TUM Entrepreneurship Research Institute
TUM School of Management
Technical University of Munich

How can a co-created and co-evaluated digital tool support the mobility of older people?

Master's Thesis
at the TUM School of Management
at the Technical University of Munich

Supervisors: Prof. Dr. Anne Tryba
David Nawrath M.Sc. & Dr. -Ing. David Duran
Technical University of Munich
TUM Entrepreneurship Research Institute
Arcisstraße 21
80333 München

Submitted by: Lennart Müller (03767541)
Steinhauser Straße 3
81677 München

Study program: Management & Technology (M.Sc.)

6 November 2024

Chair of Urban Structure and Transport Planning

Univ.-Prof. Dr.-Ing. Gebhard Wulfhorst

Arcisstr. 21

80333 München

Approval of Master's Thesis

Mr. Lennart Müller

03767541

How can a co-created and co-evaluated digital tool support the mobility of older people?

Start and end date of Master's Thesis: 20.05.2024 – 20.11.2024

1. Motivation / Background and Objectives

The world's population is aging at an accelerating rate, resulting in challenges for older people in terms of mobility, access to basic services, and social isolation (Altenberichtskommission, 2010). Mobility is a cornerstone of general life satisfaction and active aging and directly impacts people's independence, autonomy, quality of life, and health (Mollenkopf, 2005; Wong, Szeto, Yang, Li, & Wong, 2018; Parker, Baker, & Allman, 2002; Taylor, Buchan, & van der Veer, 2019). Reduced mobility can lead to social withdrawal, declining morale, and an increased risk of depression and loneliness in older people (Atkins, 2001).

It is, therefore, essential that future transport policies prioritize the mobility needs of older people. Social participation of older people should be supported to ensure that they continue to participate in civic and social life, to take part in community activities, and to maintain human contacts, which can improve their health, well-being, and quality of life from a social inclusion perspective (Fatima & Moridpour, 2019; Dickerson et al., 2007; Wong et al., 2018).

In addition, the gradual introduction and integration of older people into the digital world can not only improve their mobility but also represent a general step towards digitalization. The use of digital technology (DT) can facilitate access to transportation options and information and thus increase the independence of older people. It can also encourage social activities such as visiting family, shopping together, or attending group events (e.g., senior meetings) to keep this age group active and mobile. All of this underlines the importance of a comprehensive approach to DT for older people (Pekkarinen Satu, Melkas Helinä, 2019).

2. Research Question and Aim

Understanding how older adults acquire and use (new) DT, considering their socio-technical environment, past habits, and current attitudes, is essential to address digital inequalities in later life. This is particularly important given the aging population (Neves & Mead, 2021). Therefore, involving older adults in the design process and exploration of DT is essential to improve well-being (Mannheim et al., 2019). Older people over the age of 65 are not a homogeneous group. Like all people, they have different backgrounds, abilities, motivations, and personalities (Mannheim et al., 2019), so more attention must be paid to intersectionality. Different aspects of social inequality can reinforce each other, making access to DT even more difficult (Fang et al., 2019). This means that researcher and designers must deal with a wide age range of older people with different technological abilities and needs (Harvey et al., 2019).

To achieve this, a stakeholder analysis will be conducted according to the principles of co-creation. It is an open process of participation, exchange, and collaboration with relevant stakeholders within a design process to ensure that the product meets the needs of its users (Voorberg et al., 2015). The involvement of older people in the design process and research of DT is crucial if the technology is to deliver on its promise to improve their well-being (Mannheim et al., 2019). It can potentially avoid the mismatch between what is developed and what is adopted and used (by older people) (Greenhalgh et al., 2013). The aim is to define various (innovative) solutions for older people that are tailored to their needs. The framework in which the co-creation process will be carried out is a mixture of focus groups and workshops.

Focus groups are conducted by researchers who gather a group of people (around four to fifteen) to talk about a specific topic to gain insight into the participants' complex personal experiences, beliefs, perceptions, and attitudes through facilitated interaction (Cornwall & Jewkes, 1995; O.Nyumba et al., 2018). This approach of gathering qualitative data is relatively open and exploratory, offering insights into the specifics of actual usage and the perceived benefits and drawbacks of DT across various domains (Krueger, 2014).

Workshops, on the other hand, are a common method in collaborative design research, facilitating the co-creation of innovations and the assessment of propositions. They can foster individual learning and innovative problem-solving and focus on how participants express themselves (Westerlund, 2007). Essentially, workshops provide a clear purpose and set of goals for participants and can combine various research methods such as group discussions, creative tasks, interviews, and observations (Thoring et al., 2020). Within this framework, the co-creation process will be used to interact with the participants during the sessions in which prototypes will be elaborated.

Houde & Hill (1997) define a prototype as “any representation of a design idea, regardless of medium. This includes a pre-existing object when used to answer a design question” (p. 369). Prototypes can increase awareness of technological possibilities, build knowledge, and facilitate discussion. It can help evaluate the usability of a solution, and a distinction can be made between functional, partially functional, and non-functional prototypes (Sumner et al., 2021). An example of a non-functional prototype could be a pen and paper drawing or cardboard cutout (Ehn & Kyng, 2020; Giorgi et al., 2013).

To evaluate and compare different ideas and designs, the Multi-Actor Multi-Criteria Analysis (MAMCA) (for Mass-Participation Decision Making) (Huang et al., 2021) is suitable. MAMCA is a method that allows multiple stakeholders to be involved in a decision-making process (Huang et al., 2021). These stakeholders could include academics, governments, citizens, etc. This analysis can show the consensus and conflicts among the various groups of people representing different interests involved in the assessment. By including 'stakeholder groups' more than one evaluator can be included in a particular stakeholder group to ensure that all the voices of the group are heard rather than being represented by just one (Huang et al., 2021). This is particularly important for the group of older people as this group contains a large variation in interests, concerns, and socio-economic status (SES). A diverse group of participants with different SES is also crucial for the co-creation approach. In this analysis, different criteria are defined and weighted with each stakeholder/stakeholder group based on which the evaluation is then carried out (Macharis et al., 2009).

This work aims to develop a co-created and co-evaluated partially functional prototype of a "digital tool" for older people to see if it can increase their mobility. The exact specifications of the tool will only emerge in the process of this work through the interactions and collaboration with older people. To guide this process, the following research question has been formulated:

How can a co-created and co-evaluated digital tool support the mobility of older people?

By addressing this question, this study’s goal is to identify strategies for improving the mobility behaviors of older people using DT. The focus on co-creation and co-evaluation ensures that the solutions designed are user-centered and address the specific needs of older people.

3. Methodology

The methodology consists of three main methods: Literature review, focus groups/workshops, and evaluation through Multi-Actor Multi-Criteria Analysis (MAMCA)

The initial step is the analysis of digital literacy among older people. This will be based on a literature review that aims to show how older people engage with DT, what skills they have, and how these can influence their everyday lives and mobility habits. It will also examine what research has already been carried out, which digital concepts already exist, and what gaps exist in the current research.

The second step is to determine the needs and requirements of older people for DT to enhance their mobility. This will be done through focus groups/workshops emphasizing co-creation and elaborating prototypes. This should help to better understand the perceptions and demands of older people towards DT. In this stage, the prototypes will be non-functional or partially functional.

In the third step, the co-created prototypes will be evaluated and compared using the MAMCA (for Mass-Participation Decision Making). This method involves multiple stakeholders, including academics, governments, public transport providers, and representatives of older people. This makes it possible to include different perspectives and identify consensus and conflict between different interest groups.

Based on the results of the evaluation/MAMCA, the best prototype will be updated and selected for testing. In this stage, the prototype will be functional or partially functional to ensure appropriate testing. The prototype's success is measured using the criteria derived from the established criteria during the MAMCA, focusing on the effectiveness in enhancing the mobility behaviors of older people.

4. Expected Results

The goal of this study is to demonstrate how co-creation and stakeholder engagement can increase the acceptance and adoption of DT among older people. The result of this work should provide a comprehensive understanding of the extent to which DT can support the mobility of older people. The following key results are expected:

The literature review helps to understand the specific advantages, concerns, and requirements of older people regarding DT (for mobility purposes) and should identify gaps in the current research.

The stakeholder analysis in the form of focus groups or workshops aims to incorporate these findings into various prototypes in collaboration with the older people.

The MAMCA is used to identify the best alternative for a potential prototype of the digital mobility tool. The defined criteria of the involved stakeholders can be used for the future development of digital mobility concepts.

Furthermore, this work also aims to provide insights into how the acceptance and adoption of digital tools can be increased for older people, which can be valuable not only for mobility concepts but also for digitalization in general. The provided framework helps further research and DT development to overcome barriers to technology adoption and potentially improves the overall usability and relevance of DT among older people.

Supervision

The academic supervision is provided by Dr.-Ing. David Telmo Duran Rodas (Chair of Urban Structure and Transport Planning).

Two weeks after the day of issue the student submits a concept and a detailed structure of his work to both supervisors. Further appointments for any advisory service can be made according to necessity. No later than two weeks after the end date the candidate must give a presentation of 20 minutes with a scientific discussion followed. The presentation is part of the evaluation.

The candidate is completely responsible for all results.

Dr.-Ing. Benjamin Büttner | Dr.-Ing. David Telmo Duran Rodas

Bibliography

Altenberichtskommission. (2010). Sechster Bericht zur Lage der älteren Generation in der Bundesrepublik Deutschland - Altersbilder der Gesellschaft und Stellungnahme der Bundesregierung. 1994(November), 1–312. http://www.bmfsfj.de/RedaktionBMFSFJ/Pressestelle/Pdf-Anlagen/sechster-altenbericht,property=pdf,bereich=bmfsfj,sprache=de,rwb=true.pdf Zugriff: 2.10.2014

Atkins, W. S. (2001). Older People: Their Transport Needs and Requirements-a Summary Report. Department of Transport, Local Government and the Regions.

Cornwall, A., & Jewkes, R. (1995). What is participatory research? Social Science & Medicine, 41(12), 1667–1676.

Ehn, P., & Kyng, M. (2020). Cardboard Computers: Mocking-it-up or Hands-on the Future. In Design at work (pp. 169–195). CRC Press.

Fang, M. L., Canham, S. L., Battersby, L., Sixsmith, J., Wada, M., & Sixsmith, A. (2019). Exploring Privilege in the Digital Divide: Implications for Theory, Policy, and Practice. Gerontologist, 59(1), E1–E15. https://doi.org/10.1093/geront/gny037

Fatima, K., & Moridpour, S. (2019). Measuring Public Transport Accessibility for Elderly. MATEC Web of Conferences, 259, 03006. https://doi.org/10.1051/matecconf/201925903006

Giorgi, S., Ceriani, M., Bottoni, P., Talamo, A., & Ruggiero, S. (2013). Keeping "InTOUCH": an ongoing co-design project to share memories, skills and demands through an interactive table. International Conference on Human Factors in Computing and Informatics, 633–640.

Greenhalgh, T., Wherton, J., Sugarhood, P., Hinder, S., Procter, R., & Stones, R. (2013). What matters to older people with assisted living needs? A phenomenological analysis of the use and non-use of telehealth and telecare. Social Science and Medicine, 93, 86–94. https://doi.org/10.1016/j.socscimed.2013.05.036

Harvey, J., Guo, W., & Edwards, S. (2019). Increasing mobility for older travellers through engagement with technology. Transportation Research Part F: Traffic Psychology and Behaviour, 60, 172–184. https://doi.org/10.1016/j.trf.2018.10.019

Houde, S., & Hill, C. (1997). What do prototypes prototype? In Handbook of human-computer interaction (pp. 367–381). Elsevier.

Huang, H., Mommens, K., Lebeau, P., & Macharis, C. (2021). The Multi-Actor Multi-Criteria Analysis (MAMCA) for Mass-Participation Decision Making. https://doi.org/10.1007/978-3-030-73976-8

Krueger, R. A. (2014). Focus groups: A practical guide for applied research. Sage publications.

Macharis, C., De Witte, A., & Ampe, J. (2009). The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice. Journal of Advanced Transportation, 43(2), 183–202. https://doi.org/10.1002/atr.5670430206

Mannheim, I., Schwartz, E., Xi, W., Buttigieg, S. C., McDonnell-Naughton, M., Wouters, E. J. M., & van Zaalen, Y. (2019). Inclusion of older adults in the research and design of digital technology. International Journal of Environmental Research and Public Health, 16(19). https://doi.org/10.3390/ijerph16193718

Mollenkopf, H. (2005). Enhancing mobility in later life: personal coping, environmental resources and technical support; the out-of-home mobility of older adults in urban and rural regions of five European countries (Vol. 17). Ios Press.

Neves, B. B., & Mead, G. (2021). Digital Technology and Older People: Towards a Sociological Approach to Technology Adoption in Later Life. Sociology, 55(5), 888–905.

https://doi.org/10.1177/0038038520975587
O.Nyumba, T., Wilson, K., Derrick, C. J., & Mukherjee, N. (2018). The use of focus group discussion methodology: Insights from two decades of application in conservation. Methods in Ecology and Evolution, 9(1), 20–32. https://doi.org/10.1111/2041-210X.12860
Parker, M., Baker, P. S., & Allman, R. M. (2002). A life-space approach to functional assessment of mobility in the elderly. Journal of Gerontological Social Work, 35(4), 35–55.
Pekkarinen Satu, Melkas Helinä, H. M. (2019). Elderly Care and Digital Services: Toward a Sustainable Sociotechnical Transition. Toivonen, M., Saari, E. (Eds) Human-Centered Digitalization and Services. Translational Systems Sciences, 19, 259–284. https://doi.org/10.1007/978-981-13-7725-9_14
Sumner, J., Chong, L. S., Bundele, A., & Wei Lim, Y. (2021). Co-Designing Technology for Aging in Place: A Systematic Review. Gerontologist, 61(7), E395–E409. https://doi.org/10.1093/geront/gnaa064
Taylor, J. K., Buchan, I. E., & van der Veer, S. N. (2019). Assessing life-space mobility for a more holistic view on wellbeing in geriatric research and clinical practice. Aging Clinical and Experimental Research, 31(4), 439–445. https://doi.org/10.1007/s40520-018-0999-5
Thoring, K., Mueller, R., & Badke-Schaub, P. (2020). Workshops as a research method: Guidelines for designing and evaluating artifacts through workshops.
Voorberg, W. H., Bekkers, V. J. J. M., & Tummers, L. G. (2015). A Systematic Review of Co-Creation and Co-Production: Embarking on the social innovation journey. Public Management Review, 17(9), 1333–1357. https://doi.org/10.1080/14719037.2014.930505
Westerlund, B. (2007). A workshop method that involves users talking, doing and making. Proceedings of International Conference on Human-Machine Interaction, Human07, IEEE.
Wong, R. C. P., Szeto, W. Y., Yang, L., Li, Y. C., & Wong, S. C. (2018). Public transport policy measures for improving elderly mobility. Transport Policy, 63(December 2017), 73–79. https://doi.org/10.1016/j.tranpol.2017.12.015

Abstract

This study examines how (digital) mobility solutions can support the mobility needs of older people against the current trend of population aging and increasing digitalization. Using a Design Science Research (DSR) approach, the research explores older people's mobility behavior, digital literacy, and the factors influencing their acceptance of technology.

Four prototypes of mobility aids were developed and evaluated through the Senior Technology Acceptance Model (STAM) to assess older people's willingness to adopt these innovations. Additionally, Multi-Actor Multi-Criteria Analysis (MAMCA) was used to gather further insights from older people and other relevant stakeholders and to provide a broader, multi-perspective assessment of these prototypes. To better categorize the different needs of the heterogeneous group of older people, a cluster analysis was carried out in which representative personas were created based on factors such as age, health, and digital literacy.

The results highlight the barriers and motivators in the various groups of older people and emphasize the need for inclusive and barrier-free mobility concepts that are tailored to their specific needs. These insights contribute to the development of mobility solutions that enhance independence, quality of life, and social inclusion for older people. They include the need for customized and adaptable mobility aids, the integration of mobility aids into familiar systems, features that promote social interactions, and a support network that promotes and accompanies the adoption of new technologies.

Keywords: *Older People, Inclusive Mobility, Digital Literacy, Technology Acceptance, STAM*

Table of Contents

List of Figures

List of Tables

Abbreviations

ASZs	Alten- und Seniorenzentren
AHP	Analytical Hierarchical Process
DSR	Design Science Research
DT	Digital Technologies
FOF	Fear of falling
MaaS	Mobility-as-a-Service
MAMCA	Multi-Actor Multi-Criteria Analysis
PT	Public Transport
QOL	Quality of Life
SMART	Simple Multiattribute Rating Technique
STAM	Senior Technology Acceptance Model
TAM	Technology Acceptance Model
WTP	Willingness to pay

1 Introduction

This chapter provides an introduction to the study. Section 1.1 explains the background of the topic. Section 1.2 highlights the motivation and purpose of the research, and Section 1.3 introduces the research questions. The chapter concludes with an overview of the thesis structure in Section 1.4.

1.1 Background

Population Aging & Digitalization

One of humanity's success stories is the aging of the population. It reflects progress in public health, medicine, and economic and social development, which help to combat disease, prevent injuries, and reduce the risk of early death (United Nations, 2019). As a result, the proportion of the world's population over 60 is expected to double by 2050 (based on 2015), corresponding to more than 2.1 million people. Moreover, the number of people aged 80 or older is expected to grow even faster, tripling between 2020 and 2050, leaving around 426 million people in this age group (World Health Organization, 2024).

Parallel to this demographic trend, digitalization is rapidly changing the lifestyles of all generations (Bundesministerium für Familie Senioren Frauen und Jugend, 2020). This digital transformation is characterized by the emergence of advanced technologies, usually combining physical and digital systems. This results in innovative business models, new production processes, and the creation of new products and services (Verhoef et al., 2021).

Role of Mobility & Digital Technology (DT) for Older People

Digitalization is making the introduction of DT an integral part of all service and business areas (Parviainen et al., 2017). In this context of an aging population, DT is seen as a new way to address various challenges associated with aging, such as declining physical and cognitive functions, numerous chronic diseases, and changing social networks (Oh et al., 2021). Among older people, access to mobility is a prerequisite for independence and active aging and, thus, also for overall quality of life (QOL) (Banister & Bowling, 2004; Stein et al., 2017). Increasing digitalization, which is also strongly affecting and changing the mobility sector (Durand et al., 2022), can benefit older people by giving them better access to mobility and more independence (Harvey et al., 2019).

Furthermore, DT has become an essential component for full participation in society (Hardill & Olphert, 2012; Yoo, 2021). It is widely recognized that DT will play an important role for older people by helping them to access information easily, stay connected with family and friends, and promote independence (Carney & Kandt, 2022; Hardill & Olphert, 2012; Harvey et al., 2019; Metz, 2017). Smart mobility concepts such as Mobility as a Service (MaaS) are becoming increasingly important for future urban mobility (Pangbourne et al., 2020). These concepts aim to integrate various transport services into a single digital platform, offering users more flexibility, better accessibility, and on-demand and shared services (Butler et al., 2021; Hietanen, 2014). Thereby, the mobility and independence of older people could be promoted (Mulley et al., 2018). At the same time, however, it can also exacerbate the exclusion of older people from transport services and society if existing services are digitalized or replaced and older people are unable/unwilling to adapt to this change (Pangbourne et al., 2020; Stein et al., 2017).

1.2 Motivation & Research Purpose

The aging population and digitalization described above represent two major challenges for policymakers, technology developers, and service providers. Due to the heterogeneity of older people, who differ in terms of their state of health, mobility habits, and digital competence, they cannot be regarded as a single entity (Guo et al., 2017). This diversity requires the development of accessible mobility solutions that consider the specific needs of the various user groups within this population (Mannheim et al., 2019).

In response, this research examines older people's mobility behavior and DT use to identify specific needs and requirements for inclusive mobility solutions that can guide future design and development processes. In addition, two evaluation methods are compared to better assess the acceptance of early mobility prototypes to promote innovations that better match the expectations and requirements of this user group.

1.3 Research Question

Research on the breakdown of the heterogeneous group of older people in terms of their mobility behavior and digital skills is still scarce. To gain more detailed insights into this topic and address this gap, this study takes a qualitative approach to identify distinct user groups among older people. It further examines the acceptance of co-created (digital) mobility aids to get a better understanding what such new mobility solutions could look like and what requirements older people have of them. The resulting two research questions guiding this study are:

"How do the barriers, needs, and technology acceptance levels vary among different groups of older people, and how can these findings contribute to the development of inclusive (digital) mobility solutions?"

