Rei, Minas Gerais, Brazil
bsm.thalia@gmail.com

Dárlinton B. Feres Carvalho
Univ. Federal de São João del-Rei
São João del-Rei, Minas Gerais, Brazil
darlinton@acm.org

Matheus Carvalho Viana
Univ. Federal de São João del-Rei
São João del-Rei, Minas Gerais, Brazil
matheuscviana@ufsj.edu.br

ABSTRACT

Population ageing comes with multifaceted challenges that stretch beyond health-related advancements and demographic shifts. Older adults are confronted by significant healthcare obstacles, requiring special needs, remarkably in their home environment. The present study draws upon Smart Home Automation technology to develop an Ambient Assisted Living (AAL) prototype aimed at enhancing daily living activities, health monitoring and independence for older adults, thereby improving their overall quality of life. Employing the Design Science Research (DSR) method of research combined with the Double Diamond process of design, this study intends to create and evaluate a solution particularly tailored to the needs of older adults, furthering a more safe and dignified ageing experience.

KEYWORDS

Smart Home, Ambient Assisted Living, Design Science Research, Assistive Technology, Elderly Care

1 INTRODUCTION

As people worldwide live longer, a growing need emerges for intensified research and innovation efforts to address the demands of the so-called ageing population. The Decade of Healthy Ageing initiative, launched in 2020 by the World Health Organization (WHO) [17], represents the global commitment to the well-being of older people. This initiative underscores the importance of fostering policies and advancements that enhance health outcomes and overall quality of life (QoL) for the aged population.

While the QoL is initially an individual perception [15], its dynamics shift in old age as various factors heighten vulnerability. These include physical and mental decline, retirement from the workforce, family fragmentation, and social isolation due to the loss of contemporaries. Additionally, the desire for meaningful social relationships and the preservation of autonomy emerge as critical factors shaping the QoL experience of older adults.

In Brazil, recent data from the Brazilian Institute of Geography and Statistics (IBGE) [7] indicate a notable trend: an increasing number of older adults are opting to live alone, exceeding 4 million. This preference may stem from factors such as the death of relatives, marital separation, the pursuit of individuality, and economic constraints preventing family support. Remarkably, lonely older adults in such situations often confront significant health and safety challenges, highlighting the intricate balance between personal choices and societal influences on their QoL.

Digital Information and Communication Technologies (ICTs), including software innovations, play a pivotal role in addressing these challenges by facilitating access to healthcare and social connections through virtual networks, promoting healthy aging, and enhancing community well-being [8]. Ambient Assisted Living (AAL) [1] integrates these technologies into individuals' daily living and working environments, enabling them to maintain activity, social connections, and independence as they age. This approach enhances the safety and autonomy of elderly individuals.

In light of this context, smart home and Internet of Things (IoT) technologies are promising alternatives to support elderly individuals, enhancing their QoL. According to the IEEE, IoT refers to "a network of items—each embedded with sensors—which are connected to the Internet" [6]. The "smart home" concept involves the integration of different services within a home using a standard communication system. It ensures an economical, secure, and comfortable home operation and includes a high degree of intelligent functionality and flexibility [11].

The purpose of this study is to innovate by proposing a smart home automation solution designed to mitigate the challenges typically encountered by ageing population individuals who live independently, with the goal of enhancing their overall QoL.

2 RELATED WORKS

The adoption of AAL technology has been extensively analyzed in recent years, particularly concerning its potential benefits and challenges for older adults. Li et al. [9] conducted a systematic literature review to explore the motivations, barriers, and risks associated with smart home adoption. Their study highlights the importance of healthcare, energy efficiency, and home security as key drivers for adoption, while also identifying significant barriers such as privacy concerns, technology anxiety, and financial issues. These factors are critical when considering the implementation of smart home solutions tailored for elderly care.

In: Proceedings of the Brazilian Symposium on Multimedia and the Web (WebMedia'2024). Juiz de Fora, Brazil. Porto Alegre: Brazilian Computer Society, 2024.

ISSN 2966-2753

From a healthcare perspective, medication adherence among older adults can be improved through AAL solutions, as noted by Choukou et al. [2] in their systematic review. These technologies play a crucial role in managing health conditions and preventing adverse outcomes. Features such as automated reminders, smart pill dispensers, and real-time health monitoring support adherence to prescribed regimens, thereby enhancing overall medication management and promoting better health outcomes.

As analyzed by Ghorayeb et al. [4] two recent systematic reviews conclude that there is a absence of literature investigating older people's experiences of living with smart home technology or involves them in the design of the technology, and highlight that older people's views of smart home technologies change between the pre- and post-implementation stage. Ghorayeb et al. [5] then propose the development of a smart home interface for the elderly using co-design, a participatory design process where the elderly participants collaboratively produced a user-friendly prototype that presents data in an easy and meaningful way to assist in the health and well-being of the elderly and in monitoring their health status.

This study presents features similar to those of Ghorayeb et al. [5], such as health monitoring, and adds additional functionalities. Unlike the collaborative approach, our objective is to first develop the prototype and then evaluate the interface with users. This sequential process allows for feedback on more concrete solutions, ultimately enhancing the quality of the final product.

3 METHODOLOGY

Adopting the Design Science Research (DSR) approach known for its academic rigor, this study seeks to construct and evaluate artifacts intended to solve relevant problems. Additionally, integrating the Double Diamond process and diverse software engineering tools recognizes the software-centric nature of the proposed artifact, facilitating a creative exploration of the problem domain and the streamlined development of innovative software solutions. Thus, the methodology employed for this study integrates DSR with the Double Diamond approach, utilizing User-Centered Design (UCD) tools such as Personas, Empathy Maps, and Use Case Diagrams.

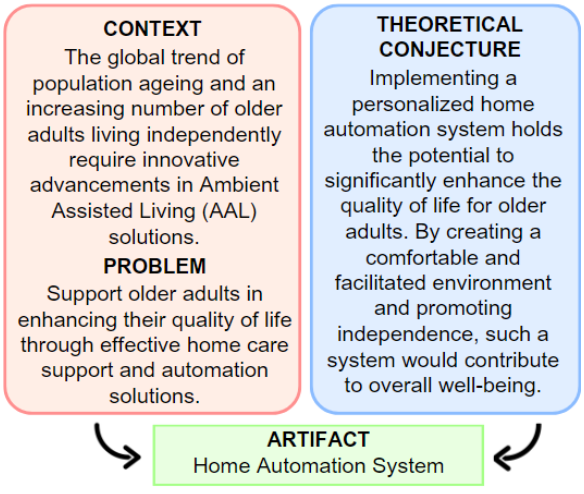

Figure 1: DSR-model employed in this study.

DSR methodology can guide the creation of cutting-edge ideas and the definition of technical capabilities and products through the iterative development process of artifacts [12]. It aims to achieve dual objectives: developing practical solutions to solve specific problems in defined contexts and generating new technical and scientific knowledge. This approach emphasizes iterative cycles of design, development, and evaluation to foster the creation of innovative solutions that not only address immediate challenges but also contribute to advancing knowledge within the field. Thus, Figure 1 depicts the DSR-model underpinning this research.

In addition to DSR, we also applied the Double Diamond process, which is popularized by the Design Council [16], a UK-based organization focused on promoting the use of design to enhance products, services, and environments. This approach is a structured way to tackle complex challenges and find creative solutions. The process is divided into four distinct phases:

(1) **Discovery**: Understand the problem through research and empathy with users to identify needs, opportunities, and potential solutions.
(2) **Definition**: Synthesize insights to clearly define the problem scope and goals for solution creation.
(3) **Development**: Generate and explore ideas through brainstorming, prototyping, and experimentation.
(4) **Delivery**: Refine, develop, and implement the final solution, including detailed prototyping and user testing.

The four phases, in pairs, comprise the "Double Diamond", which represents the iterative approach of the design process, where divergence (broad exploration) and convergence (refinement and selection) are alternated twice throughout the process. The goal is to deliver a comprehensive and user-centered strategy to solving complex design problems.