1.4 Thesis Outline

The thesis is divided into six chapters. The introduction is followed by Chapter 2, in which the challenges for older people regarding mobility and DT are explained. To this end, the current literature is analyzed, and various concepts and methods are examined, which are applied in the course of the work. Chapter 3 describes the methodology used. It presents the research design and then shows how the data was collected, the resulting samples, and how the data was subsequently analyzed. Chapter 4 describes the results that emerged from the methods and analyses used. These results are then discussed in Chapter 5, linked to the literature, and recommendations are made in relation to the research question. In addition, the limitations of this work are pointed out. Chapter 6 concludes the work with the conclusion, where the research question is finally answered, and an outlook for further research is given.

2 Literature Review

To gain a comprehensive understanding of the challenges faced by older people regarding mobility and digital technologies, a comprehensive analysis of the focus group of older people was carried out. After explaining the trends of population aging and digitization in Chapter 2.1, Chapter 2.2 examines the general mobility behavior of older people. This is followed by a chapter on the digital literacy of older people, in which their DT use and barriers to DT use are analyzed (Chapter 2.3). Chapter 2.4 deals with smart mobility and the role of digitization in the mobility sector. This is followed by a chapter on the acceptance of technology by older people (Chapter 2.5), and the participatory approach of this work is outlined (Chapter 2.6). The literature review concludes with a thematic overview (Chapter 2.7) summarizing the main findings.

2.1 Current Trends and the Role of Older People

Before exploring the characteristics of older people, it is imperative to examine two prevailing megatrends - digitalization and population aging - that significantly impact each other.

2.1.1 Demographics / Population Aging

Historical Context and Emergence

The phenomenon of population aging has been the subject of considerable attention in recent decades (Bloom & Luca, 2016). This trend is defined by a gradual increase in the population's average age and a corresponding rise in the proportion of older individuals in the overall population (Lutz et al., 2008). The roots of this demographic change can be traced back to several important historical developments, including advances in healthcare and improved living standards, which have led to increased life expectancy, and the post-World War II baby boom period, which significantly influenced the age structure of many industrialized countries, resulting in a noticeable bulge in the population pyramid that is now moving into older age groups (Aguiar & Macário, 2017; Bloom & Luca, 2016). At the same time, both the population growth rate and the proportion of children are declining (Weil, 1997). Migration, mortality, and fertility are the three primary factors influencing population size and age (Grundy & Murphy, 2017).

Current Trends and Projections

The World Health Organization (2022) projects that the proportion of people over 60 will nearly double from 12% to 22% of the world's population by 2050 as the global population ages faster than in previous generations. In the European Union, where the share of the population aged 80 and over is projected to increase by a factor of 2.5, from 6.0% in 2023 to 15.3% by 2100 (see Figure 1). In Germany, the number of over 67-year-olds is expected to rise by 22%, from 16 million in 2020 to 20 million in 2035 (Statistisches Bundesamt (Destatis), n.d.).

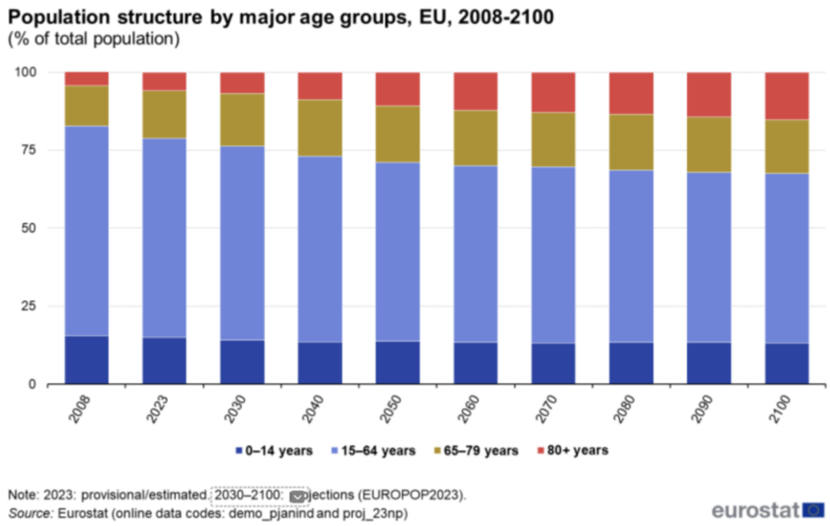


Figure 1: Population structure by major age groups, EU, 2008-2100 (Eurostat, 2024)

Definition Older People

According to the United Nations, which uses chronological age to define age groups, people aged 60 or 65 years and older are considered "older people" (United Nations, 2019). This classification is primarily influenced by economic and social categories such as average retirement age and life expectancy (Grundy & Murphy, 2017). This thesis categorizes individuals aged 60 years and older as 'older people,' mainly to align with the definitions commonly used in cities and senior associations (muenchen.de, n.d.-a).

Heterogeneity

The 60+ years cohort encompasses a highly diverse group. Older people are not a homogeneous population (Bundesministerium für Familie Senioren Frauen und Jugend, 2020; Doh, 2020; Gallistl et al., 2020; Mannheim et al., 2019; Neves & Mead, 2021; van Boekel et al., 2017). As noted by Schwanen & Páez (2010) and the World Health Organization (2018), biological aging does not always correspond to chronological age. Generally, heterogeneity within an age cohort tends to increase with chronological age (Metz, 2017). Therefore, older people should not be viewed as a single entity (Guo et al., 2017). This heterogeneity among older people will be further analyzed in the course of this thesis.

2.1.2 Digitalization

Besides the aging of the population, digitalization is another megatrend in the world. Like other modern societies, Germany is undergoing a comprehensive social upheaval characterized by two dynamic processes: demographic change and digitalization/mediatization (Doh, 2020).

Digitalization is fundamentally and rapidly changing the way of life for all generations (Bundesministerium für Familie Senioren Frauen und Jugend, 2020). Digitization refers to converting analog data (especially text, images, and video) into digital form (Parviainen et al., 2017). It is defined by the combination of advanced technologies and the integration of digital and physical systems. New business strategies, new manufacturing techniques, and the development of knowledge-based goods and services result (Almeida et al., 2020; Verhoef et al., 2021). The digitalization of society means that even those who are not "online" are affected by digitalization. All areas of society are permeated by digital technologies and shaped by them. For example, digitalization impacts local supply and purchasing structures as more and more purchases are made online and administrative services are used online (Bundesministerium für Familie Senioren Frauen und Jugend, 2020).

Digitization has proven to improve quality of life and access to public services. By replacing paper and manual processes with software, organizations can automatically collect data that can be used to better understand process performance, cost drivers, and sources of risk (Parviainen et al., 2017).

While digitalization offers many benefits, it also brings challenges, particularly for certain demographic groups, such as older people (Mitzner et al., 2008). The impact of digitalization on older people and the associated challenges, such as the ‘digital divide’ and changes in mobility, are examined in more detail in the following chapters.

2.2 Mobility Behavior of Older People

Definition and Importance of Mobility

Mobility can be defined as the movement of people outside their immediate environment to access desired locations, activities, and people. It is possible to consider both destination-independent and destination-dependent scenarios (Levin, 2019). Mobility is often regarded as a fundamental aspect of an individual's autonomy and capacity to engage in activities, access services, and foster social connections. It is essential for the development and maintenance of society, the satisfaction of daily needs, and access to healthcare. Consequently, it plays a significant role in maintaining the quality of life (Mollenkopf, 2004).

With the aging of the population, the mobility of older people is becoming increasingly important for their social integration and participation. Aging is often accompanied by physical, cognitive, and sensory impairments that limit mobility. The importance of mobility is further compounded by the withdrawal of older people from the workforce, as well as their household type and income (Mollenkopf, 2004). One of the most relevant aspects of mobility for older people is connecting them to family and friends and giving them access to the shops and services they want (Musselwhite, 2019).

Barriers and Needs

Older people's interaction with the transportation system is influenced by a variety of socioeconomic, financial, and demographic factors, as well as their mobility options. Older people generally have less financial resources but more time, influencing their travel patterns and transport mode choices (Li et al., 2012). According to Solomon (2009) the top four transport issues for older people are safety, accessibility, reliability, and affordability (SARA). Furthermore, the quality of mobility is determined by factors such as feasibility, safety, and personal control (Carp, 1988).

Musselwhite & Haddad (2010) propose a three-level model of needs and motivations for traveling in older age, which has been further refined by Musselwhite (2019) (Figure 2).

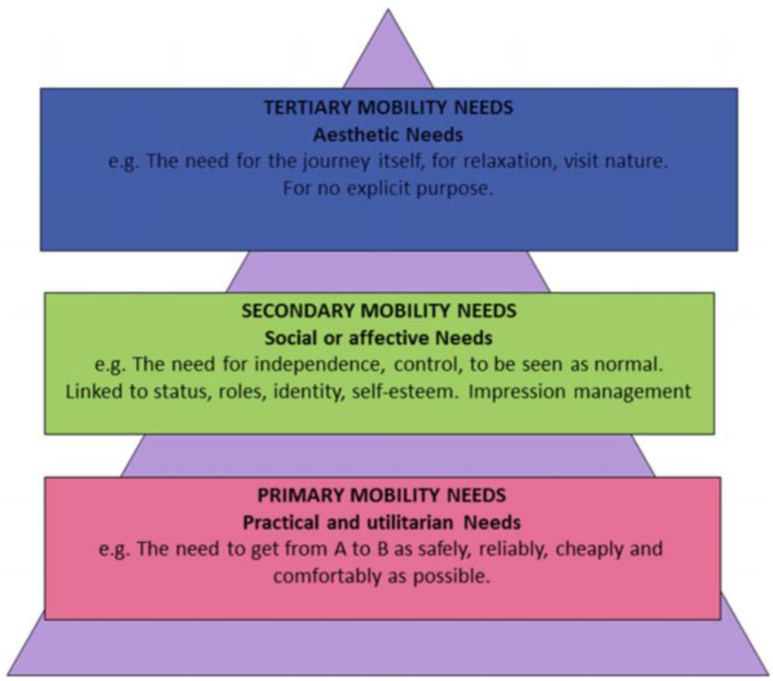


Figure 2: A model of a hierarchy of travel needs in later life (Musselwhite, 2019)

The primary level of needs consists of practical or utilitarian needs. These include getting from one place to another cheaply, reliably, safely, and quickly to perform everyday tasks such as visiting shops, using services, or attending social events (Musselwhite, 2019; Musselwhite & Haddad, 2010). The secondary mobility needs are summarized under the term social or affective needs. These include a sense of purpose, independence, and control, which traveling can satisfy (Musselwhite, 2019). The top-level (tertiary mobility needs), the aesthetic needs, involves traveling for its own sake, without an explicit purpose, i.e., the pleasure of traveling as a primary motivation for traveling (Musselwhite, 2019; Musselwhite & Haddad, 2010).

For example, cars can satisfy all three levels of transportation needs. In contrast, alternative modes of transportation typically meet only some of the needs. Walking, for instance, mainly satisfies social and affective needs but could also satisfy aesthetic needs (tertiary mobility needs). However, walking falls short of meeting practical or utilitarian needs (primary mobility needs) because it is physically demanding and often more time-consuming than other modes of transportation. Buses, on the other hand, usually address practical or utilitarian needs (primary mobility needs) and can occasionally fulfill aesthetic needs as well (e.g. if the routes go to aesthetically pleasing places). Nevertheless, buses often fail to meet freedom, independence, and control (secondary mobility needs). (Musselwhite, 2019; Musselwhite & Haddad, 2010)

Health-related mobility limitations

Of the many factors influencing personal mobility, the state of health is the most important (Nobis & Kuhnimhof, 2018). The proportion of people with health limitations increases significantly with age (see Figure 3). While less than one in ten people under the age of 50 have a health limitation, this number increases significantly in older age groups. Between the ages of 60 and 70, about one in five people are affected by such limitations, and this number rises to about half for people over 80 (Nobis & Kuhnimhof, 2018).

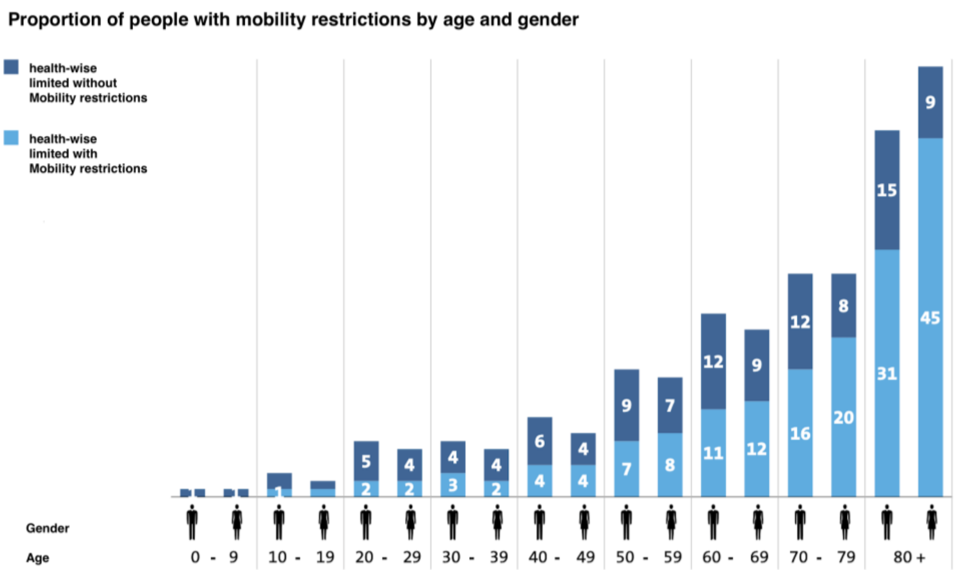


Figure 3: Proportion of people with mobility restrictions by age and gender (Nobis & Kuhnimhof, 2018)

Among people over the age of 70, two-thirds to three-quarters of those with health limitations also experience mobility limitations. A significant proportion of these limitations are due to walking impairments, which result in mobility limitations in 27% of cases. Although visual impairment accounts for only 13% of health limitations, it results in mobility limitations for more than half of those affected (53%). In addition, other health problems contribute to mobility limitations in about half of cases (Nobis & Kuhnimhof, 2018).

Health-related mobility limitations can increase the risk of falling, while falls are, in turn, one of the most common causes of poor health in people over 65 (Evitt & Quigley, 2004). Many older people suffer from loss of function after a fall (Scheffer et al., 2008) and psychological problems that are directly related to the fall. These include fear of falling (FOF), loss of self-efficacy[1], avoidance of activities, and loss of self-confidence (Legters, 2002). In addition, FOF has also been frequently identified in older people who have not yet experienced a fall (Jørstad et al., 2005; Suzuki et al., 2002).

Advances in medical technology may delay the onset of mobility limitations, but the underlying relationship between aging and mobility limitations is expected to persist and affect a significant portion of the older population (Nobis & Kuhnimhof, 2018).

Travel patterns and transport modes

Similar to a study of New Zealanders by O'Fallon & Sullivan (2003), Nobis & Kuhnimhof (2018) showed that older people (60+) in Germany have different travel behavior than their younger counterparts. Those aged 70+ make fewer trips per day, with an average of 2.6 trips for those aged 70-79 and 1.9 trips for those aged 80+, compared to a peak of 3.7 trips per day for those aged 40-49 (the average for all age groups is 3.1 trips per day). Older people also tend to take shorter trips and travel fewer vehicle miles per day or year, with an average of 14 kilometers for those aged 80 and older, compared to an overall average of 39 kilometers for all age groups (Nobis & Kuhnimhof, 2018). The primary purposes of travel for older people are social, recreational, and personal business activities, including travel for shopping, health care, and senior recreation (Fobker & Grotz, 2006; O'Fallon & Sullivan, 2003). In addition, older people are more likely to be passengers in a vehicle than drivers. For example, the proportion of people traveling as passengers in a car increases from 7% in the 50-59 age group to 14% in the 70-79 age group. In addition, the proportion of trips made on foot increases with age, from about 20% for 20-59 year olds to 34% for those aged 80 and over (Nobis & Kuhnimhof, 2018). In contrast, the use of bicycles and public transport hardly changes with age. However, car use declines significantly, from 49% for 60- to 69-year-olds to only 32% for 80-year-olds and older (Nobis & Kuhnimhof, 2018). In addition, a higher proportion of older women than older

---

[1] Self-efficacy is a person's belief in their ability to succeed in a given situation (Bandura, 1982).

men use some kind of mobility aid, such as a walking stick, walking frame, or wheelchair. Depending on age, the differences vary between 19% and 29%. But as age increases (over 75), the use of electric mobility scooters is higher among men than among women (Gell et al., 2015).

However, travel patterns do not depend solely on age and health. In addition, gender, income, education, ethnicity, geographic location, and living arrangements also play an important role (Nobis & Kuhnimhof, 2018; Schwanen & Páez, 2010; Zmud et al., 2017). For example, senior citizens in cities cover shorter distances per day than their counterparts in rural areas. It can also be seen that although the gender-specific differences in the distance traveled per day decrease with age, male older people are still more active than female older people in terms of the distance traveled (Nobis & Kuhnimhof, 2018; Zmud et al., 2017).

In summary, the mobility behavior of older people depends on many different factors and is also influenced by experiences and choices made earlier in life, making it difficult for them to adapt to new travel modes (Heikkinen, 2004; Schwanen & Páez, 2010).

2.3 Digital Literacy among Older People

Digital technologies (DT) are seen as a new way to overcome various challenges associated with aging. These include deficits in physical and cognitive functions, chronic diseases, and reduced social engagement (Oh et al., 2021; Tun & Lachman, 2010). Overall, DT promises to improve older people's well-being and promote independence and “aging in place” (Choi & DiNitto, 2013; Mannheim et al., 2019). This assertion is supported by the fact that the proportion of the older population using the Internet has risen sharply in the last decade (see Chapter 2.3.2). DT can help older people move more freely by removing certain barriers. Innovations that enable seamless door-to-door connectivity can make travel planning and execution easier and increase the level of independent mobility for older people (Harvey et al., 2019).

2.3.1 Definitions

Digital literacy can be defined as a set of competencies that enable an individual to use and understand computers and various forms of information technology and to evaluate and integrate the information they provide (Gilster, 1997; Leaning, 2019). Digital literacy requires specific digital competencies. These "digital competencies" describe the ability to access, classify, evaluate, and, where appropriate, use digital products and systems according to one’s own needs, interests, and preferences and in the context of the social, institutional, and societal references involved (Kubicek & Lippa, 2017).

According to Bundesministerium für Familie Senioren Frauen und Jugend (2020), the concept of digital literacy distinguishes between three levels of digital skills, which help develop a more comprehensive understanding of the appropriation of ICT and the acquisition of digital skills. The first level comprises the knowledge of how to operate and handle DT (user competence). The second level includes the knowledge to adapt DT to individual needs and use media creatively (design competence). The third level consists of the knowledge that people need to orient themselves in the DT landscape by being able to reflect on digital possibilities, adapt them to their own life situations, and evaluate them (orientation competence).

Despite a notable increase in DT usage among older people during the COVID-19 pandemic, a significant proportion of this demographic remains excluded from DT and digital media. This is primarily attributed to a lack of perceived benefits and suitable devices, as well as experience scarcity in this domain (Seifert, 2020; Seifert et al., 2021). Even among those who do engage with DT, the use is very heterogeneous among older people, and for some of them, sophisticated functions and services remain limited (Seifert et al., 2021; van Boekel et al., 2017).

Digital exclusion refers to being excluded from a society where the internet and other digital technologies permeate many aspects of daily life. Subjective feelings of social exclusion can sometimes result from being excluded from participating in these digital spaces (Seifert et al., 2018). It implies the inequality of access to and the inability to use ICTs, which is nowadays considered a prerequisite for full participation in society (Schejter et al., 2015). Digital exclusion affects the use of public services, which are increasingly offered online. It restricts access to products and services that can improve convenience, independence, and quality of life (e.g. online banking and shopping), and it discourages people from going to places that promote social and civic engagement (Francis et al., 2019).

The studies from Mihelj et al. (2019) and (Ramsetty & Adams, 2020) suggest that the increasing use of DT in public transport and society as a whole could widen the *digital divide* between those who are more familiar with and able to use these technologies and those who are less connected and less technically adept (Carney & Kandt, 2022). The most common definition of the Digital Divide is that it is “a division between people who have access and use of digital media and those who do not” (Van Dijk, 2020, p. 1).