For this reason, techniques such as creating personas and developing empathy maps are employed to gain a deeper understanding of users and their needs. These UCD elements provide a better understanding of users, allowing for precisely identifying system requirements based on their expectations, desires, and behaviors.

The concept of personas is widely used to understand better and communicate user groups' behaviors, thoughts, goals, and motivations in product design [3]. Personas are fictional representations, composite archetypes derived from observed behavior patterns identified during research. They formalize and humanize user characteristics, aiding designers in making informed decisions throughout the design process.

Empathy maps, on the other hand, are a helpful tool that enables us to dive deeper into the emotional world of users. They provide a visual representation of users' experiences, feelings, frustrations, and concerns. By mapping these aspects, empathy maps offer valuable insights that can guide design decisions, align designs with users' needs and expectations. Empathy maps form a robust foundation for developing user-centered solutions that meet end-users' demands and aspirations when used with personas.

Also, this study implements models from the Unified Modeling Language (UML), to more thoroughly understand user interactions and document software systems [13]. The Use Case Diagram, which graphically represents the relationships between actors (users or

systems) and use cases (system functions or processes) is essential for outlining interaction goals, specifying context, organizing system functional requirements, and modeling the flow of events, thereby furthering the understanding of system functionality and simplifying communication among project stakeholders.

Finally, the C4 model [14] a set of layer-based hierarchical diagrams that can be used to describe the architecture of a software at different levels of abstraction, is used. It is a visual documentation that has 4 layers/levels: Context, Container, Components, and Code. As the depth increases, the higher the level of detail.

4 RESULTS

The results presented in this section correspond to the initial stages of the Double Diamond process. Specifically, the current emphasis is on the Discovery, Definition, and Development phases. During the Discovery phase, extensive research was carried out to understand the challenges faced by the elderly living independently. This involved data collection through interviews, surveys, and literature review to identify essential needs and opportunities. Afterward, in the Definition phase, the insights acquired were synthesized to clearly define the project's scope and establish specific goals and objectives. These preliminary results laid the groundwork for the subsequent phases of design and prototyping, where the interface for the smart home automation solution could be defined.

4.1 Personas and Empathy Maps

4.1.1 ***Isabel Torres.*** Isabel, at 68 years old and retired as a teacher, has found a routine that balances tranquility with community engagement since her husband's passing. As she puts it, "There's nothing more important than looking after my physical and mental well-being, especially as I live on my own." Her morning starts peacefully as she uses her blood pressure monitor to check her blood pressure upon waking up, a ritual that ensures her health remains stable, particularly important given her hypertension. After that, she is fond of reading the newspaper over a warm cup of coffee. Throughout the day, she actively gets involved in local book clubs, social events, and contributes to food drives, in addition to volunteering at an animal shelter. In the evenings, Isabel connects virtually with her daughter Camila and other loved ones via Zoom, nurturing important emotional bonds in her life.

Her primary concerns are centered around the affordability and accessibility of various services, along with the challenge of remembering her daily health routines and appointments, given occasional memory lapses. Nevertheless, Isabel acknowledges several significant advantages in her life: enhanced daily independence and autonomy, continuous gains in health and well-being facilitated by assistive technologies. She also values the convenience offered by alerts that assist in managing both her health and schedule more effectively, enabling her to fully enjoy her retirement years.

4.1.2 ***Luís Cardoso.*** Luís Cardoso is a 75-year-old retiree who lives alone, leading an independent and active life that includes physical activities, intellectual pursuits, and relaxation. Apart from tending to his garden and enjoying hobbies such as painting and reading, Luís has a strong interest in technology and enjoys exploring new apps on his smartphone. Intrigued by smart home solutions, Luís is contemplating adopting technologies that can simplify managing his health, particularly as he manages diabetes and measures his glucose levels at least four times a day. For Luís, ensuring comfort and streamlining his daily routine are key priorities. As he puts it, "Every decision we make regarding our health is an investment in our future. It's important to choose wisely.".

His primary concerns revolve around the affordability and accessibility of support services, as well as feelings of loneliness stemming from living alone without immediate companionship or support during emergencies. However, Luís recognizes the numerous benefits of integrating such technologies into his life: they contribute to his independence and autonomy, improve his overall health and well-being through continuous health monitoring, and provide support in seeking help during emergencies. These technologies are beneficial to his emotional well-being and QoL

4.2 Use Case Diagram and C4 Model

Below, the initial versions of the diagrams that play a fundamental role in the construction of the proposed system can be found. These diagrams are valuable for clarifying system functionality and for understanding user interaction with the system and with external software, they guide structured system development, ensuring that all user requirements are met.

The Use Case Diagram (Figure 2) outlines the features the system offers, allowing a clear view of the operations that end users can perform, from safety and health monitoring to the control of environmental aspects of the house, such as lighting and temperature.

On the other hand, the Container diagram at the second level of the C4 model (Figure 3) simplifies the architecture, detailing the technologies employed and illustrating communication flows. In this scenario, elderly users interact with a tablet-based user interface application that enables them to access health data, control home IoT devices, and receive notifications. Furthermore, users can engage with medical monitoring devices, which gather health data and transmit it to the backend server.

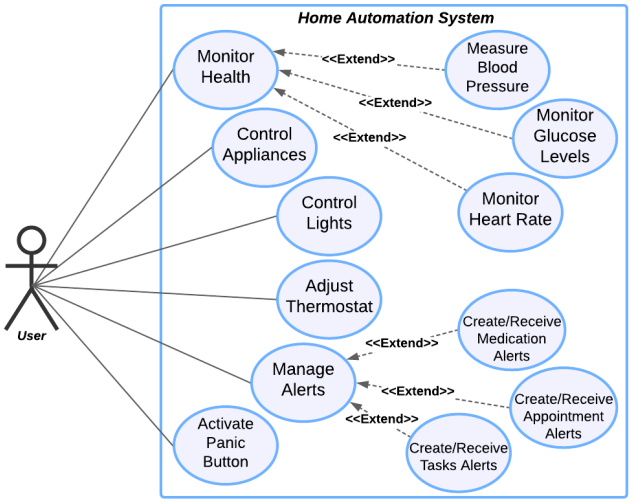

Figure 2: Use Case Diagram illustrating the main functionalities of the system.

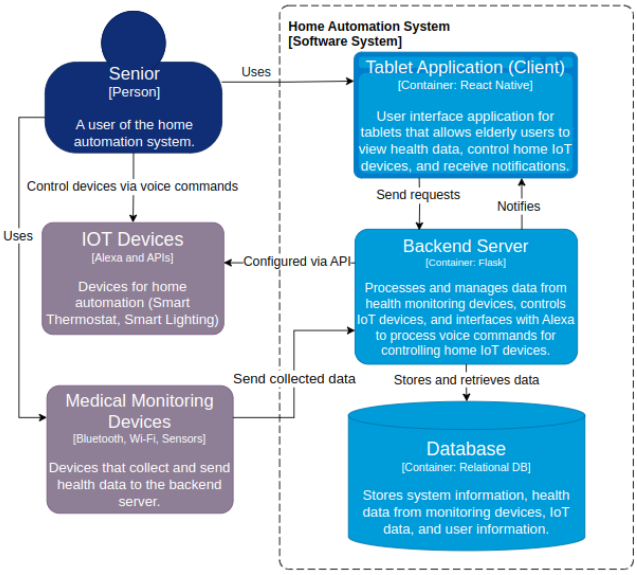

Figure 3: C4 Model - Container Level of the proposed system.

The backend server assumes a central role in processing and managing data sourced from health monitoring devices. It also governs IoT devices within home environment and interfaces with Alexa for executing voice commands to control these devices. This integrated setup ensures elderly users can seamlessly manage both health monitoring and home automation tasks.