People who have grown up with DT are referred to as *Digital Natives* as opposed to *Digital Immigrants* who have adapted to technology later in life. Research by Prensky (Prensky, 2001a, 2001b) suggests that these groups have different responses to stimuli and require different motivators for engagement. Digital Natives, accustomed to a rapid flow of information, tend to multitask and prefer parallel processing. They prefer graphical content over textual information, are comfortable in networked environments, and seek instant gratification and frequent rewards. In general, they prefer playful activities to traditional "serious" work (Prensky, 2001a). In addition, Digital Natives tend to consider technological solutions more quickly than Digital Immigrants, who are more cautious about immediate technological problem-solving. This generational divide also extends to differences in cognitive processing that affect the skills and abilities of each group. For example, Digital Natives use different brain regions and engage in other cognitive processes when interacting with computers than adults (Prensky, 2001b).

The older population is predicted to be predominantly Digital Immigrants, while the working population will be predominantly digital natives. To promote equitable market participation, it is critical that product development, business development, and strategic planning consider the needs and perspectives of both Digital Natives and Digital Immigrants, regardless of their representation in the workforce.

2.3.2 General DT Usage by Older People

Due to factors such as digital literacy and internet access, older adults use less technology for daily services and communication than younger people (Hunsaker & Hargittai, 2018). Older people have been shown to be reluctant to adopt new technologies if their perception of the technology's benefits and ease of use is less than their perception of its shortcomings (Heinz et al., 2013).

In the United States, the prevalence of smartphone ownership varies significantly by age group. Among individuals aged 18 to 29, smartphone ownership reached 97% in 2023, compared to 76% among those aged 65 and older, marking a 23-percentage point gap. In 2015, this discrepancy was 56 percentage points, when 86% of the younger population (aged 18-29) and only 30% of the older population (aged 65+) owned a smartphone (Pew Research Center, 2024). This trend of increasing smartphone adoption among older people has accelerated, particularly due to the COVID-19 pandemic (Sixsmith et al., 2022). Similar trends can be observed in the United Kingdom and Germany. In 2023, the number of smartphone users in the UK aged 65 or older was 71% compared to a share of 99% for individuals between 16 and 44 years old. The proportion decreases slightly in the older age groups: 98% in the 45 to 55 age group and 91% in the 55 to 65 age group (Ofcom, n.d.). In Germany, 85% of 60 to 69-year-olds and 68% of 70-year-olds and older owned a smartphone in 2021, while the proportion was over 90% in all other age groups (VuMA, n.d.). Figure 4 shows an overview of smartphone use in Germany in 2021 by age group.

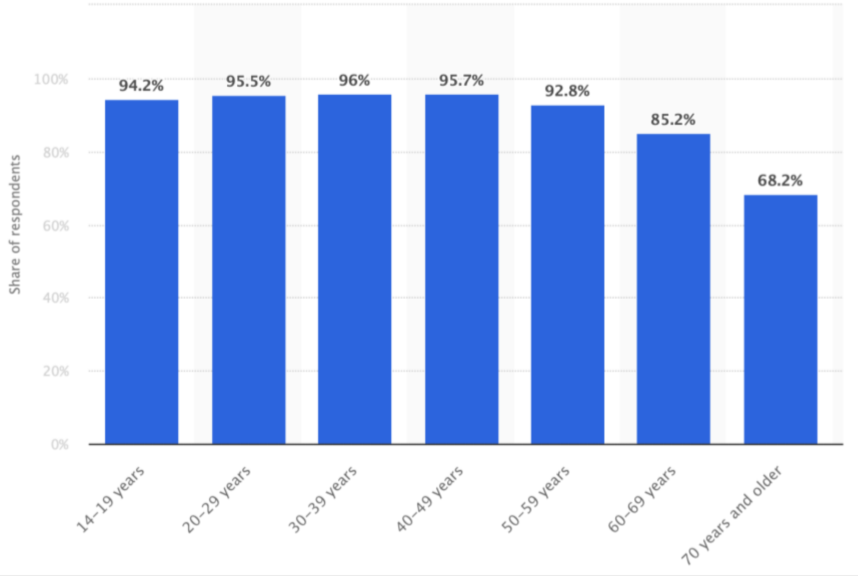


Figure 4: Smartphone users in Germany in 2021 by age group (VuMA, n.d.)

However, usage varies significantly between the different age groups; many older people own smartphones but often only use the basic functions and do not fully exploit the potential of the devices (Seifert et al., 2021; van Boekel et al., 2017).

Consequently, individuals aged 60 and above, particularly those in the post-working phase, continue to experience difficulties accessing digital resources. Some of the underlying causes can be traced back to the early stages of digitalization in the 1990s when there was a lack of training opportunities for older employees, and the establishment of low-threshold and sustainable access and learning spaces for older individuals was not prioritized (Doh, 2020).

In addition to age, it is also essential to consider the concept of intersectionality. The various dimensions of social inequality tend to reinforce one another, thereby creating additional obstacles to accessing digital technology (Fang et al., 2019; Kärnä et al., 2022). Older people are a heterogeneous group in terms of their socio-economic and socio-demographic background (Bundesministerium für Familie Senioren Frauen und Jugend, 2020; Doh, 2020; Gallistl et al., 2020; Mannheim et al., 2019; Neves & Mead, 2021; van Boekel et al., 2017). Therefore, age, gender, education, income, prior professional experience (with technologies), social salience, regional/national content, and subjective state of health determine the affinity for Internet use (Doh, 2020; Fang et al., 2019; Gallistl et al., 2020; Seifert et al., 2021).

2.3.3 Barriers of DT Usage among Older People

The acceptance and use of a product (or service) depends primarily on its ability to solve a specific problem and how easy it is for the user to operate. Therefore, when developing products for older people, it is important to understand their characteristics and age-related changes (Nunes et al., 2010). A synthesis of barriers to DT usage that older people face due to age-related changes is described below. Following the work of Nunes et al. (2010), it is categorized into physical, cognitive, psychological, and social factors. In addition, *Access to Technology* was included as a factor. Appendix 1 shows a comprehensive overview of the findings described below.

1. Physical Factors

Physical factors (or health problems) can be categorized into three main factors: Hearing Impairment, Visual Impairment, and Motor Impairment. Hearing impairment was not included as it was not mentioned in the literature as a major obstacle to the use of DT.

Vision Impairment

With increasing age, vision deteriorates and impairs activities such as reading small texts or recognizing detailed images. Problems such as reduced visual acuity and loss of peripheral vision are common (Fisk et al., 2020). These changes affect how older people interact with user interfaces, as small fonts and peripheral notifications may go unnoticed (Harvey et al., 2019; Nunes et al., 2010; Pangbourne et al., 2018).

Motor Impairment

Aging affects the human motor system, leading to reduced psychomotor performance, touch, sensitivity, and difficulties in coordination (Fisk et al., 2020). Therefore, navigating small keypads and touchscreens presents significant challenges (Harvey et al., 2019; Pangbourne et al., 2010; Yoo, 2021).

2. Cognitive Factors

Cognitive Changes can be divided into memory impairment and attention impairment. Short-term memory tends to decline with age, which affects the ability to memorize multiple pieces of information, complete tasks in a certain order, or learn new processes (Fisk et al., 2020; Satre et al., 2006). Further, older people often struggle with multitasking and selective attention (Fisk et al., 2020). As a result, many studies have identified the complexity of digital technology as a significant barrier for older people. Older people are often overwhelmed when too much information is displayed at once (Lamont et al., 2013) or they have to navigate small icons (Yoo, 2021). Moreover, they have difficulties memorizing complex sequences to operate an app (Harvey et al., 2019; Kim et al., 2016) or learning new complex interface operations (Tsai et al., 2017).

3. Psychological and Social Factors

Psychological and social factors play an important role for older people and can represent major barriers to DT usage. They have to deal with declining physical abilities, losses, and changing social networks (Nunes et al., 2010).

Lack of self-efficacy

Self-efficacy is a person's belief in their ability to succeed in a given situation (Bandura, 1982). Some older people perceive themselves as incapable of learning a new DT and refuse to learn it. The lack of skill, therefore, represents a big barrier (Carney & Kandt, 2022; Kärnä et al., 2022; Kim et al., 2016).

Lack of Motivation

A lack of interest in learning new DT is also a common barrier (Durand et al., 2022; Kärnä et al., 2022; Kim et al., 2016; Pangbourne et al., 2010; Selwyn, 2004). Some older people are satisfied with their familiar ways and see no need to change (Harvey et al., 2019; Kim et al., 2016). Others become frustrated when they cannot apply their existing skills to a new DT (Kim et al., 2016).

Fear / Security Concerns

When it comes to using DT, many older people experience anxiety and security concerns. Issues such as privacy, data protection, and the potential for abuse and crime are major concerns (Damant et al., 2017; Fischer et al., 2021; Harvey et al., 2019; Pangbourne et al., 2018). There is often a general lack of trust in new DT (Harvey et al., 2019). In addition, older people may be sensitive to making mistakes (Yoo, 2021) and fear public embarrassment or looking foolish when using DT (Kim et al., 2016; Sochor & Nikitas, 2016). These fears can be compounded by a strong need to feel in control when using technology (Harvey et al., 2019; Pangbourne et al., 2010; Shirgaokar, 2020).

Social & Support

Social and support factors also play a critical role in older people's adoption of DT. A common concern is the fear of losing social interaction when using digital technology (Harvey et al., 2019). Older people often prefer to use the same hardware as their relatives rather than devices designed specifically for them, which they may find unattractive (Neves & Mead, 2021). In addition, opportunities for learning and support are critical. Access to training and support networks can significantly increase their confidence and willingness to engage with new technologies (Harvey et al., 2019; Kärnä et al., 2022).

4. **Access to Technology**

Access to technology is a significant barrier for many older people. The cost of digital devices can be a barrier, as noted in several studies (Harvey et al., 2019; Sochor & Nikitas, 2016). In addition, the different options available when purchasing digital technology can be overwhelming, making it difficult to distinguish between different products and their features, sometimes resulting in not buying anything (Kim et al., 2016). Harvey et al. (2019) also mentioned, there is a perceived lack of trusted places for older people to purchase technology and receive support. Some older people may not have access to the necessary equipment (Carney & Kandt, 2022). In addition, the quick obsolescence of devices means that older people often have to replace their technology, which can be annoying and costly (Durand et al., 2022; Harvey et al., 2019). Other obstacles include the challenge of keeping programs and operating systems up to date and preserving battery life (Golub et al., 2019; Groth, 2019; Harvey et al., 2019). Additionally, the unfamiliarity with the vocabulary associated with DT can create an additional obstacle for older people unfamiliar with this specialized language (Harvey et al., 2019; Kim et al., 2016).

2.4 (Digital) Technology for Mobility / Smart Mobility

The way people access and navigate transportation services is changing due to digitalization (Durand et al., 2022), and travelers increasingly depend on digital technologies in transport (Carney & Kandt, 2022; Pangbourne et al., 2018). In the coming years, transportation services will likely be transformed by advances in digital technology, increasing automation, and expanding the sharing economy (Metz, 2017). Access to mobility is a prerequisite for independence and active aging and, therefore, the general QOL of older people (Banister & Bowling, 2004; Stein et al., 2017). Such transformations, like the digitalization of transport services, can benefit older travelers by giving them better access to mobility and more independence (Carney & Kandt, 2022; Harvey et al., 2019; Metz, 2017). On the other hand, it could disadvantage older people by replacing or digitizing existing services, potentially excluding them from transportation options (Pangbourne et al., 2020; Stein et al., 2017).

Chapter 2.4.1 takes a closer look at the concept of smart mobility and its impact on older people.

2.4.1 Smart Mobility

Many metropolitan areas have already adopted strategies to leverage technological advancements, transform urban areas, and address sustainability and quality of life

(Yigitcanlar & Kamruzzaman, 2018)issues. These strategies are part of the smart city concept, a city that is “efficient, technologically advanced, green and socially inclusive […]” (Vanolo, 2014, p. 883). Smart mobility, a sub-field of smart cities (Yigitcanlar & Kamruzzaman, 2020), promises to transform cities and provide multiple benefits, including increased infrastructure capacity, reduced consumption and emissions, improved accessibility of services, and simplified access to data that can be used to optimize the efficiency of transportation systems (Yigitcanlar, 2016). This improvement in digital infrastructure includes real-time traffic information, intelligent ticketing, improved taxi services, autonomous driving services, shared mobility services, and Mobility-as-a-Service (MaaS) (Musselwhite, 2019).

Smart mobility includes applications and services such as MaaS, traffic flow optimization, logistics optimization, autonomous vehicles, and outdoor navigation technologies (Paiva et al., 2021). New business models have developed primarily around mobility services and away from private use and ownership. This has led to the establishment of business models such as car sharing, e-hailing, and on-demand shuttles (Schade et al., 2014). These new mobility services are mainly based on the concept of MaaS.

Mobility-as-a-Service (MaaS)

MaaS has been proposed as a potential smart mobility solution that can solve transport-related problems in urban areas (Butler et al., 2021). It offers a tailored mobility package by integrating various transport modes into a single digital platform for trip planning, real-time information, reservations, and payments (Hietanen, 2014; Ho et al., 2018). This allows the integration of traditional services, such as public transport, with other on-demand and sharing services, like ride-, bike- and car-sharing (Butler et al., 2021). The bundling of these different modes of transport means a shift away from the current ownership-based modes of transport towards access-based, demand-driven modes of transport with the aim of seamless door-to-door mobility (Caiati et al., 2020; Ho et al., 2018; Jittrapirom et al., 2017).

Despite the potential benefits of MaaS, there remains a strong correlation between older people and reluctance to use digital services, raising doubts about the adoption of MaaS by older people (Caiati et al., 2020; Fitt, 2018; Ho et al., 2018). If they are unwilling or unable to embrace the digital transformation of such services, this can lead to a form of transport disadvantage[2] (Durand et al., 2022). Although technology use is increasing among older people (see Chapter 2.3.2), there is still a reluctance, which is partly due to a lack of familiarity

[2] Transport disadvantage refers to the lack or difficulty of access to basic resources, activities, and opportunities for interaction, as well as a lack of skills, autonomy, and influence over decisions related to transport and mobility services (Butler et al., 2020; Schwanen et al., 2015).

with smartphones and online applications (Fioreze et al., 2019; Pangbourne et al., 2020; Sourbati & Behrendt, 2021) and a habitual dependence on private vehicles (Caiati et al., 2020). Furthermore, digital and financial requirements of MaaS platforms - such as the need for digital literacy and access to online banking/credit cards - present additional challenges that may exclude older people from these services (Musselwhite, 2019; Pangbourne et al., 2020; Shirgaokar, 2020). So, while MaaS has the potential to improve mobility for many and increase equity in transportation services, it risks increasing transportation inequality for those already struggling with digital inclusion (Pangbourne et al., 2020).

2.5 Technology Adoption in Later Life

It is critical that researchers and practitioners who seek to promote the independence of older people study and understand older peoples' use of DT. Identifying key factors influencing older peoples' adoption of such DTs will help explain and predict their attitudes toward accepting or adopting new technologies (Lu et al., 2017). The literature shows that many older people recognize the benefits of DTs and express a desire to learn how to use these DTs effectively (Betts et al., 2019; Neves & Mead, 2021).

However, their willingness and enthusiasm to engage with DTs depend on various factors. Often, the availability of appropriate training and support plays an important role (Betts et al., 2019; Mitzner et al., 2008), while barriers such as lack of skills, lack of access to devices, and health issues contribute to a persistent digital divide (Carney & Kandt, 2022). Older people are a diverse group, and age alone does not determine digital exclusion. Other factors such as education, socioeconomic status, living conditions, social norms, and attitudes also play a decisive role (Doh, 2020; Fang et al., 2019; Gallistl et al., 2020; Neves et al., 2018; Seifert et al., 2021).

The following subchapters will examine different technology acceptance (and adoption) models. Chapter 2.5.1 explains the generally recognized Technology Acceptance Model (TAM), followed by Chapter 2.5.2, introducing the Senior Technology Acceptance Model (STAM), a modification of TAM designed specifically to address technology acceptance among older adults.

2.5.1 Technology Acceptance Model (TAM)

Technology adoption and acceptance models help anticipate future needs in a complex and evolving market scenario. It is essential to distinguish between the acceptance and adoption of technology. Technology adoption is a process that begins with the user becoming aware of the technology and ends with the user adopting it and using it entirely. A person who has adopted a technology is more likely to replace it when it breaks, find new uses, and cannot contemplate life without it. Acceptance, different from adoption, is an attitude toward a technology that is influenced by various factors. A user who has purchased a new technology product has not yet accepted it. There are other phases beyond simple purchase, and acceptance plays an important role. Without acceptance, it is unlikely that adaption will occur. (Renaud & Van Biljon, 2008)

In order to develop a reliable model that could predict the actual use of any specific technology, in 1985, Fred D. Davis proposed the Technology Acceptance Model (TAM), which was based on the Theory of Reasoned Action and the Theory of Planned Behavior (Davis, 1985). TAM has taken a leading role in explaining user behavior toward technology and is used to provide a clearer understanding of individuals' acceptance of technology (Davis, 1985; Guner & Acarturk, 2020).

This behavioral model predicts the acceptance (*behavioral intention*) and use of technology by assessing an individual's attitude toward using a system, which is influenced by *Perceived Usefulness (PU)* and *Perceived Ease of Use (PEOU)* (Francis et al., 2019; Guner & Acarturk, 2020).

Davis (1985) defined *perceived usefulness* as “[t]he degree to which an individual believes that using a particular system would enhance his or her job performance“ and *perceived ease of use* as “[t]he degree to which an individual believes that using a particular system would be free of physical and mental effort“ (Davis, 1985, p.82). Consequently, people who find technology useful and easy to use are more likely to adopt and integrate it into their lives (Guner & Acarturk, 2020; Neves & Mead, 2021). Figure 5 illustrates the concept of the TAM.

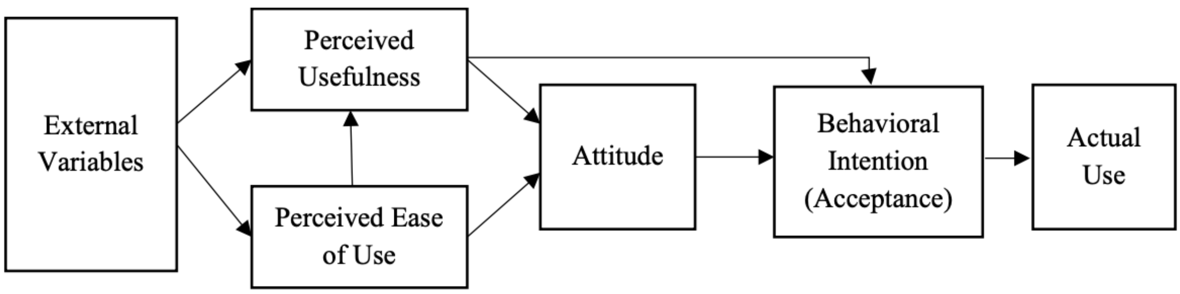


Figure 5: Technology Acceptance Model (TAM) (Guner & Acarturk, 2020)

It is assumed that the attitude towards accepting technology is due to personal and social influences. The fact that TAM does not compensate for social influence is a limitation (Davis et al., 1989; Renaud & Van Biljon, 2008). Furthermore, TAM is limited because the only determinant of actual system use is *behavioral intention to use* (Renaud & Van Biljon, 2008).

Subsequent studies have confirmed the relationship between perceived usefulness, perceived ease of use, and technology acceptance, leading to several updates and extensions such as TAM2 (Venkatesh & Davis, 2000), TAM3 (Venkatesh & Bala, 2008), and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). These modifications of the TAM usually include additional external factors that are thought to influence technology acceptance (Kim et al., 2016; Venkatesh et al., 2016). While the core elements of the TAM, perceived usefulness and perceived ease of use, remain consistent across versions, the external factors that influence these perceptions may vary. These factors include social influence, peer support, (computer) anxiety, self-satisfaction, self-efficacy, cost tolerance, perceived enjoyment, and prior experience (Abdullah & Ward, 2016; Kim et al., 2016).

The focus of the TAM (and its extensions) is to explain the determinants of technology use among different groups of participants in different contexts (Guner & Acarturk, 2020). Since the context of older users is very different from that of other (age) groups, variants have been developed, including the Senior Technology Acceptance and Adoption Model (STAM) (Renaud & Van Biljon, 2008), which will be examined in more detail below.

2.5.2 Senior Technology Acceptance Model (STAM)

Renaud & Van Biljon (2008) introduced the STAM to explain the adoption and acceptance of mobile technology. STAM consists of seven components distributed across three procedural phases that older people go through to either accept or reject a new technology. The model is illustrated in Figure 6.

In the *objectification phase*, the determination of the role that the technology will play is determined, embodied by the behavioral intention (*intention to use*). This intention is influenced by social factors (*user context*) and PU. These factors help to shape the initial willingness to engage with the technology. Interaction with the technology is described in the *integration phase*. The *Experimentation and Exploration* module involves the first use of the technology and the impressions gained from this initial interaction. The experience gained here feeds back into the *Confirmed Usefulness* module. The Facilitating Conditions module also considers discriminators such as the price. This module, along with *perceived usefulness* and *ease of learning and use,* all influence the *Actual Use*. Finally, *Acceptance* occurs when the user has progressed through all stages without being deterred by the various facilitating factors. Conversely, *Rejection* results from a poor experimentation experience, leading to the perception that the device is too difficult to learn or use. The modules are included in the

Conversion and *Non-Conversion* phases, respectively. While PU and PEOU are confirmed as fundamental factors in technology acceptance, as seen in most other TAMs, STAM uniquely accounts for the possibility that some older people may never fully accept a technology (*Rejection*/*Non-Conversion*).

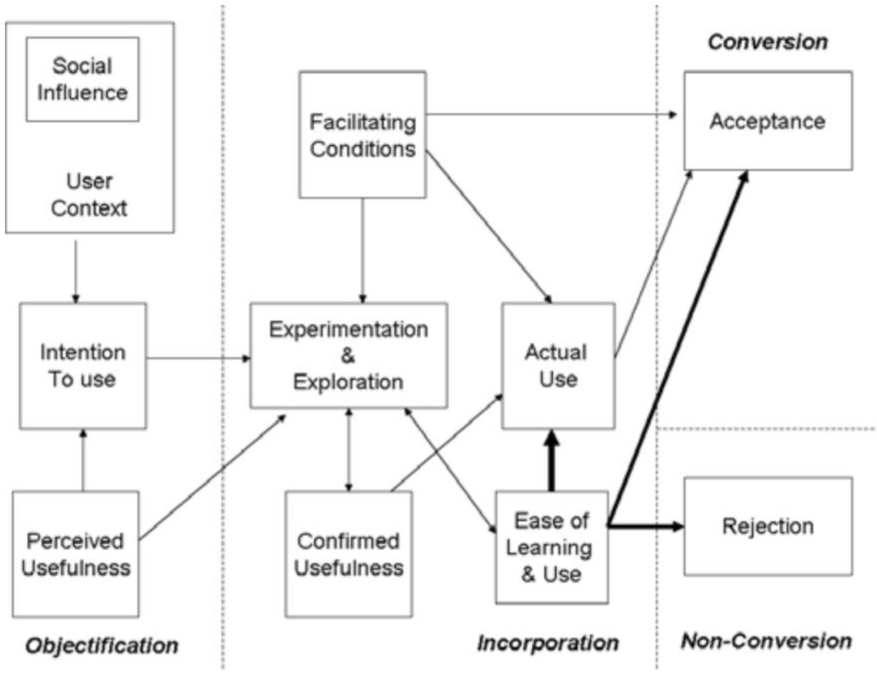


Figure 6: Senior Technology Acceptance & Adoption Model (STAM) (Renaud & Van Biljon, 2008)

While there are various extensions and modifications of the original STAM by Renaud & Van Biljon (2008), such as those by Kim et al. (2016) (for mobile technology) and Yu-Huei et al. (2019) (for wearable devices), this paper focuses on the modified STAM developed by Chen & Chan (2014) and the resulting questionnaire they present.

The modified Senior Technology Acceptance Model (STAM) developed by Chen and Chan (2014) refines the understanding of gerontechnology[3] acceptance among older people by incorporating age-related health and ability characteristics into the traditional TAM framework. This approach acknowledges that older peoples' technology acceptance is influenced by their

[3] Gerontechnology is an interdisciplinary field that combines gerontology, the study of aging (Stuart-Hamilton, 2011), with technology. It aims to develop solutions that improve older people's health, independence, and overall QOL by helping with problems and difficulties that arise from aging (Lesnoff-Caravaglia, 2007).

physical, functional, psychological, and social conditions (Erber, 2012). The model consists of five TAM-related and six age-related constructs.

The TAM-related constructs in this model include PU, PEOU, *Attitude Towards Technology*, *facilitating conditions*, *gerontechnology self-efficacy*, and *gerontechnology anxiety* (Chen & Chan, 2014). *Facilitating conditions* refer to perceived environmental and resource factors that support the use of technology, including basic knowledge, available help, financial resources, accessibility, and social influences (Chen & Chan, 2014; Venkatesh et al., 2003). *Gerontechnology self-efficacy* involves an individual's confidence in their ability to use gerontechnology successfully, while *gerontechnology anxiety* refers to fears or anxieties when considering or using gerontechnology (Venkatesh et al., 2003). Both concepts are adapted from the UTAUT (Chen & Chan, 2014; Venkatesh et al., 2003).

The age-related constructs in the modified STAM comprise six elements. *Self-reported health Conditions are* measured through five items: general health status, health conditions compared to same-age peers, visual ability, auditory ability, and movement ability. *Cognitive Abilities* are related to memory, learning, concentration, and thinking abilities. *Social Relationships* are the satisfaction with personal relationships, support from friends and family, and participation in social activities. *Physical Functioning* is assessed as the ability to perform activities of daily living independently, while *Psychological Functioning* is an individual's attitude towards their own aging and general satisfaction with life. (Chen & Chan, 2014)

These constructs were validated through confirmatory factor analysis and hierarchical multiple regression, ensuring their reliability and relevance in predicting technology acceptance among older adults. The model also includes four control variables: age, gender, education level, and economic status, which are also expected to influence technology acceptance (Chen & Chan, 2014). In total, the modified STAM from Chen & Chan (2014) comprises 38 items and consists of 11 conceptual subscales (5 TAM-related constructs and 6 age-related constructs). The full questionnaire can be found in Appendix 2.

To simplify the assessment of technology acceptance among older adults, Chen & Lou (2020) condensed the 38-item questionnaire from Chen & Chan (2014) into a shorter, 14-item questionnaire. This brief version retains the core constructs of the original model while reducing the burden on respondents (Chen & Lou, 2020). A brief scale is advantageous as it takes less time to complete, results in fewer missing data, minimizes respondent burden, reduces refusal rates, and enhances data quality (Beaton et al., 2005). The 14-item STAM includes four constructs (Chen & Lou, 2020). *Attitudinal Beliefs* combine two items from the original PU and one from AT. *Control Beliefs* merge PEOU, self-efficacy, and two items from the original facilitating conditions. *Gerontechnology Anxiety* retains the original items from the STAM by Chen & Chan (2014). *Health Characteristics* include one item on general health condition, one on cognitive ability, two on satisfaction with social relationships, and one on satisfaction with the quality of life (QOL). An overview of the four constructs with the corresponding questions can be found in Figure 7.

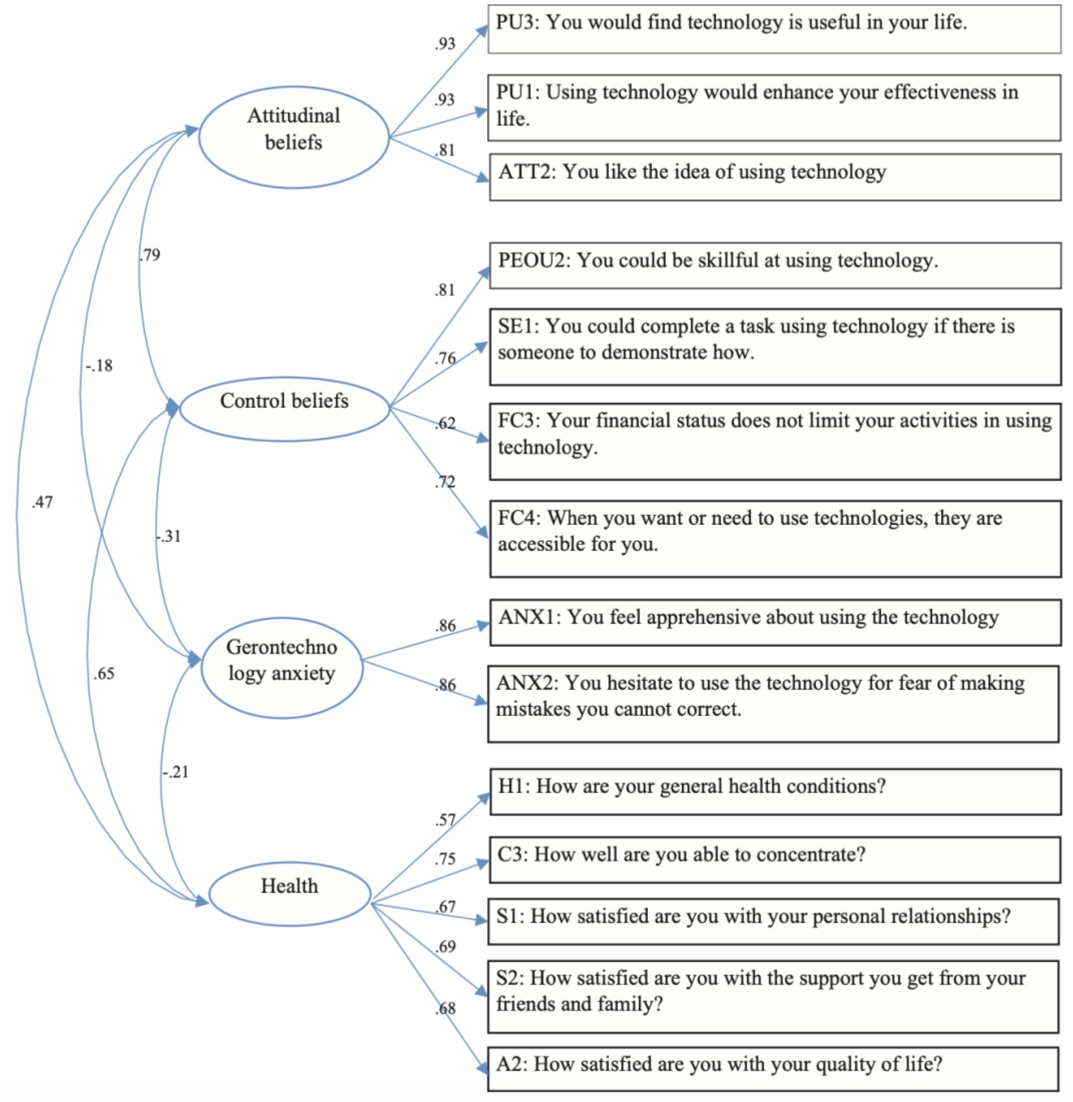


Figure 7: 14-item scale STAM (Chen & Lou, 2020)

2.6 Participatory Approach

This chapter looks at the participatory approaches used in this study. It emphasizes the importance of involving users (and other relevant stakeholders) as active participants in the research and development process to ensure that solutions are tailored to their specific needs, preferences, and challenges.

2.6.1 Co-creation

Co-creation is a collaborative approach that involves end users in the design and development process (Lu et al., 2017; Mannheim et al., 2019; Vargo et al., 2008). The literature shows that this is an important method for developing technologies for older people (Fischer et al., 2021). Involving older people in the research and design process can mean that solutions are seen as more relevant, have a greater impact, and better address specific needs (Mannheim et al., 2019). This chapter explores the principles, methods, and benefits of co-creation in the context of developing (digital) tools for older people.

Definition

The terms co-design and co-creation are often used synonymously and interchangeably (Sanders & Stappers, 2008). The term co-creation is now widely used to describe a shift in perspective from the definition of the organization as the source of value to a more collaborative process in which individuals and organizations work together to create and develop meaning (Ind & Coates, 2013). It refers to the involvement of customers or users in various stages of a product's lifecycle, such as ideation, design, development, and implementation (Tran & Park, 2015; Vargo et al., 2008). This means that the customer is actively involved as a contributor from the beginning of the innovation process. Customers can add value by contributing creative ideas for the company's future products or by sharing their consumption experiences to such an extent that the company feels compelled to redesign its current range of goods and services (Kristensson et al., 2008). A specific form of co-creation is co-design (Sanders & Stappers, 2008; Windasari & Visita, 2019). Co-design mainly focuses on the early stages of the product design and development phases (Shaukat et al., 2014). Since this work is interested in a product's ideation, design, and development, co-creation is the appropriate vocabulary.

Importance of Co-creation

Accordingly, studies have shown that co-creation influences customer satisfaction and loyalty and gives organizations a competitive advantage (Grissemann & Stokburger-Sauer, 2012). Customers typically participate passively in the design process through focus groups and surveys. They react to designs that companies have already created. Co-design, on the other hand, allows users to contribute their ideas and play an active role in the design of products. Such a co-design process has several advantages over the traditional method (Shaukat et al., 2014). Co-creation significantly impacts customer satisfaction and loyalty and can, therefore, contribute to a competitive advantage for companies (Grissemann & Stokburger-Sauer, 2012). By actively involving older people in the design process, companies can develop digital tools that are more closely aligned with their expectations and needs, leading to higher satisfaction and sustainable use (Mannheim et al., 2019).

2.6.2 Co-evaluation / MAMCA

The Multi-Actor Multi-criteria Analysis methodology, as developed by Macharis (2005), provides a robust framework for decision-making that integrates the diverse perspectives of various stakeholders. The involvement of stakeholders in MAMCA enables more rationalized decision-making (Huang et al., 2021). MAMCA can be applied in various areas where complex scenarios are compared with each other. These include areas such as energy (Lode, 2020), transport (Macharis et al., 2004), logistics and mobility (Macharis & Baudry, 2018). The method consists of seven steps, as shown in Figure 8, and is discussed below.

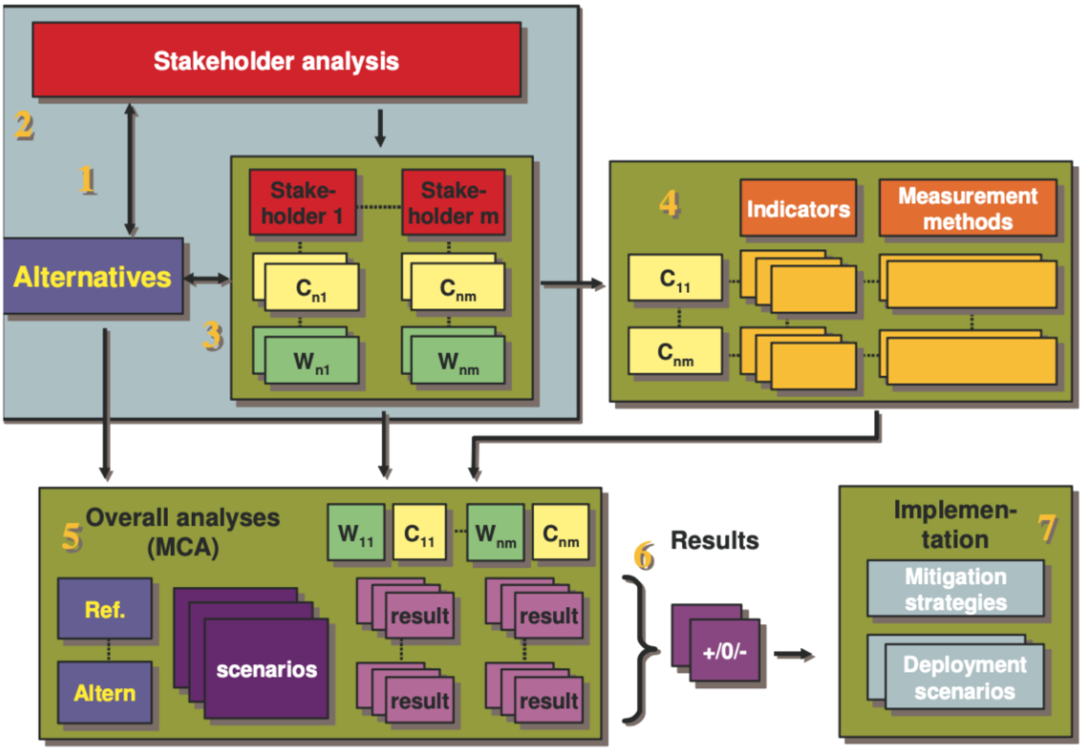


Figure 8: Methodology for Multi-Actor Multi-Criteria Analysis (MAMCA) (Macharis, 2005)

Step 1: Define alternatives

The first step is to define the problem and the alternatives. The alternatives, for example, can be different technological solutions, possible future scenarios with a base scenario, or long-term strategic options. In the MAMCA, at least 2 alternatives should be compared (Macharis, 2005).

Step 2: Stakeholder analysis

All relevant stakeholders must be identified, as well as their key objectives. (Stakeholders are people with an interest, financial or otherwise, in the consequences of any decisions taken)

(Macharis, 2005). It is a crucial step in MAMCA as each stakeholder (group) has a different criteria tree (Huang et al., 2020). An in-depth understanding of each stakeholder group's objectives is important to appropriately assess the alternatives (Macharis, 2005).

Step 3: Define criteria and weights

The stakeholder's objectives are translated into criteria and given relative importance in the form of weights. The weights of each criterion represent the importance that the stakeholder allocates to the considered criterion (Macharis, 2005). Several methods for determining the weights have been developed, including the allocation of 100 points for every criterion (Huang et al., 2020).

Step 4: Criteria, indicators, and measurement methods

One or more indicators are constructed for each criterion. These indicators can be used to measure whether or to what extent an alternative contributes to a criterion. Indicators can be quantitative, like money spent and reductions in CO_2 emissions achieved, or scores on an ordinal scale, like high/medium/low, for criteria with values that are difficult to express in quantitative terms. The measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation). This permits the measurement of each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Alternatively, participants can indicate how they expect each alternative to impact their criteria. (Macharis, 2005)

Step 5: Overall analysis and ranking

An evaluation matrix aggregates each alternative contribution to the objectives of all stakeholders by using Multi-Criteria Decision Analysis methods such as the Analytical Hierarchical Process (AHP) (Saaty, 2008) or Simple Multiattribute Rating Technique (SMART) (Edwards, 1977). In SMART, the alternatives are rated on a 10-point scale for each criterion, and a performance score for each alternative is calculated using weighted sums of these ratings. In AHP, a pair-wise comparison of each alternative is done for every criterion to determine their relative importance (Macharis, 2005).

Step 6: Results

The MCDA ranks the various alternatives and gives the strong and weak points of the proposed alternatives. The robustness of the results can be assessed through a sensitivity analysis to see if the result changes when the weights are changed (Huang et al., 2020; Macharis, 2005).

The MAMCA evaluates the different alternatives and supports the decision-maker in making a decision by highlighting for each stakeholder which factors of the alternatives have a positive or negative impact (Macharis, 2005).

Step 7: Implementation

The final step of the methodology involves the actual implementation when a decision is made. A feedback loop to the start of the MAMCA could also be created when new or modified alternatives are developed based on the new insights gained from the stakeholder's involvement (Huang et al., 2020; Macharis, 2005).

2.6.3 Personas

Personas are fictional but realistic representations of archetypal users created on the basis of user research (Cooper, 1999; Grudin & Pruitt, 2002). Originally developed by Cooper (1999) in the context of software design, personas have since been used in various fields such as marketing, product development, and policy-making (Gonzalez de Heredia et al., 2018; Vallet et al., 2020). Personas help visualize a typical user, support empathy, and help designers better understand the users they are designing for (Fuglerud et al., 2020).

Personas can be a powerful tool for participatory design because creating personas requires designers to engage with users (Grudin & Pruitt, 2002). These user models are used throughout the design process to ensure that the final products meet the target users' needs, behaviors, goals, and frustrations and facilitate communication within design teams (Cooper, 1999; Grudin & Pruitt, 2002). In addition, it allows designers to empathize with users, forces designers to consider social and political aspects that are otherwise often ignored, and adopt a user-centered approach during the development process (Gonzalez de Heredia et al., 2018; Grudin & Pruitt, 2002). The benefits of personas include focusing on the target audience by challenging assumptions, avoiding self-referential design, and prioritizing product requirements and target groups (Miaskiewicz & Kozar, 2011).

Creating personas

Personas can be based on qualitative and quantitative research, including interviews, focus groups, questionnaires, and demographic data (Fuglerud et al., 2020). Although there are different approaches, they are generally characterized by three main steps: 1) collecting user data, 2) clustering the data, and 3) transforming the data into narrative persona descriptions (Wöckl et al., 2012). Most persona studies still use a qualitative approach (Lee et al., 2021).

Qualitative and quantitative methods can be used to ensure that the resulting personas are both data-driven and contextualized (Reeder et al., 2011; Tu et al., 2010). The first step is to collect user data through questionnaires, surveys, and interviews to capture the target users' demographics, behavior, goals, and motivations. Based on this quantitative data, a cluster analysis is then carried out to identify different subgroups of users with similar characteristics.