4.3 Prototype Development

In the prototyping phase of the automation system, the key screens and workflows are being meticulously developed. A high-fidelity prototype was created using the Figma[1] tool to build an interactive app prototype. It accurately encapsulates both the appearance and functionality of the proposed system, intensifying the comprehension of user interactions with the interface.

Figure 4 depicts the main screen of the system. In pursuit of an accessible user interface for older adults, established accessibility standards were rigorously adhered to. Besides, design practices from Human-Computer Interaction (HCI) user evaluation studies focused on healthcare specifically for Elderly were meticulously examined and adopted. This approach was informed by findings such as those from Zhou et al. [19], which highlighted the superior performance of simple line icon buttons. The color scheme of the UI was designed based on preferences identified among elderly users, favoring warm hues, high lightness, and medium saturation, as detailed by Liu et al. [10]. The design of temperature sliders, incorporating horizontal sliders with gradient color bars, aligns with the preferences observed in elderly users, as outlined by Yu et al. [18]. Also, a panic button is always displayed in the UI, allowing the user to request immediate help whenever needed. This not only has the potential to save lives but also promotes a sense of security and confidence in older adults, family members, and caregivers.

[1]https://www.figma.com

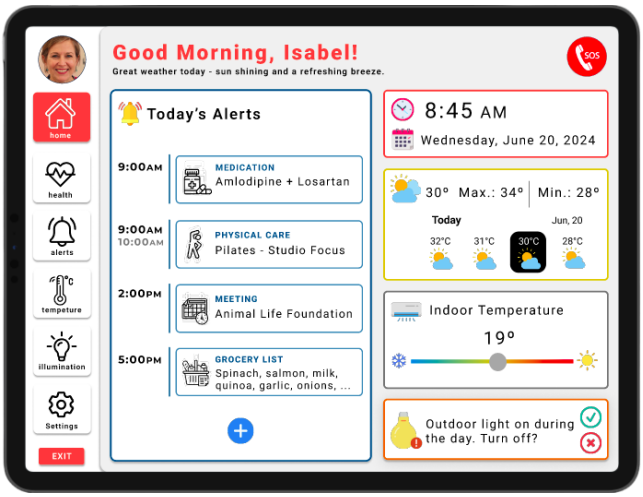

Figure 4: Prototype main screen of the proposed smart home automation system.

5 DISCUSSION AND NEXT STEPS

This article has outlined ongoing research focusing on the development of a smart home system tailored to meet the needs of elderly individuals. The proposed system aims to enhance health monitoring, ensure home safety, manage daily activities and appointments, and integrate smart home appliances effectively.

To ensure the highest level of precision in our work, we are committed to completing the final phase of the Double Diamond approach, which involves refining the development processes. Currently, we are in the process of planning the validation of our solution, employing established methodologies. The overview plan can be summarized as follows: 1) creating an online questionnaire to invite participants, delimiting our target demographic; 2) conducting usability tests to evaluate the UI through practical user scenarios; and 3) conducting a questionnaire to measure overall user acceptance of the proposed technology. This phase is crucial to validate our design choices and ensure that the smart home system effectively meets the needs and expectations of elderly users.

The relevance of this research lies in its potential to significantly improve the QoL for older adults through innovative smart home technologies. Our system addresses critical needs such as health monitoring, safety assurance, and daily activity management, fostering independence and well-being in a supportive living environment. The social impact is profound, encouraging dignified aging and supporting autonomy within their homes. Ultimately, our goal is to contribute both to academic knowledge and to real-world improvements that empower older generations.

6 ACKNOWLEDGMENTS

We extend our sincere gratitude to the university for their unwavering support throughout this research. Their resources were instrumental in the successful completion of this study. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Finance Code 001.

REFERENCES

[1] Ageing Well in the Digital World. [n. d.]. *Ageing Well in the Digital World.* www.aal-europe.eu

[2] M.A. Choukou, A. Polyvyana, Y. Sakamoto, and A. Osterreicher. 2021. Ambient Assisted Living Technologies to Support Older Adults' Health and Wellness: A Systematic Mapping Review. *European Review for Medical and Pharmacological Sciences* 25, 12 (2021), 4289–4307. https://doi.org/10.26355/eurrev_202106_26135

[3] Alan Cooper, Robert Reimann, David Cronin, and Christopher Noessel. 2014. *About Face: The Essentials of Interaction Design* (4 ed.). Wiley, Indianapolis, IN.