From the resulting clusters, representative personas are developed by integrating qualitative insights from the interviews to provide a deeper understanding and context to the quantitative data.

2.7 Thematic Overview & Research Gap

Based on the literature review presented, a thematic overview is derived, which can be seen both as a guideline for the theoretical part of the thesis and as a summary of the literature research carried out. The table in Chapter 2.7.1 summarizes the core statements of the individual sub-topics resulting from this thesis's five main topics (themes): Current Trends, Mobility Behavior of Older People, Digital Literacy among Older People, Technology Acceptance in Later Life, and Participatory Approach. The literature review is concluded with the identification of the research gap in Chapter 2.7.2.

2.7.1 Thematic Overview

Table 1: Thematic Overview

Sub-Chapter	Key Message	Supporting Literature
Theme: Current Trends		
Population Aging	- Aging is a significant demographic shift, characterized by increased life expectancy and declining birth rates, leading to a larger population of older people - The proportion of people over 60 is expected to nearly double by 2050 - Older people are typically classified as those aged 60 or 65 and above, based on factors like retirement age and life expectancy - This thesis uses 60 years as the threshold - Older people are a heterogenous group	(Lutz et al., 2008) (Grundy & Murphy, 2017) (World Health Organization, 2024) (United Nations, 2019) (Mannheim et al., 2019)
Digitalization	- The rapid integration of digital technologies (DT) impacts all areas of society - While digitalization has proven to improve quality of life and access to public services, it also brings challenges for certain population groups such as older people	(Bundesministerium für Familie Senioren Frauen und Jugend, 2020) (Parviainen et al., 2017)
Theme: Mobility Behavior of Older People		

Mobility Behavior	- Mobility is important for older people as it enables autonomy, social connections, access to services such as healthcare and quality of life **Barriers & Needs** - For older people mobility is influenced by socioeconomic, demographic, financial, and physical factors - Health limitations have the highest influence, especially walking and vision impairments **Travel Patterns** - In general, older people travel less frequently, shorter distances and are more likely to be passengers rather than drivers - Walking becomes more common, while care use declines with age - Travel behavior also depends on other factors like gender, income, and geography	(Mollenkopf, 2004) (Li et al., 2012) (Nobis & Kuhnimhof, 2018)
Theme: Digital Literacy among Older People		
Definitions	- DT offers potential to overcome challenges related to aging - It promotes independence and enables better mobility and access to services **Digital Literacy** - The ability to use and understand computers and digital technologies **Digital Exclusion** - Exclusion due to the lack of integration and use of DT that are now considered a prerequisite for full participation in society **Digital Divide** - The separation between people who have access to and use digital media and those who do not **Digital Natives vs. Digital Immigrants** - Different understanding, skill levels and approaches when it comes to DT use and learning	(Oh et al., 2021) (Mannheim et al., 2019) (Gilster, 1997) (Seifert et al., 2018) (Schejter et al., 2015) (Van Dijk, 2020) (Prensky, 2001a, 2001b)
General DT Usage by Older People	- Older people generally use less DT for daily services and communication compared to younger people, often due to limited digital literacy	(Hunsaker & Hargittai, 2018)

	Smartphone Ownership - Has increased, especially due to COVID-19 pandemic, but still lags behind younger generations **Intersectionality** - Social inequalities and factors like gender, health socio-economic background, and prior experience with technology influences the ability to use DT **Barriers to DT Usage** 1. Physical Factors o Visual Impairments → Display & Letters too small o Motor Impairments → Problems with Touchscreens 2. Cognitive Factors o Memory & Attention Impairments → Apps too complex 3. Psychological & Social Factors o Lack of self-efficacy o Lack of Motivation o Fear / Security Concerns o Social & Support 4. Access to Technology o Cost o Trusted places o Quick obsolescence of devices o Maintenance o Jargon	(VuMA, n.d.) (Sixsmith et al., 2022) (Fang et al., 2019) (Neves & Mead, 2021) (Kim et al., 2016) (Harvey et al., 2019) (Kärnä et al., 2022) (Carney & Kandt, 2022) (Yoo, 2021) (Pangbourne, 2018) (Pangbourne et al., 2010) (Durand et al., 2022)
DT for Mobility / Smart Mobility	**Digitalization in Transportation** - Travelers are increasingly dependent on DT - New mobility services are likely to be of great benefit to older people, but could also lead to further exclusion from transport options **Smart Mobility** - Includes real-time traffic info, intelligent ticketing, improved taxi services, autonomous vehicles, shared services and MaaS - Access mainly through DT **Mobility-as-a-Service (MaaS)** - Integrates multiple transport modes into a single digital platform	(Banister & Bowling, 2004) (Pangbourne et al., 2020) (Stein et al., 2017) (Yigitcanlar & Kamruzzaman, 2018) (Butler et al., 2021) (Caiati et al., 2020) (Musselwhite, 2019)

	Challenges for Older People - Often Reluctant to adopt such services due to unfamiliarity, reliance on private cars and missing digital literacy	(Pangbourne et al., 2020)
	Theme: Technology Acceptance in Later Life	
TAM	- TAM is a model that predicts user acceptance and use of technology by focusing on two key factors: o Perceived usefulness o Perceived ease of use	(Davis, 1985) (Guner & Acarturk, 2020)
STAM	- STAM was developed to explain technology adoption by older people - Modified models include age-related constructs like physical, cognitive, and psychological functioning, as well as social relationships to predict technology acceptance	(Renaud & Van Biljon, 2008) (Chen & Chan, 2014) (Chen & Lou, 2020)
	Theme: Participatory Approach	
Co-creation	- Approach where users are involved in various stages of a product's lifecycle - Involving older people in the design process impacts customer satisfaction and acceptance	(Lu et al., 2017) (Mannheim et al., 2019)
Co-evaluation /MAMCA	- Provides a structured framework for decision-making by incorporating diverse perspectives from various stakeholders	(Macharis et al., 2004)
Personas	- Fictional but realistic representations of typical users based on user research - Help to ensure user-centered product development and policy-making	(Cooper, 1999) (Grudin & Pruitt, 2002)

2.7.2 Research Gap

Although the mobility of older people and their need for mobility aids in an aging society are receiving increasing attention, there are still significant gaps in research. This study addresses three key gaps that should make an important contribution to the design and evaluation of digital mobility aids.

1. Acceptance of different mobility aids

Although the importance of digital technologies for improving the mobility of older people is recognized, there are few studies on the practical acceptance of such technologies. Digital mobility aids, like MaaS, offer a theoretical solution to mobility barriers for older people. At the same time, however, there is a risk that the introduction of digital mobility systems will exclude older people. Therefore, this study aims to analyze the acceptance of digital mobility solutions.

2. Categorization of older people according to digital literacy and mobility habits

Older people form a heterogeneous group with different needs and abilities. While approaches to cluster older people already exist, a study that categorizes different groups of older people based on their digital literacy and mobility habits is still lacking. In this work, a cluster analysis approach is used to identify subgroups of older people and detailed personas are created to map the preferences and barriers of the different groups.

3. Combination of evaluation methods

Another aspect of this work is the use of STAM and MAMCA to analyze the acceptance of proposed mobility prototypes. These evaluation methods offer different perspectives and approaches to evaluating mobility solutions and can thus provide complementary insights into the needs and preferences of the user groups. As there are currently few studies that utilize these approaches (in combination), this work can lay the foundation for the development of a new, more comprehensive evaluation framework that is more responsive to the specific needs of older people.

Contribution of this research

By filling these gaps, this study makes an important contribution to research in the field of (digital) mobility aids for older people. It can clarify how barriers vary between the identified groups. The results of this research could ultimately contribute to the development of more inclusive MaaS solutions that consider the needs of different user groups in older age.

3 Methodology and Research Design

This chapter presents the methodology used in this study to answer the research question. The chapter is divided into three parts: Section 3.1 explains the general research design and why it was chosen, and the following sub-chapters explain the various steps and data collection methods used. Section 3.2 describes the composition of the samples that resulted from the respective methods, and Section 3.3 explains the approach used to analyze the data.

3.1 Research Design / Design Science Research

Choosing the right research methodology is crucial for the research design and, therefore, for answering the underlying research question (Bhattacherjee, 2012; Recker, 2021). This study's research question is: "*How do the barriers, needs, and technology acceptance levels vary among different groups of older people, and how can these findings contribute to the development of inclusive (digital) mobility solutions?""*.

To address this question, a design science methodology is chosen. Design science methods include methods for creating and evaluating novel artifacts such as new models, methods, and systems within a research process. Design science methods are characterized by the goal of constructing the artifact and demonstrating its usefulness in solving an organizational problem. In this context, an artifact refers to something humans constructed and does not occur naturally. (Recker, 2021)

The research interest lies in creating or modifying such artifacts to improve existing problem solutions or discover new ones (Recker, 2021). The chosen design science method is the design science research (DSR) process developed by Peffers et al. (2007) (based on the work of Hevner et al. (2004). DSR does not aim to explore, describe, or explain but to intervene and solve problems through constructed novel artifacts. However, qualitative or quantitative research can be combined or complemented within the design science methodology (Recker, 2021). Figure 9 shows the six steps of the DSR process and which (qualitative) data collection methods were used for each step.

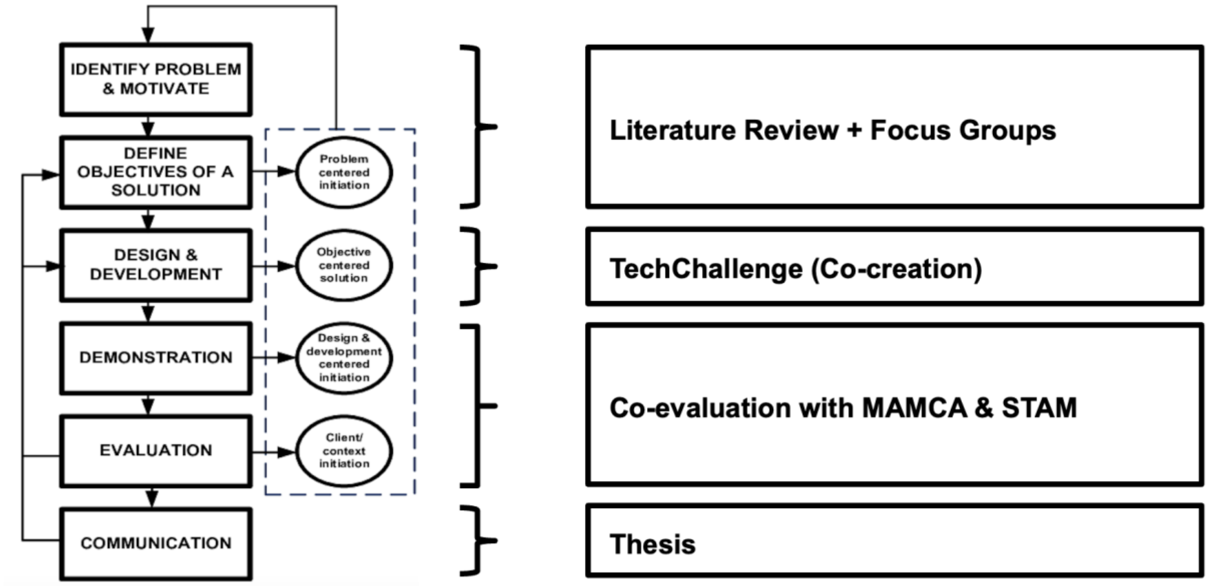


Figure 9: Design Science Research Process (based on Azasoo & Boateng (2015) and Peffers et al. (2007))

In the following subchapters, the six steps of the DSR process will be explored in detail, illustrating which data collection methods are integrated and combined in each step.

3.1.1 Problem identification and motivation (Literature Review)

The first step in DSR is defining the research problem and justifying the value of a solution (Peffers et al., 2007). A literature review and focus groups were conducted for this.

A literature review is crucial for identifying the research problem and thus formulating a research question that contributes to the academic field. It is also important to provide an overview of the current state of knowledge and identify key articles, theories, findings, and research gaps to justify the proposed research (Bhattacherjee, 2012; Recker, 2021). In addition, it provides strategies and methods used in previous research and provides a theoretical framework for the research (Recker, 2021).

The main related topics and theories were identified according to the underlying research question and examined in detail. The identified topics included digitalization, population aging, and the use of digital technologies across different age groups, recognized as general topics and current megatrends. Specific attention was given to the characteristics of older generations, particularly their mobility habits, data literacy, and use of digital technologies. The topic of technology adoption and acceptance by older people was explored by identifying the benefits and challenges they face with technology. Consequently, the Technology Acceptance Model (TAM) and the Senior Technology Acceptance Model (STAM) were identified as pertinent theories for this study and examined in greater detail. Additionally, two participatory approaches, co-creation and co-evaluation, were explored. However, the co-creation approach is not a central part of this work and was only mentioned for the sake of completeness (see Chapter 3.1.3). This study employs these methods to involve older people in the development process of a digital tool, which is the central focus of this work. Finally, the concept of Personas was discussed.

According to Bhattacherjee (2012), the literature review was conducted using a computerized keyword search in online search engines/electronic databases, especially *GoogleScholar* and the online university library of the Technical University of Munich *OPAC*. Often *GoogleScholar* leads to other databases such as *ScienceDirect*, *Jstor*, *Elsevier,* and *IEEE*. Combining search terms (with "AND" and "OR") has resulted in queries, some of which are listed below:

- („Older people“ OR „older adults“ OR „seniors“) AND („Digital technology“ OR „ICT“)
- („Older people“ OR „older adults“ OR „seniors“) AND „Digital Literacy“
- („Older people“ OR „older adults“ OR „seniors“) AND „Digital technology“ AND „Mobility“
- “Smart Mobility” AND (“Older People” Or “Elderly People”)
- ”(Senior) Technology acceptance model”
- („Co-creation“ OR „co-design“) AND „Digital technology“
- „Co-evaluation“
- „Multi-Actor Multi-Criteria Analysis“

In addition, a backward search was conducted to identify relevant papers cited in the articles that were selected (Webster & Watson, 2002; Xiao & Watson, 2019).

The literature review concludes with a thematic overview summarizing the key findings of the identified topics. It highlights the research gap and provides guidance on addressing the underlying research question.

3.1.2 Objectives of a Solution (Literature Review + Focus Group)

The second step of the DSR consists of deriving the objectives of a solution from the previously defined problem. The objectives can be of a qualitative or quantitative nature. Quantitative objectives can, for example, be related to the question of the extent to which a desirable solution is better than the current one. The objectives are qualitative if, for example, a new artifact is expected to support solutions to problems that have not yet been addressed (Peffers et al., 2007). Both types of objectives have been defined in this paper and will be presented and discussed later in the discussion. In addition to the literature review, workshops and focus groups were held to gain qualitative insight from the older people in order to better understand their views, behavior, and requirements and to validate and expand the objectives from the literature.

According to Bhattacherjee (2012) and Recker (2021), qualitative research methods are best suited for research phenomena that have not been extensively studied. Furthermore, qualitative research methods help to gain in-depth knowledge and insight into people's experiences and opinions (Recker, 2021). These methods include workshops and focus groups.

Workshops

As mentioned above, DSR usually involves developing and evaluating an artifact (Hevner et al., 2004; Peffers et al., 2007) , which is often done in workshops (Thoring et al., 2020).

Workshops are a common technique in collaborative design research that facilitates the evaluation of proposals and the co-creation of innovations (Sheahan et al., 2023). Workshops emphasize how participants can express themselves in different ways, encouraging and documenting discussions and constructive processes as a participatory approach where people can solve creative problems together (Westerlund, 2007). Moreover, workshops provide participants with a clear purpose and objectives. They typically involve predetermined roles and often include various research methods such as group discussions/focus groups, interviews, observations, and creative tasks (Thoring et al., 2020). The goal of the workshop can be twofold: either to generate new outputs such as ideas, concepts, and designs or to evaluate specific aspects or tools (Thoring et al., 2020). Since both objectives are pursued in the course of this work, group discussions (in focus groups) are used first to obtain new outputs, and later, the workshops are used to evaluate the results obtained.

Focus Groups

A focus group is defined as a group discussion led by a moderator whose role is to encourage participation and steer the conversation towards the topic of interest (Stewart & Shamdasani, 2014). It typically lasts two hours and covers a fixed list of topics, which six to twelve people usually discuss. Because participants can freely interact, influence, and be influenced by others, focus groups provide a far more natural setting than individual interviews and help to understand the range of opinions of participants across multiple groups (Krueger, 2014).

Following the procedure of Ørngreen & Levinsen (2017), the focus groups were audio-recorded (event recalling when audio-recording was not possible), and notes were taken by an observer. The discussion followed a (simple) semi-structured approach. Furthermore, a paper questionnaire was used to obtain insights about their familiarity with the topic and their socio-economic background. The respective procedure and structure are explained in more detail below.

Question Guidelines and Questionnaire

To extend the existing knowledge base and identify gaps, semi-structured interviews or discussions represent an opportunity to identify unknown but potential issues in a certain domain tailored to the objectives of the research (Saunders et al., 2019). The focus groups contain predefined themes and questions that are addressed based on the nature and relation of the interview partner with the research topic. This allows the moderator to omit and tailor the interview or discussions to specific needs to generate prioritized insights (Kallio et al., 2016; Saunders et al., 2019). Following the process of Kallio et al. (2016), the semi-structured discussion was pilot-tested with two older people fitting the target group to ensure that the questions were understandable and facilitated a stimulating discussion. The final interview guide used to guide the focus groups is shown in Appendix 3.

During the focus groups and later in the evaluation workshops, a questionnaire was distributed to collect demographic and socio-economic data as well as the preferred modes of transport of the participants. The questions were mainly based on the factors identified in the literature (see Chapters 2.2 & 2.3) that influence digital literacy and mobility. These include nationality, gender, age, education, income, residential status, work status, DT experience, and preferred transport mode. Like the interview guide, the two older people also tested the questionnaire to see whether the questions were comprehensible. The complete questionnaire can be found in Appendix 4. The questionnaire was written in German, as the study was conducted in Germany, and most participants did not speak English. The results were translated before the analysis.

3.1.3 Design and Development (*TechChallenge*)

The third step is the designing and development of artifacts. This includes defining requirements, functionalities, the overall design, and the actual creation of the artifacts (Peffers et al., 2007).

TechChallenge seminar organized by *UnternehmerTUM* was used as a central platform for the development. The challenge for the seminar participants was: “*How can we develop technology-based/digital mobility aids that enable older people to move safely and easily through cities and lead an active life by taking into account their specific needs, such as accessibility and user-friendliness?*” The seminar was supervised and guided by *VentureLab Mobility* in collaboration with the author of this paper.

The participants of the seminar were encouraged to enter direct dialogue with the target group, the older people, conduct interviews, make observations, and thus identify obstacles and problems that restrict the mobility and tech usage of older people. In addition, the seminar participants had the opportunity to participate in focus groups (see Chapters 3.1.1 & 3.1.2) to present their concepts and test initial prototypes. Co-creating the ideas and prototypes with the older people was essential to ensure that the solutions developed met the needs and wishes of the target users. However, this work does not focus on the detailed development process of the prototypes. Rather, it is about understanding the target group of older people for tech-driven and digital mobility aids and analyzing possible correlations between the acceptance of the solutions and the different types of older people. The developed prototypes are outlined below.

Prototype 1

Prototype 1 is a mobility aid designed to improve the walking ability of older people while reducing the risk of injury. The system is illustrated in Figure 10. The walking aid consists of a hip belt stabilizing the back (7), leg straps that are fastened above the knee (4), springs attached to the leg straps (5), and a webbing strap (3) that connects the springs with the hip belt. The pretension of the springs can be adjusted using the webbing straps. The energy stored in the springs (the pretension) helps lift the leg when walking by providing an upward force. This means that less effort is required when walking, which prevents fatigue and allows you to cover longer distances. The system also has two safety features consisting of an airbag (8) and an emergency call system. The airbag deploys when a fall is detected using an accelerometer and a CO_2 cartridge (6) and cushions the fall while an emergency message is automatically sent to a pre-selected contact.