[4] Abir Ghorayeb, Rob Comber, and Rachael Gooberman-Hill. 2021. Older adults' perspectives of smart home technology: Are we developing the technology that older people want? *International Journal of Human-Computer Studies* 147 (2021), 102571. https://doi.org/10.1016/j.ijhcs.2020.102571

[5] Abir Ghorayeb, Rob Comber, Rachael Gooberman-Hill, et al. 2023. Development of a smart home interface with older adults: multi-method co-design study. *JMIR aging* 6, 1 (2023), e44439.

[6] IEEE. [n. d.]. *Internet of Things.* https://www.ieee.org/iot

[7] Instituto Brasileiro de Geografia e Estatística – IBGE. 2023. *Dados sobre População do Brasil, PNAD (Pesquisa Nacional por Amostra de Domicílios).* https://biblioteca.ibge.gov.br/

[8] N. Kasoju, N.S. Remya, R. Sasi, S. Sujesh, B. Soman B, C. Kesavadas, C.V. Muraleedharan, P.R.H. Varma P.R.H., and S. Behari. 2023. Digital health: trends, opportunities and challenges in medical devices, pharma and bio-technology. *CSIT* 11, 1 (2023), 11–30. https://doi.org/10.1007/s40012-023-00380-3

[9] Wenda Li, Tan Yigitcanlar, Isil Erol, and Aaron Liu. 2021. Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework. *Energy Research Social Science* 80 (2021), 102211. https://doi.org/10.1016/j.erss.2021.102211

[10] Bai Liu and Chuncheng Wang. 2024. Elderly-Centric Chromatics: Unraveling the Color Preferences and Visual Needs of the Elderly in Smart APP Interfaces. *International Journal of Human-Computer Interaction* (04 2024). https://doi.org/10.1080/10447318.2024.2338659

[11] R. Lutolf. 1992. Smart Home concept and the integration of energy meters into a home based system. In *Seventh International Conference on Metering Apparatus and Tariffs for Electricity Supply 1992.* 277–278.

[12] Mariano Pimentel, Denise Filippo, and Thiago Marcondes dos Santos. 2023. Design Science Research: pesquisa científica atrelada ao design de artefatos. *Educação e Cibercultura: metodologias de pesquisa, curadoria e inovação pedagógica* 3, 1 (2023), 37–61. https://doi.org/10.34627/vol3iss1pp37-61

[13] James Rumbaugh, Ivar Jacobson, and Grady Booch. 1998. *The unified modeling language reference manual.* Addison Wesley.

[14] Simon Brown. [n. d.]. *The C4 model for visualising software architecture.* https://c4model.com/

[15] The WHOQOL Group. 1994. *The Development of the World Health Organization Quality of Life Assessment Instrument (the WHOQOL).* Springer, Berlin, Heidelberg, 41–57. https://doi.org/10.1007/978-3-642-79123-9_4

[16] UK Design Council. [n. d.]. *The Double Diamond.* https://www.designcouncil.org.uk/our-resources/the-double-diamond

[17] World Health Organization (WHO). 2020. *Decade of Healthy Ageing.* https://www.who.int/initiatives/decade-of-healthy-ageing

[18] N. Yu, Z. Ouyang, and H. Wang. 2022. Study on Smart Home Interface Design Characteristics Considering the Influence of Age Difference: Focusing on Sliders. *Frontiers in Psychology* 13 (2022), 828545. https://doi.org/10.3389/fpsyg.2022.828545

[19] C. Zhou, Y. Dai, T. Huang, H. Zhao, and J. Kaner. 2022. An Empirical Study on the Influence of Smart Home Interface Design on the Interaction Performance of the Elderly. *International Journal of Environmental Research and Public Health* 19 (2022), 9105. https://doi.org/10.3390/ijerph19159105