Figure 10: Prototype 1

Prototype 2

The second prototype is a three-wheeled electric scooter specifically developed to improve mobility for older people, emphasizing stability, comfort, and safety. It has an adjustable seat and a large rear basket for carrying personal items. The scooter has a twist throttle and a mode selector, allowing the user to adjust the acceleration and speed settings before usage. This feature allows the scooter's performance to be adapted to the user’s physical abilities and reaction time. This scooter is intended for use in a shared service system, making it a convenient option for covering short distances, such as the first or last mile when using PT, or as an alternative to short trips with a car and bicycle. The scooter can be booked via an app. This enables real-time location tracking, simple hire and return processes, and safety functions such as emergency calls. The app is equipped with a user-friendly interface that includes large icons and minimizes interaction with the system to not overwhelm the user. The scooter and booking app are shown in Figure 11. To address common issues in current e-scooter sharing systems, like availability, improper parking, and charging of the scooters, the presented prototype can drive autonomously. This allows it to drive autonomously to a desired pick-up location (selected via app). After the user drives to their destination, the scooter can then autonomously park itself, pick up another rider, or head to a charging station, as needed.

Figure 11: Prototype 2

Prototype 3

Prototype 3 is a social engagement solution with the goal of addressing the issues of loneliness and inactivity among older people. WhatsApp is a well-known platform that many older people regularly use to stay in contact with family and friends. Therefore, this prototype utilizes the familiarity of WhatsApp to promote activities and events for older people. A chatbot within WhatsApp is used so that older people can easily discover local activities and events without learning new apps or navigating unfamiliar websites. The users can simply text with the chatbot, share their interests, location, and whether they want to network with other people. They then receive personalized offers and events that match their profile based on the database of events that local senior centers or other institutions have published. Furthermore, it can connect people with similar interests if they're interested in connecting with other people. The chatbot encourages participation in local events and fosters connections with others who share similar interests, promoting physical activity and reducing social isolation. Users can also receive reminders, traffic alerts, and navigation aids through the chatbot to make it easier to get to the events. Figure 12 shows an example of an interaction with the chatbot after the user described their hobbies.

Figure 12: Prototype 3

Prototype 4

Prototype 4 is a digital application designed to help older people with their mobility by providing personalized travel information, transportation options, and help with navigation. It has a simple, easy-to-use interface that allows older people to get travel information without being familiar with using an app. Family members, friends, or caregivers can use a separate app to enter all the necessary travel details, such as frequently visited locations, preferred modes of transportation, and any mobility limitations. The locations can be saved with a corresponding icon or image. If the older person is familiar with apps, they can enter this information themselves. The older person has a separate interface, as shown in Figure 13. They get all the travel information by clicking on the icon representing their desired locations. The directions are tailored to the needs of older people and can include pictures of the route to make navigation easier (see Figure 13, top left). If, for example, the usual means of transport is not available, the system suggests alternatives, such as a taxi, which can be booked with a single click in the same application (see Figure 13, bottom left).

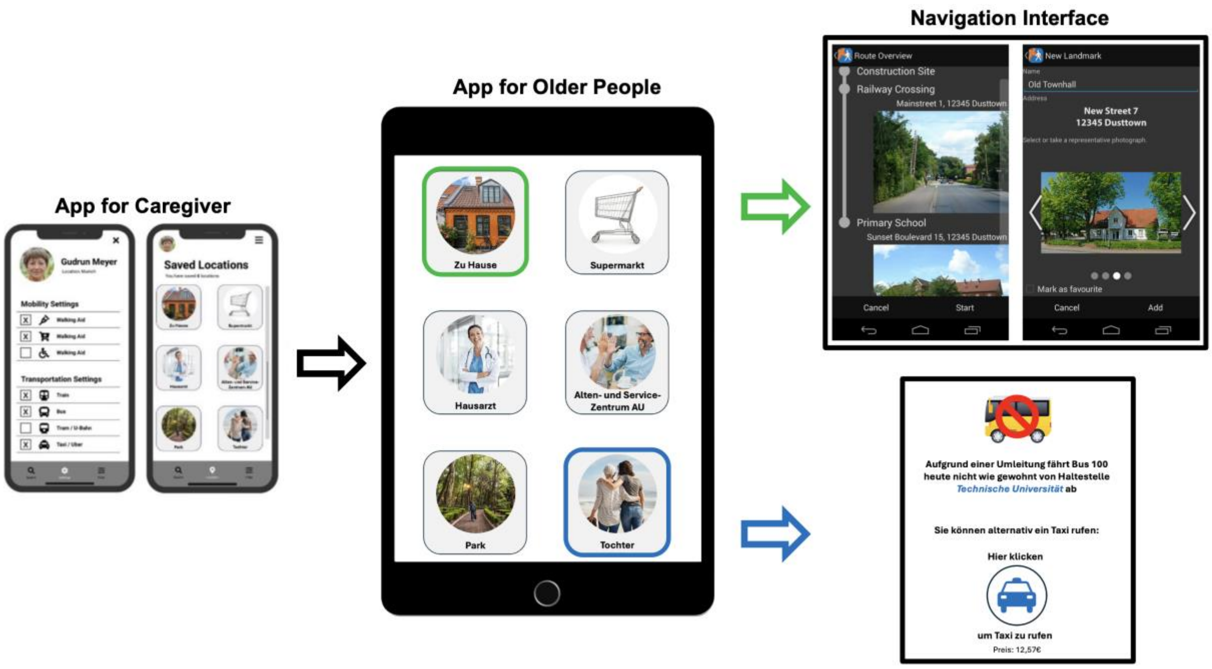


Figure 13: Prototype 4

3.1.4 Demonstration (Workshop)

In this step, the devolved prototypes are demonstrated and tested in the workshops to gather detailed feedback. Based on that feedback, the prototypes can be refined and improved (Peffers et al., 2007). To measure the effectiveness of the prototypes in solving the problem, this step is combined with the evaluation of the demonstrated prototypes (step five).

3.1.5 Evaluation (STAM & MAMCA)

Step five of the DSR is the evaluation of the artifacts. This involves observing and measuring how well the artifact addresses and solves the defined problem. Comparisons, objective quantitative performance measurements such as satisfaction surveys, user feedback or simulations can be used for the evaluation. Based on the research settings and the results of the evaluation, it is possible to iterate back to the third step (3.1.3 Design and Development) to improve the artifact. Alternatively, the improvement can also be deferred to subsequent projects. (Peffers et al., 2007)

In order to evaluate the prototypes and to assess their acceptance by older people and other relevant stakeholders, attitudes towards the prototypes will be measured using different questions and criteria. The Senior Technology Model (STAM) (see Chapter 2.5.2) and the Multi-Actor Multi-Criteria Analysis (see Chapter 2.6.2) will be used for this measurement. These models provide a structured approach for evaluating the prototypes with different stakeholders and groups. The further justification and the exact application are discussed in more detail below.

STAM Questionnaire

As described in Chapter 2.5.2, the modified STAM from Chen & Chan (2014) and (Chen & Lou, 2020) assesses older people's technology acceptance by analyzing factors such as PU, PEOU, fear of technology (gerontechnology anxiety), and health-related characteristics. In this study, this assessment is carried out using a modified questionnaire based on the work of Chen & Lou (2020) quantifying older people's attitudes toward the prototypes presented. Of the original 14 STAM questions (Figure 7), three questions were excluded:

FC3: Your financial status does not limit your activities in using technology.

Although the participants were provided with a rough cost estimate, it was not yet possible to provide precise information on the costs, as no concrete business model has yet been developed, and the general acceptance of the prototypes is to be analyzed first. In addition, subsidies can also play an important role in pricing, which has not yet been analyzed further. For this reason, the participants were unable to give a meaningful answer as to how their financial situation would affect the acceptance of these prototypes, which is why this question was removed from the questionnaire.

FC4: When you want or need to use technologies, they are accessible for you.

Since the mobility aids presented are prototypes that are not yet on the market, it makes little sense to ask about their availability, as they are not publicly accessible. Therefore, the participants cannot make a proper statement about accessibility.

ANX1: You feel apprehensive about using the technology.

This question is similar to question ANX2, which deals with the concern of making mistakes when using the technology. To avoid redundancy and reduce the length of the questionnaire, ANX1 was removed, but ANX2 was retained to ensure that the anxiety aspect was still captured without unnecessary overlap.

The final questionnaire was translated into German and contains a 7-point Likert scale ranging from *strongly disagree (0)* to *strongly agree (6)*. It can be found in Appendix 5.

MAMCA

As described in section 2.6.2, the MAMCA process consists of seven steps. The first step, the definition of the alternatives, has already been dealt with in section 3.1.3, where the four final alternatives or prototypes were presented. The *Quadruple Helix Framework* was used to select the relevant stakeholders (Lindberg et al., 2014).

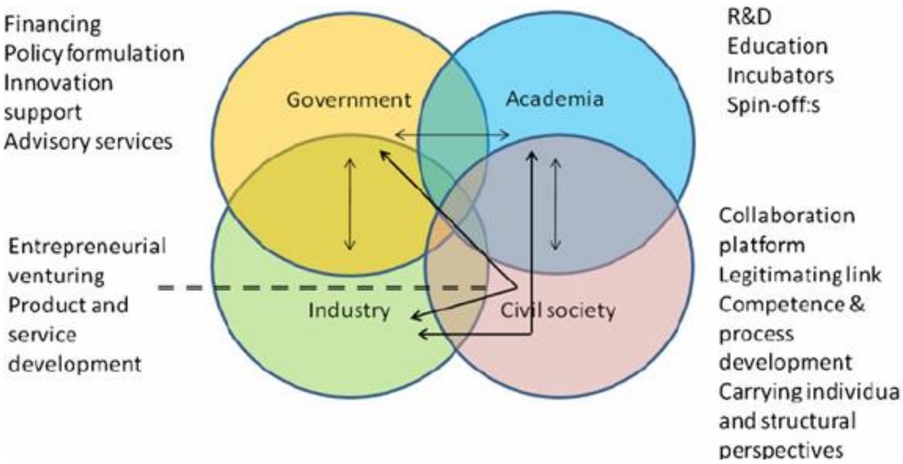


Figure 14: Quadruple Helix innovation system (Lindberg et al., 2014)

Older people were selected as stakeholders from the *Civil Society* cluster, which in turn was divided into three different groups (clusters) (see section 4.2). Senior citizens' councils from two cities - a large city and a small town - were selected for the *Government* cluster. Two representatives of *VentureLab Mobility* were included for the *Industry* Experts, while the *Academia* cluster was represented by a researcher from the *Universidad Politécnica de Madrid (UPM)*. A detailed description of the stakeholder groups can be found in Chapter 3.2.2. The third step, defining and weighing the criteria, was carried out separately for each stakeholder group. As several workshops with several participants were held for the *Civil Society* and *Government* groups, the criteria were developed jointly for all stakeholders in these groups in an initial workshop with a small group of senior citizens' councils and older people. For the evaluation workshops with the older people and the senior citizens' councils, which took place in person, a physical evaluation form was created that reflects the previously defined criteria. This evaluation form contains a total of five columns in which a weighting can be entered for each criterion, as well as the evaluation of the prototypes and a baseline. An example of this evaluation form for the older participants can be found in Appendix 6. The criteria were weighted on a scale of 1 to 100, while the prototypes and baseline were rated on a scale of 1 to 10. The results were then entered into the MAMCA software, analyzed, and visualized. A digital template was provided for the other stakeholder groups, in which the stakeholders could enter their criteria independently. Otherwise, the structure of this template was identical to that of the physical evaluation form.

3.1.6 Communication

The last step aims to communicate the findings, artifacts, and results developed during the research process to the relevant target groups (Peffers et al., 2007). This includes the involvement of a researcher from the *Technion - Israel Institute of Technology* in the continuation of the research and the eventual publication of this work.

3.2 Data Collection Method / Sampling

This chapter outlines the sampling strategy used in this study, focusing on the challenges of sampling older people, and describes the samples that were generated in this study.

Sampling Strategy

When studying population groups where the entire population cannot be identified or participate, samples are used to collect data that is representative of the target population (Stratton, 2021). The inclusion criteria for the target population of this study comprise people aged 60 years and older. It is a heterogeneous group that differs in terms of background, abilities, motivations, and personalities (see Chapter 2.1.1). For effective research, it is important to consider various factors such as functional ability, disability, gender, professional and educational background, cultural differences, computer literacy, and experience (Mannheim et al., 2019).

However, recruiting a diverse group of older adults is a major challenge. Health impairments, socially disadvantaged living conditions, and limited digital engagement make it difficult to reach many older people (Kammerer et al., 2019). Therefore, traditional face-to-face studies often rely on partnerships with community organizations such as senior centers, healthcare facilities, and public libraries to recruit participants (Verma et al., 2021; Xie & Bugg, 2009).

Given the difficulties in accessing the target population, this study used a combination of two non-probability sampling techniques, namely convenience and maximum variation (heterogeneity) sampling. Researchers often use a combination of two or more sampling strategies to select evidence that is appropriate for their purpose (Suri, 2011).

Convenience sampling

In convenience sampling, participants are selected based on their availability and willingness to participate. This method is particularly useful in qualitative research, where researchers often recruit participants in specific locations (such as hospitals) (Stratton, 2021). Accordingly, these are then random selections in which individuals are not specifically addressed, but a general call for participation is published (e.g. via a flyer) (Döring & Bortz, 2016). This can lead to a motivation bias in the study, as the motivation to participate may depend on interest in the research topic (Stratton, 2021). For this reason, this method is also referred to as self-selection.[4] It is important to note that associations and effects found with a random sample cannot be generalized to a target population (Stratton, 2021).

Maximum variation (heterogeneity) sampling

Maximum variation sampling was also employed to complement convenience sampling and ensure a more comprehensive understanding of the older population. In this method, participants are approached through different recruitment channels to create a relatively large and diverse sample. While all participants share the target characteristic (in this case, age 60 years or older), their internal heterogeneity is not precisely controlled beforehand but examined during data analysis (for example, through creating Personas) (Döring & Bortz, 2016). The sample is created by identifying the most important dimensions of variation and selecting cases that differ as much as possible. This approach produces high-quality, detailed descriptions of individual cases that are useful for documenting uniqueness. It also identifies important common patterns that emerge from the diversity (Patton, 2014; Suri, 2011).

However, for reasons of research economy, it may also be necessary to terminate the study earlier, for example, if it becomes apparent during the course of the study that many other criteria are important for the phenomenon under study, but the necessary resources for a correspondingly large sample are not available (Glaser & Strauss, 2017).

[4] However, it should be noted that there is a certain degree of self-selection in all empirical studies, as participation is generally voluntary for reasons of research ethics (Döring & Bortz, 2016).

3.2.1 Focus Groups (Method 1)

Reaching older people to participate in research is challenging, especially due to their limited digital accessibility (see Chapter 2.3) and their restricted mobility (see Chapter 2.2). In order to reach a wide range of participants, this study selected different places where older people regularly gather. Various organizations like senior centers (*Alten- und Seniorenzentren (ASZs)*), churches, and assisted living facilities were approached via mail and phone. After the agreement from the organizations, physical flyers were displayed at the locations to announce the focus group meetings, which should then take place on-site. A sample flyer is attached in Appendix 7. Three focus groups were conducted: one at an ASZ in Munich and two at an assisted living facility in Garching. These two locations were selected due to their proximity to the research facility (TUM). Munich is a large city with around 1.6 million inhabitants (muenchen.de, n.d.-b) with a diverse population, and resources such as senior centers and a good public transport infrastructure. Garching represents a smaller suburb with approximately 18,000 inhabitants (Universitätsstadt Garching, n.d.), which provides an insight into the mobility needs of older people in the suburbs. By selecting these locations, greater diversity in the sample is ensured, and different needs between large cities and suburbs can be analyzed.

Despite initial interest, there was a high attrition rate (approximately 30%), resulting in three participants in the ASZ focus group and seven and four participants in the two assisted living facility sessions, respectively. Notably, two participants attended both sessions at the assisted living facility because they had missed the second part of the first session, reducing the effective sample size to 12 participants. The final sample (n=12) consisted of predominantly female participants (n=11), with only one male participant. The age range was between 72 and 92 years, with an average age of 83.1 years (median 85.5, SD 7.0).

As the groups consisted of between three and seven participants, it was important to capture the views of all participants, as it was expected that those with greater language skills and confidence would lead the discussion (Krueger, 2014). Therefore, a moderator facilitated the focus groups and asked open-ended questions to stimulate discussion. Each session was designed to last approximately two hours and included testing of early-stage prototypes. Similar to the procedure of Ørngreen & Levinsen (2017), the focus groups were audio-recorded, and notes were taken by an observer (only in the first two sessions). A paper questionnaire was used to obtain insights about their socio-economic background, which is used for the persona creation Appendix 4.

3.2.2 Evaluation (Method 3 & 4)

In order to evaluate the prototypes, several stakeholder groups were approached to ensure different perspectives (see Chapters 3.1.4 & 3.1.5). These Stakeholder groups include civil society, government, industry, and academia (see Chapter 3.1.5).

Civil Society (Older People) & Government (Senior Advisory Council)

The evaluation sessions were organized through contacts with two senior citizens' advisory councils, one in Munich and one in Neu-Anspach. Neu-Anspach was added to represent a small town in a rural area in addition to a large city (Munich) and a suburb (Garching). The town is located in the Hochtaunus district in southern Hessen and has a population of around 14,600 (Neu-Anspach, n.d.). This further expanded the sample to cover an area with poor access to services and public transport. The senior advisory councils play a crucial role in representing older people’s needs and interests, making their involvement in the evaluation process valuable. They are also in direct contact with senior citizens and organize various events.

Two evaluation workshops were held at a “PC user group for seniors” organized by a senior citizens’ advisory council of Neu-Anspach. An invitation flyer was also distributed to the Senior Citizens Advisory Council in Munich, who shared it with their network to further broaden participation. As a result, a total of 30 participants were reached, including four senior citizens' advisory councilors[5]. The two PC groups were attended by 13 and eight people, respectively, bringing the total number of participants to 21. The remaining nine participants came mainly from Munich and were reached via the invitation flyer distributed by the Seniors' Advisory Council. The evaluation took place on five dates, each with one to three participants. The final sample consisted of women (n=10) and men (n=20), with participants' ages ranging from 64 to 89 years and an average age of 74.0 years (median 71.5 years).

Each session began with the moderator explaining the evaluation methods and then introducing the four prototypes. Afterward, the participants had the opportunity to try and evaluate the prototypes. For logistical reasons, Prototype 3 (the e-scooter) could not be transported to the sessions. Instead, a digital presentation of this prototype was shown, including images, functional descriptions, and potential use cases. The evaluations were not recorded, as the results were documented in the form of a questionnaire.

[5] The involvement of these advisory councils was particularly valuable because their members could offer insights based on their own experiences as older adults while also reflecting the needs and concerns of the wider senior population they represent.

Industry Experts

The industry expertise for evaluating the prototypes was provided by two experts from *TUM VentureLap Mobility*, an innovation platform within *UnternehmerTUM* that focuses on mobility solutions and start-up development. These experts provided insights into the feasibility of the prototypes from a market and innovation perspective.

Academia

The academic perspective was represented by a postdoctoral researcher from *Universidad Politécnica de Madrid*. The researcher specializes in Sustainability and Urban Regeneration, focusing on age-friendly cities and life-long design. In addition, the prototypes were subjected to a theoretical and research-based evaluation to determine the extent to which they are in line with current academic findings on sustainable urban mobility with a focus on the needs of the aging population.

3.2.3 Persona Questionnaire (Method 2)

The overall sample for creating the persona consisted of 42 participants who attended either the focus group sessions or the assessment workshops and were recruited from senior centers, assisted living facilities, and senior PC user groups to ensure a diverse representation of the older population. However, three questionnaires could not be used due to missing data, as not all relevant questions were answered. Therefore, the final sample size for the cluster analysis after list-wise deletion was 39 cases, including 11 people from the focus groups and 28 people from the evaluation sessions. The final sample consisted of women (n=19) and men (n=20), with participants ranging in age from 64 to 92 years and an average age of 77.1 years (median 77.0 years). The age and gender distribution is shown in detail in Table 2.

Table 2: Age and gender distribution of the sample for persona creation

	Female	Male	Total
60-74	6	10	16
75-84	6	7	13
85+	7	3	10
Total	**19**	**20**	**39**
Average Age	79.6	74.8	77.1
Median Age	81.0	73.5	77.0

3.3 Data Analysis

The data collected in the focus groups, questionnaires, and evaluation forms were thoroughly analyzed and interpreted to answer the underlying research question. This chapter describes the methods used to analyze the data and is divided into qualitative and quantitative analyses.

3.3.1 Qualitative Analysis

Analyzing the content generated from the focus groups is an important aspect of leveraging its insights (Patton, 2015). Therefore, the focus groups were recorded (Chapter 3.2.1) and transcribed using the transcription software *TurboScribe* (TurboScribe, 2024), which ensured accuracy and efficiency in converting the spoken content into written text. Afterward, coding was employed as the primary data analysis technique to analyze and interpret the qualitative data from the focus group discussions, as it is one of the most common techniques for extracting qualitative data and interpreting it for deeper insights (Recker, 2013).

Content Analysis, as outlined by Bengtsson, (2016), was applied to determine and analyze themes and topics that occurred during the focus groups. This approach allows the usage of both inductive and deductive coding strategies (Bengtsson, 2016) . It ensures enough flexibility so that the analysis can capture both emerging themes and predefined concepts from the literature review (Gibbs, 2018). The software *MAXQDA* (MAXQDA, 2024) was used to manage and organize the coding process, ensuring a structured and efficient data analysis process. It allowed for easy categorization and retrieval of coded data, ensuring that all relevant themes were captured and analyzed. To ensure the quality and transparency of the analysis, a codebook (Appendix 8) was created that shows the path from the raw data to the final results (Bengtsson, 2016). This codebook clustered the data into recurring themes, providing a systematic structure for the analysis. The data analysis consists of four stages.

The first stage is *decontextualization*. The transcribed data was read to get a sense of the general themes and important points raised by the participants. Initial codes were assigned to relevant text segments, representing the pre-defined concepts from the literature review (such as the categories defined for the barriers of DT use from Chapter 2.3.3) and emerging themes.

The second stage is *recontextualization.* Once the initial coding was complete, the transcripts were reviewed and refined again to ensure no critical data segments were overlooked. The objective was to align the data segments with the research questions and exclude information that was not pertinent to answering the research question.

This is followed by *categorization,* where codes are categorized into main and sub-categories to group recurring themes. During this iterative process, the codebook was updated with these categories to provide a structured method for categorizing and interpreting the data.

In the final step, *compilation*, the themes are summarized, and patterns and variations in the participants' responses are identified. Variations and patterns in the participants' responses could be identified by comparing similarly coded texts in the different focus groups. An overview of the categories, codes, and example quotations can be found in Appendix 8.

This complementary approach enabled a more detailed understanding of the experiences and perceptions shared by the different participants. It was used to draw out findings and link these to the literature.

3.3.2 Quantitative Analysis

Hierarchical Clustering

Following the paper of Reeder et al. (2011), hierarchical clustering was performed using RStudio software (version 2023.06.1+524) to identify different groups of older people with similar demographic, physiological, social, and cognitive characteristics that would eventually form the personas. In cluster analysis, each individual (or data point) is compared with every other individual in the dataset by measuring the similarity or dissimilarity. One of the most comment choices for this is the *Euclidean distance*, which measures the 'straight-line' distance between two data points (Kaufman & Rousseeuw, 2009). Once the distances have been calculated, the individuals are grouped into clusters according to a predefined algorithm. Here, Ward's method (*Ward.D2* in R) was used, which forms the cluster by minimizing the within-cluster variance (Kaufman & Rousseeuw, 2009; Ward Jr, 1963). As a result, the individuals within a cluster should be more similar than those in other clusters. (Bartholomew et al., 2008)

The resulting dendrogram visually represents the hierarchical relationships between the individuals. The branches or nodes indicate the clusters that form at different levels of similarity. The dendrogram can be cut at a desired level (distance or height) to form the desired number of clusters (Everitt et al., 2011).

Correlation Matrix

In addition, a correlation matrix was created to analyze the influence of the individual characteristics used in the cluster analysis. Similar to the study by Reeder et al. (2011), the Pearson correlation was used to obtain a statistical overview of the linear relationship between the individual characteristics and the STAM results. This allows for analyzing which demographic and socio-economic characteristics could strongly influence technology acceptance.

4 Results

This chapter presents the results of the study. The structure of the results is based on the different methods that were used. All quotes from Chapter 4.1 are based on the focus group transcripts, which can be found in the appendix. All data used in Chapters 4.2 and 4.3 come from the questionnaires handed out to the participants during the focus groups and evaluation workshops. To provide a better overview of the results, there is a brief summary of the most important findings of each sub-chapter at the beginning of each section, labeled 'Key Findings'.

4.1 Focus Groups

In line with the literature review's structure, the focus groups' findings are divided into two sections: *Mobility Behavior of Older People* and *Digital Literacy among Older People*.

4.1.1 Mobility Behavior of Older People

Key Findings
• With increasing age, movement outside the home becomes more and more difficult, which leads to an unavoidable restriction of mobility • Therefore, older people tend to make shorter trips and often prefer to wait for visits rather than make the trips themselves • PT is a common mode of transport for older adults, with the underground favoured due to its accessibility, while buses were described by some participants as dangerous and poorly accessible

Travel Distance

As mentioned in Chapter 2.2, older adults tend to take shorter trips and travel fewer than their younger peers. The statements from the older people in the workshops confirmed this trend. They mentioned that their range of movement decreases with age.

"Over time, you learn that the circle of life becomes narrower, and you have to learn to accept that because otherwise you despair." – FG9

One reason for this phenomenon is that longer journeys become too strenuous and time-consuming (FG4, FG9). FG9 also mentioned that she doesn't miss the longer journeys and just waits to be visited rather than taking the initiative herself.

However, these restrictions on travel distance were mentioned more by the older participants (80+) or those with severe health restrictions.

Car

Only three of the 12 participants from the workshops have a car. Two of them are over 80 years old. But many mentioned that they missed their car but had to give it away a few years ago (FG7, FG4, FG5, FG8). The car gave them more freedom and independence, allowing them to be more spontaneous and adventurous.

"[…] I had my car at home and enjoyed the freedom it gave me. Quite a lot of freedom of movement, I could also do things on my own in the evening […]" – FG8

Bus

Six participants mentioned using the bus regularly, though opinions varied regarding the accessibility. Some participants were positive about the accessibility of the bus, mentioning that the stops are usually elevated and the bus drives close to the curb, making it easy to board (FG4, FG10).

"Well, I have to say that most of the stops where I get on and off are raised. […] And most bus drivers really drive right up to the edge so that you can get on and off easily. So, I'm always very grateful to them. – FG10

However, others mentioned that the bus drivers are not considerate and do not stop where they should stop (FG6, FG8).

"It's not enough if I have the […] the rollator. The distance, they don't stop where they're supposed to. […] But that is then due to the bus driver. You can't bridge the gap. I've already fallen several times." – FG6

In general, many of the participants have a walker (rollator), and the step to the bus is a significant obstacle (FG6, FG8, FG10). They often depend on other people's help if the bus stops are not raised or the bus driver does not approach the curb properly (FG4, FG6, FG8, FG10). Additionally, even participants who haven't experienced issues with the bus themselves stated that they were afraid to use the bus because they had heard from their peers about falls or negative experiences with drivers.

"And with the bus, I'm afraid to move; I've heard too many experiences from others who have fallen and broken all kinds of things and the trouble with the drivers, so I avoid the bus." – FG8

Subway

The most frequently used mode of transport by the 12 participants was the subway, which eight people mentioned using. The subway doesn't have that problem with the gap while entering, making it more convenient for older people with health issues like arthritis:

“Due to my state of health [arthrosis], it is no longer possible to go on such long tours. So, traveling by bus and so on is out of the question. The only thing left is the subway.” – FG6

Waiting Times

An interesting difference between the younger and older participants was the planning and efficiency of using public transport. The younger participants prepared their journeys carefully and used navigation apps to obtain information about PT. The older participants showed the opposite picture. They usually have the departure times roughly in their heads or simply wait longer at the stop. They stated that efficiency is no longer important to them and that they accept the waiting times.

“… [the train] drives to Salzburg every hour. And my God, if I can't reach one of them, I'll take the next one. I've got time to wait.” – FG4

Taxi

Taxis were not mentioned frequently. Only two participants said that they occasionally used taxis. HM talked about the advantages of taxis and how convenient they are in other countries where they are cheaper, but said that they are far too expensive in Germany:

“[Taking a taxi] It’s much easier, but that’s unthinkable. A taxi is a fortune.” – FG8

Three participants also talked about traveling certain routes as a passenger in a car with friends or family. In particular, trips to the doctor or out-of-town visits were mentioned here (FG6, FG7, FG10).

Bicycle

The bicycle as a transport mode was mentioned three times. One lady still uses her bike with her 86-year-old (FG5). Two ladies talked about not using it anymore because it’s too dangerous (FG1, FG7). The younger lady (FG1) talked about not using the bike anymore since there are too many bikes in Munich nowadays, which increases the risk of injury.

“And gave up cycling […] because there are simply too many bikes.“ – FG1

Walking

For most participants, walking is a common mode of transport. Most of the 80+ participants had a walker (rollator) as a walking aid. Stairs are a major barrier for them. One person mentioned that the elevators in the subway stations in Munich often don’t work and that this is way better in Austria (FG4). Another person talked about an event for seniors in a rooftop bar, but there was no elevator, so many of them couldn’t go.

“[…] there is no lift. It’s on the third or fourth floor without a lift. And then, of course, all the senior citizens said it was dead for us.” – FG3

Health-related Problems that reduce social contact and radius

Several participants pointed out that health problems can limit social interactions and reduce activity radius. A common theme that emerged in the discussions was that older people tend to avoid public spaces because they feel uncomfortable due to their health condition. For example, some participants reported that visiting restaurants or cafés is becoming increasingly difficult due to the noise associated with hearing problems, which leads to discomfort and difficulties in socializing.

“That's what you don't do as an older person. You'd rather make yourself comfortable at home. Or invite a friend or two if it's still feasible.” – FG9

Participants (FG9, FG11) also report that as they get older, health problems become more frequent and make it increasingly difficult to move around and go out. This often leads to an unavoidable restriction of mobility in old age and limits the radius of action and social interaction.

“But at some point, the moment will come when you have to stay in your chair. And then you have to be satisfied. I think we're all like that.” – FG9

4.1.2 Digital Literacy among Older People

Key Findings
• The main reason for using DT is to keep in touch with family and friends, especially via WhatsApp • Some participants felt excluded by digital services and the attitude towards DT also varies among older people • Many older people have only adopted DT through the encouragement and support of family members or friends

General DT Usage

Only one participant didn’t own a smartphone or computer. The primary reason for smartphone ownership was to communicate with family and friends. The most popular application for this is *WhatsApp*. All smartphone owners (9/12 participants of the workshops) said they use WhatsApp. FG2 stated that he prefers to use Signal or Telegram due to privacy concerns. FG1 also reported that she uses Signal and knows some people who refuse WhatsApp and only use Signal for security reasons. FG8 and FG4 also mentioned using WhatsApp to make international calls because they are free and would otherwise be too expensive. Other applications mentioned by the participants were navigation or travel apps such as *Google Maps* (FG1, FG3), *Maps.Me* (FG1), *MVGO,* and *MVV* (FG1, FG5).

The computer was mainly used for e-mails and research on *Google*, as the larger screen is more comfortable (FG4, FG8, FG10). Other tasks on the computer were playing cards (FG4, FG12) and creating photo albums (FG5) or using *ChatGPT* (FG1). Communication tools like *Skype* (or *WebLink*) were also mentioned (FG2, FG4).

Reason for DT

Ten out of 12 of the participants own a computer, and nine out of 12 own a smartphone. Most of them acquired a smartphone or computer to stay in contact with friends and family (FG4, FG5, FG6, FG7, FG8).

"I actually bought this just to talk to my grandchildren via WhatsApp […]" – FG4

One of the younger participants bought her phone because she was going on a long trip. Before that, she had been reluctant to use a smartphone for a long time because she was afraid of the radiation (FG1).

Attitude towards DT

One important finding from the focus groups was the different attitudes towards technology and digitalization. Some participants tend to have a positive attitude towards technology and digitalization in general, or at least accept it and try to adapt to the technologies:

"But if I'm interested in something, I try to get to the bottom of it and find something. It doesn't always work, but most of the time. I also have a tablet, but I inherited it from the children. But I use it relatively rarely. Because I obviously haven't explored the possibilities enough yet. And I have to keep searching." FG7

In contrast, some of the older participants (especially those over 85) were more critical of digitalization and the increasing use of technologies.

"Yes, I say to myself, it doesn't have to be that way [that everything is getting digital]. It has worked so far. I realize that technology is moving on, but the old people should be taken into account" – FG6

Digital Exclusion

Building on the previous point, some older people feel excluded because more and more services and offers require apps or can only be done online. Among other things, train tickets, plane tickets, and discounts/offers in shops and supermarkets were mentioned.

„Even the supermarkets only give discounts if you use the app. I think that's anti-consumer behavior towards older people who can't use it now.“ – FG3

“What really annoys me in this context is that the railway has changed the Bahncard to computer only. I was so annoyed about that because it automatically excludes older people. Not everyone of any age has a computer or mobile phone. And the result was that I canceled my Bahncard.” – FG5

Switching to online banking and card payments is also often a major barrier for older people. For example, one participant (FG3) reported that during the COVID-19 pandemic, lunch at a senior citizens' meeting place was switched from cash to debit cards or invoices, and many older people stopped coming because they couldn't or didn't want to.

Online Banking and Debit-Cards

Online banking and card use were frequently discussed in the focus groups. While some users were satisfied with online banking (FG1, FG3) and received help directly from the bank, others had their reservations. Two participants discussed that older people are more vulnerable to robbery and theft of their debit cards (FG10, FG11). They are, therefore, very careful when shopping or withdrawing money and sometimes even let their family do it for them.

Motivation and Lack of Motivation

Lack of motivation was the main reason for not embracing digitalization and new technologies. Although they see the benefits of change, they simply don't want to learn new things because they find it difficult and like doing things the way they've always done them.

“[…] the whole digitalization thing, I'm too old for that; I'm not interested in that either. I'd rather do things in person or over the phone or something like that. And not be dependent on digital connections.” – FG6

“[Learning to use DT] That is now a tedious business for us older people, and that we no longer want to do it, so I'd rather do less and do what I know.” – FG9

On the other hand, some of the older people showed a high motivation to learn and tried to learn or find out things on their own. For example, FG1 read magazines such as *PC World* or *Chip.de* to learn more about computers and smartphones, and others said that they tried to understand some functions of their smartphones themselves and were willing to learn (FG5, FG7).

Personal Contact

Another reason for rejecting or not using digital products or services that crystallized from the focus groups is the desire for personal contact.

“[…] do you have an e-mail? I do, but I don't want to correspond by e-mail. I would like to be called by landline. Yes, because I am more or less interested in personal contact.” – FG6

The same applies to online shopping. As FG4 and FG9 mentioned, they prefer to see and try out products.

Tech Support

In most cases, the older participants only started using a new technology after it was suggested by someone close to them. For example, one participant mentioned that she uses several applications that she would never have discovered or found useful without her son's encouragement.

„Most of the ones [Apps …] was set up for me by my son […] I would never have realized that I needed it. I use it now, too. But without my son, I probably wouldn't have it at all. – FG5

Support emerged in the focus groups as one of the most important issues for the use of DT for older people. It was the most frequently mentioned topic in all three workshops. Even one of the tech-savvy participants who helps other older people with their technical problems said that she got help from her tenants when she started using a phone (FG1). Many of the participants mentioned that they are dependent on help and support. In most cases, they receive support from family and friends and said they couldn’t do it without support.

“You don't do it without support.” – FG6

“I always have to rely on other people. But it works.” – FG9

Afraid of being a burden

Besides the need for support, a second often-mentioned statement was that older people don’t want to utilize too much support and time from family and friends. They don’t want to be a burden.

“And I mean, I have a lot of support from my daughter and son-in-law here in Garching, but they are also so busy at work that I don't want to burden them unnecessarily either” – FG7

This is not only the case when it comes to learning new (digital) technologies but also regarding support and daily tasks in general. One participant talked about being a burden with a walker (rollator) on the bus:

“With a rollator [in the bus]. Does someone help you? Does the rollator get in the way? That's not so easy. You don't want to disturb anyone.” – FG8

4.2 Personas

Key Findings
• **Persona 1**: Anna (69) is tech-savvy and lives alone in a city. She regularly uses public transport and likes to keep up to date with digital trends • **Persona 2**: Due to her low digital literacy, Helga (86) relies on her family for support and only uses her smartphone for communication via WhatsApp. • **Persona 3**: Klaus (72), who lives in a rural area with his wife, is moderately tech-savvy and attends computer classes.

Hierarchical Clustering

The personas were developed based on the results of the hierarchical cluster analysis (Chapter 3.3.2), in which older people were grouped according to their common demographic, social, and cognitive characteristics. This clustering provides a basis for understanding the different needs and behaviors of older people in relation to mobility technologies. The key characteristics used for clustering were selected based on the findings from the literature review on factors influencing mobility (Chapter 2.2) and digital literacy (Chapter 2.3). These characteristics also coincide to a large extent with the factors used by Reeder et al. (2011) for modeling the oldest old and include:

Table 3: Cluster Characteristics & Label Codes

Characteristic	Label Encoding
Age	
Tech Experience	None = 0, Bad = 1, Medium = 2, Good = 3, Very Good = 4
Gender	Female = 1, Male = 0
PT Usage	No = 0, Yes = 1
Region	City = 1, Rural = 0
Total[6]	0 (very bad) – 6 (very good)
Living Status	Alone = 0; Assisted Living = 1; Partner = 2
Education Level	High school = 0; University entrance qualification = 1; University = 2
Income	<1.000 = 0; 1.000-2.000 = 1; 2.000-3.000 = 2; >3.000 = 3

[6] The Total variable represents the sum of the values for the individual aspects of Health, Concentration, Relationship, Support, and QOL. Each of these aspects could be rated by the participants on a scale from 0 to 6, with higher values reflecting a more positive assessment of the respective aspect.

The standardization of qualitative characteristics through label coding enables simpler numerical analysis. Label coding is a technique for converting categorical columns into numerical columns. The specific label codes are shown in the list above.

The dendrogram shown in Figure 15 resulted from the cluster analysis based on the abovementioned characteristics. The numbers represent the focus group and workshop participants (Appendix 9). It was cut at a threshold value of h=7 to form three clusters, each having similar characteristics and behaviors within their group members. The three clusters are highlighted in color.

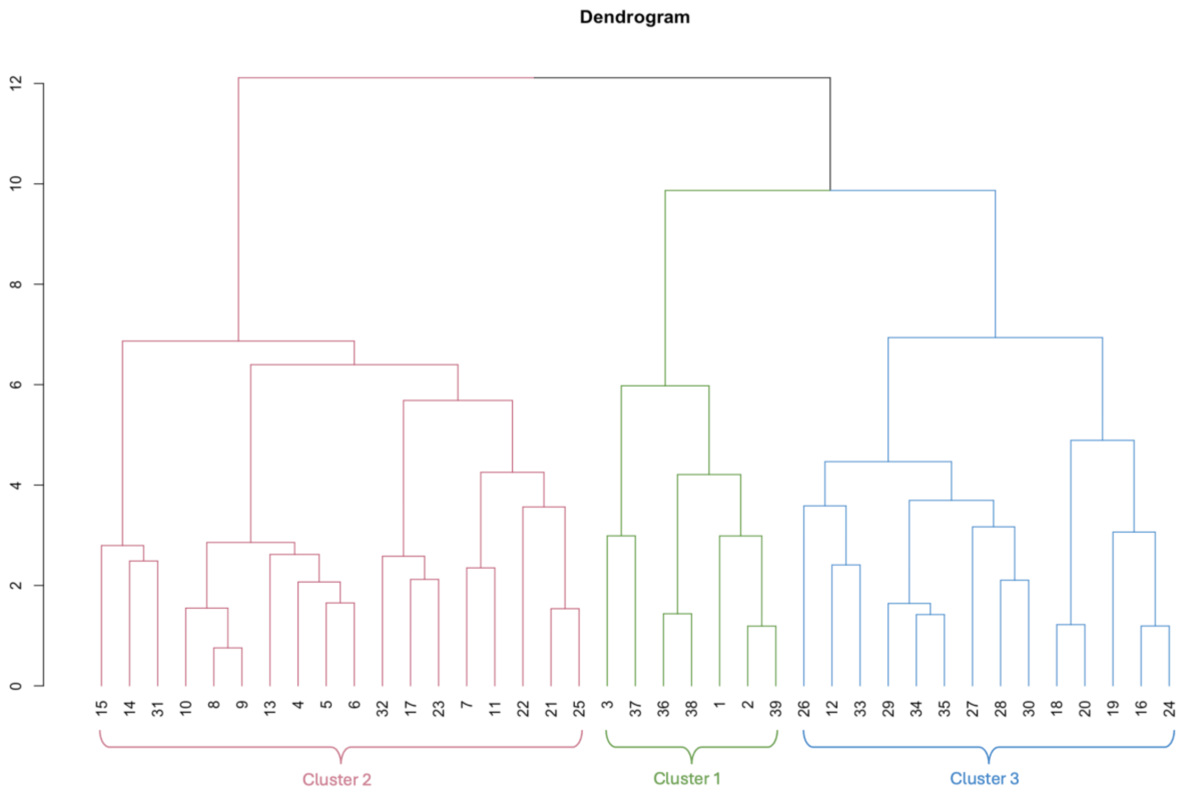


Figure 15: Dendrogram for Personas Clustering (Hierarchical Clustering)

Characteristics of Cluster Analysis

The three clusters identified are shown based on the average values of the characteristics in Table 4. The characteristics are divided into those used for the cluster analysis and those not used.

Table 4: Average characteristics of three clusters from the cluster analysis

Characteristic	Cluster 1	Cluster 2	Cluster 3
Age (SD)	70.9 (4.06)	83.9 (5.64)	71.5 (5.57)
Gender	0.29	0.72	0.29
Region	City	Rural	Rural
Education	1.86 / 2	0.56 / 2	1.07 / 2
Income	1.86 / 3	1.78 / 3	1.64 / 3
Digital Literacy	2.86 / 4	1.89 / 4	2.79 / 4
Total	20.3 / 30	23.3 / 30	23.3 / 30
Living Status	1.14	0.56	1.86
PT Usage	100%	44%	29%

Cluster 1: This cluster can be described as older people with high education (most university level) and rather good technology experience. The average age in this cluster is 70.9 years (median 72, SD: 4.06). Compared to the other two clusters, they are the most digitally literate, with an average of 2.86 out of 4 points. Cluster 1 has the lowest *Total* score with 20.3 out of 30. This is made up of average health (3.86/6), fairly good ability to concentrate (4.57 out of 6), lower satisfaction with relationships and support (3.43 & 3.29 out of 6), and rather higher satisfaction with QOL (4.57 out of 6). All participants in this cluster live in a city and use PT. The cluster consists predominantly of men (71%). On average, this cluster has the highest income.

Cluster 2: The average age in this cluster is 83.9 (median 85, SD: 5.64). It comprises older people with lower education (most high school or university entrance qualifications) and technology experience. The self-rated digital literacy averaged 1.89 out of 4. This cluster has an average *Total* score of 23.3. This is made up of an average state of health (3.83), a fairly good ability to concentrate (4.44), a high level of satisfaction with relationships and support (5.06 & 5.0), and the highest satisfaction with quality of life (4.57) of all clusters. The cluster consists predominantly of women (72%).

Cluster 3: This group comprises older people with moderate education and technological experience. The average age in this cluster is 71.5 years (median 70, SD: 5.57). This group has an average overall score of 23.3, made up of good health (4.5) and ability to concentrate (4.86). This cluster, therefore, has the best (self-rated) health. In addition, the cluster has a fairly high level of satisfaction with relationships and support (4.79 & 4.43) as well as general satisfaction with quality of life (4.71). They all live in rural areas and tend to have the lowest incomes in comparison. The use of public transport is quite low. Only 29% of people in this cluster use it. The majority of this cluster is male, with only 29% females. On average, this cluster has the lowest income.

Based on these clusters, three personas were created representing different subgroups of heterogeneous older people. The findings from the focus groups were incorporated to further enrich the personas. The Personas were developed based on the guidelines from Olsen (2004) and Tu et al. (2010). The descriptions of the personas reflect the diversity of skills of the participants in this study.

Persona 1:

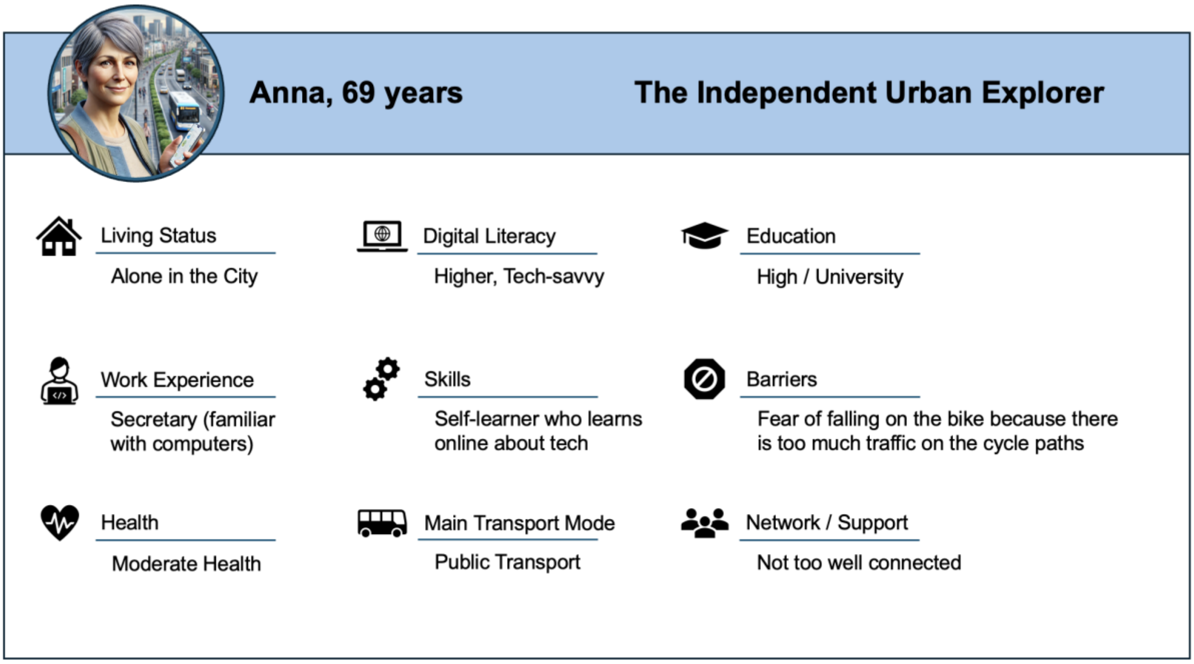


Figure 16: Persona 1 – Anna

Biographical background: Anna is 69 years old and lives alone in a large city. She has an active social life and regularly takes part in community events. Initially skeptical about using smartphones, she decided to get one before a big trip abroad. She now appreciates her device and uses numerous apps to communicate, find her way around, and shop online.

Technology experience and use: Anna is now experienced in using digital technology. She uses her smartphone not only for communication but also for online shopping, online banking, and navigation apps. Her interest in technology means she regularly keeps up to date with digital trends and reads tech magazines. She also passes on her knowledge and helps other older people to use smartphones and computers.

Use of mobility and public transport: Anna regularly travels by public transport and uses buses and subway trains to explore the city. She feels confident using navigation apps to help her on her journeys. However, due to the increasingly dense traffic on the cycle paths, she has limited her use of her bike as she is afraid of falling.

Personal attitude and values: Anna values her freedom and the opportunity to explore new places on her own. She enjoys learning new skills and sharing her knowledge with others, which motivates her and strengthens her connection to technology.

Persona 2:

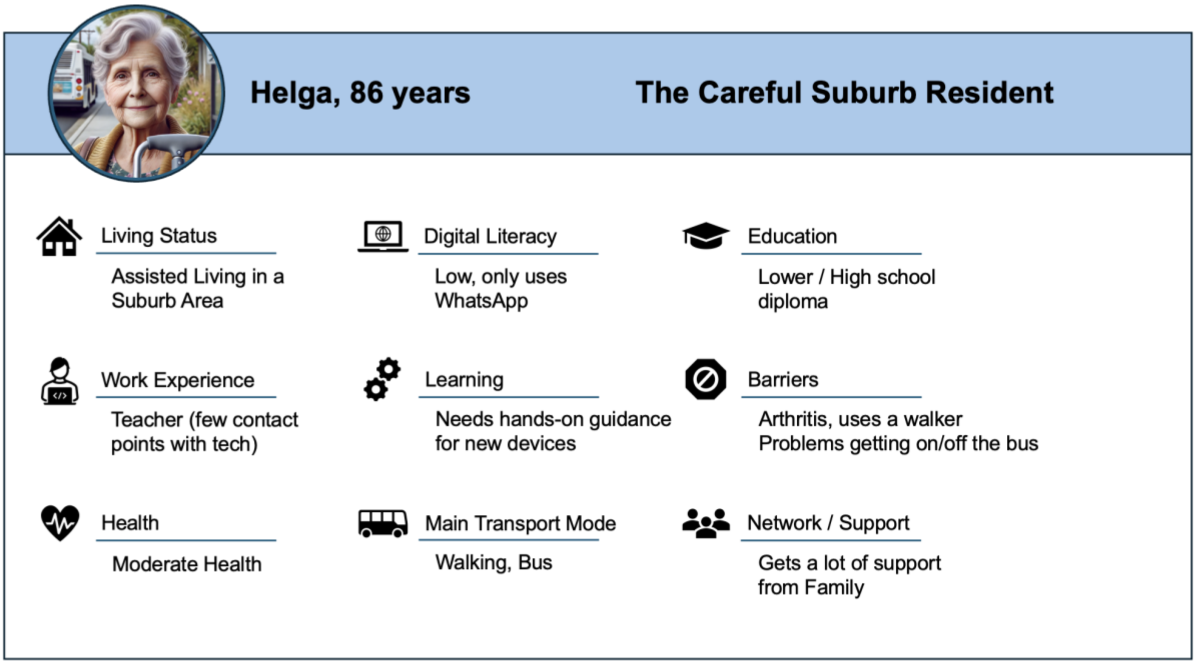


Figure 17: Persona 2 – Helga

Biographical background: Helga is 86 years old and lives in an assisted living home in the suburbs, close to her daughter. She enjoys spending time with her grandchildren and socializing. Her family environment gives her a sense of security and supports her in her everyday life.

Mobility use and challenges: Helga uses the bus for short shopping trips and occasionally the subway. Her osteoarthritis makes walking difficult, which is why she relies on a walking aid. Getting on and off the bus is often challenging due to the steps, especially if the bus does not stop close enough to the curb. She finds the subway more comfortable as there is no gap. Maria rarely uses mobility apps as she mainly takes the bus and relies on simple timetables.

She relies on the bus to run regularly and prefers to wait. For longer journeys, such as visits to the doctor, her daughter often drives her by car.

Technology experience and support: Helga has little experience with digital technology. Although she owns a smartphone, she mainly uses it to keep in touch with her family. She likes to use user-friendly apps that offer communication and simple functions. She also uses the computer occasionally, for example, for emails and simple internet searches.

Personal attitude and values: Helga is cautious when dealing with new technologies and relies on her family for support when needed. Safety and closeness to her family give her a feeling of security. She favors simple, accessible mobility solutions that do not require complicated digital skills.

Persona 3:

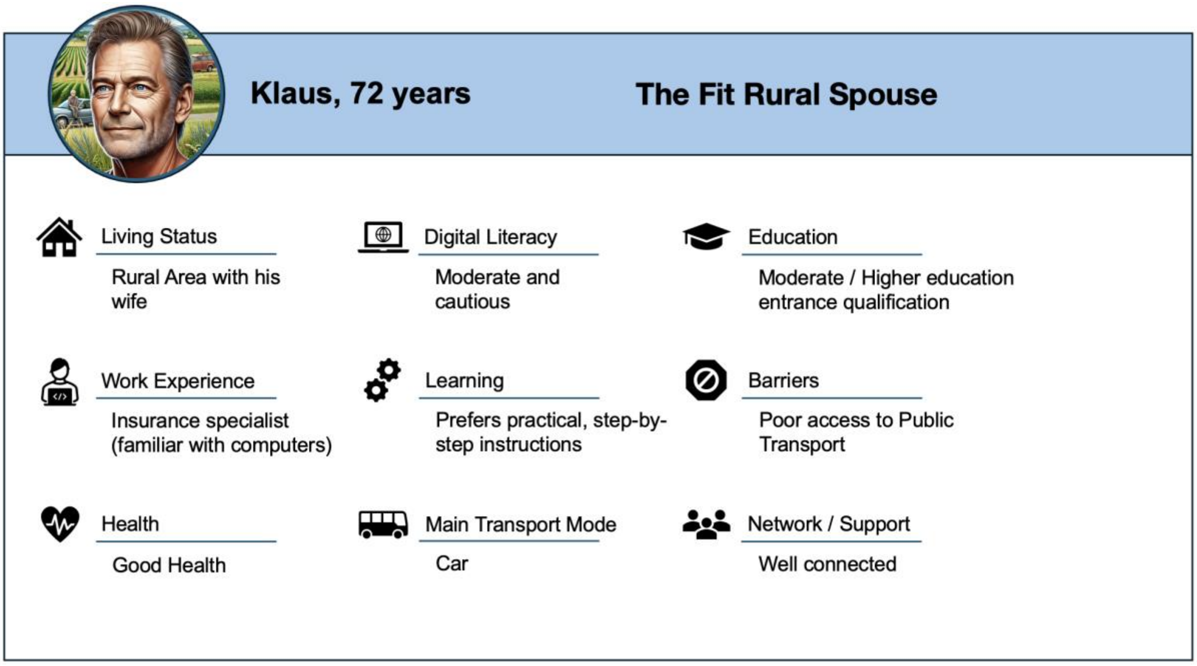


Figure 18: Persona 3 – Klaus

Biographical background: Klaus is 72 years old and lives with his wife in a rural area. He is physically fit and enjoys good health, which enables him to lead an active lifestyle. He attends a weekly computer course for seniors to further his education and socialize.

Technology experience and use: Klaus owns both a smartphone and a computer and feels quite confident using digital technologies. Nevertheless, he tends to remain cautious when trying new technologies and thoroughly informs himself before using new applications. The computer course helps him expand his digital skills and allows him to socialize with other older people.

Mobility use and challenges: Klaus mainly relies on his car in his rural environment, as public transport in the region is irregular and long waiting times are common. He occasionally uses the bus, but the unreliability of public transport makes the car his preferred mobility solution.

Personal attitude and values: Klaus is somewhat tech-savvy but cautious and appreciates pragmatic solutions. He favors mobility solutions that are easily accessible and offer direct assistance without guiding him through complicated digital processes.

4.3 Co-Evaluation

4.3.1 STAM Results

Key Findings
• Prototypes 3 & 4 overall performed best, with the highest STAM scores across all clusters • Female Participants generally rated all prototypes higher than their male counterparts • *Age*, *Living* Conditions, *Health*, *Concentration* and *Tech Experience* had the most influence on the overall STAM scores

The STAM questionnaire used in this study is divided into two sections. The first section deals with background information, including health-related information and information about the personal network and support. This section does not change for the different prototypes and is used to divide the participants into clusters based on the information in the questionnaire. The second section of the questionnaire is used to evaluate and compare the prototypes. This part assesses older people's technology acceptance by analyzing factors such as PU, PEOU, and fear of making mistakes (see Chapter 3.1.5).

The responses from the second part were analyzed to investigate older people's attitudes towards the prototypes and to compare the acceptance of the individual prototypes. In this analysis, the scores for the first five questions were added together since a high score indicates a higher technology acceptance (here, acceptance of the prototypes). The score for the last question was subtracted from this total, as a higher score for this question has a negative impact on acceptance. The resulting score represents the evaluation of each prototype, with a maximum of 30 points (equal to 100%). To facilitate the comparison between the prototypes and other evaluation methods (see chapter "Comparison STAM vs. MAMCA"), the actual score of each prototype was divided by the maximum value to obtain a percentage statement. This percentage provides a standardized measure of technology acceptance. Due to missing data, three evaluations had to be excluded from the analysis, resulting in a final sample size of 23 older people. The sample consists of 16 male and 7 female participants. The male participants' ages range from 64 to 89, with an average age of 75.3 (median 71.5, SD 7.67). The age of the women ranged from 64 to 84 years, with an average age of 72.3 (median 69, SD 7.52).

The resulting scores are presented in Table 5 and grouped according to the clusters defined in Chapter 4.2. The scores are the average value of all participants or all participants from the corresponding cluster. The complete results of the evaluation can be found in Digital Appendix 1.

Table 5: STAM Results by Cluster

	Prototype 1	**Prototype 2**	**Prototype 3**	**Prototype 4**
Cluster 1	32.2%	62.2%	72.2%	66.7%
Cluster 2	48.8%	60.0%	69.6%	69.6%
Cluster 3	61.7%	73.1%	83.9%	87.5%
Overall	**53.3%**	**67.1%**	**77.4%**	**78.6%**
Female	78.1%	77.1%	86.2%	86.2%
Male	40.0%	59.0%	69.2%	70.8%

Cluster 1

The scores from Cluster 1 are the average results of the participants 36, 37, and 38 (see Appendix 9). This cluster consists of three males between 64 and 71 years old, with an average age of 67.3 (median 67.0; SD = 3.5). They all live in the city, and two of them drive a car. They all use PT and have a medium level of digital literacy (average score of 2.0 out of 4). Their self-rated health is rather good, with an average of 3.7 out of 6.

In this cluster, Prototype 1 has the lowest value of 32.2%, indicating a moderate level of acceptance. Prototype 2 had a significantly higher score of 62.2%. Prototypes 3 and 4 had the highest values in this cluster, with 72.2% and 66.7%, respectively, indicating that these two prototypes were perceived as more favorable than the other two. It can be concluded that prototypes 3 and 4 have the highest acceptance and are the prototypes most likely to be used by the senior group.

The fear of making irreversible mistakes when using the prototypes (Question 6) was very low for all prototypes. In general, this cluster had the least concerns, with an average score of 1.08 out of 6 on a 7-point Likert scale (where a score of zero means no concerns; see Chapter

3.1.5). When using prototype 2, people were most concerned about errors during use, with an average score of 1.33 out of 6.

Cluster 2

The scores from Cluster 2 are the average results of the participants 14, 15, 17, 21, 22, 23, 31, and 32 (see Appendix 9). This cluster consists of three females and 5 males, between 77 and 89 years old, with an average age of 81.4 (median 83.0; SD = 6.4). They all live in a rural area and still drive a car except for one person. Only one person uses PT, and they have a medium level of digital literacy (average score of 2.3 out of 4). Their self-rated health is rather good, with an average of 4.0 out of 6.

For Cluster 2, the scores are generally lower than in Cluster 1 (except for Prototype 4). Prototype 1 also has the lowest score in this cluster, with 48.8%. Prototype 2 achieved a score of 60.0%. Prototypes 3 and 4 have the highest score, with 69.6%. Overall, this group has the greatest concerns about making mistakes, with an average rating of 1.88 out of 6 across all prototypes. Prototype 2 has the highest score of 2.25. Nevertheless, these values are still quite low and correspond to a ‘tend to disagree’ on the Likert scale.

Cluster 3

Cluster 3 is formed by participants 16, 18, 19, 20, 24, 26, 27, 28, 29, 30, 33, and 34 (see Appendix 9). This cluster consists of three females and 9 males, between 64 and 82 years old, with an average age of 71.4 (median 70.0; SD = 5.3). They all live in a rural area, and still drive a car. PT usage is quite low, with only four people using it. They have the highest level of digital literacy among the three clusters (average score of 2.7 out of 4) and the best self-rated health (average score of 4.6 out of 6).

Cluster 3 shows the overall highest score over all three clusters. Prototype 1 has a score of 61.7%. Prototype 2 scored 73.1%, while prototypes 3 and 4 received a score of 83.9% and 87.5%, respectively. In cluster 3, the average concern about making mistakes when using the prototypes was relatively low, with an average score of 1.08 out of 6. However, participants in this cluster expressed the greatest concern in relation to prototype 1, which had the highest average score of 1.33 out of 6.

Overall Scores

Looking at the average results of all 23 participants (for which complete STAM results are available) without clustering, prototype 1 has the lowest score of 53.3%. In addition to the quantitative results, qualitative feedback from some participants revealed concerns about the usefulness of Prototype 1. Participants expressed that although the prototype fulfilled its intended function, it was not perceived as particularly helpful for improving mobility, partly because it would not help with stair climbing and the device was not easy to use. Prototype 2 has a higher score of 67.1%, while prototypes 3 and 4 perform best with 77.4% and 78.6%, respectively. The overall data indicate a clear preference for the two digital prototypes (Prototypes 3 and 4) across the entire sample. The average responses to the individual questions for each prototype are quite homogeneous, i.e., the scores of the first five questions (question 6 excluded because the scale is reversed) are close to each other (SD between 0.15 and 0.17). It is noticeable that for question 6, which refers to the fear of making mistakes during use, the scores for prototypes 1 and 2 are higher (1.43 and 1.61) than for prototypes 3 and 4 (1.22 and 1.17).

To further deepen the evaluation and better understand individual characteristics, the results were also analyzed by gender and age group.

Gender

Of the 23 results, seven were from female participants and 15 from males. The female sample has an average age of 72.3 years (median 69, SD = 7.5), while the male sample is slightly older at 75.3 years (median 73.5; SD = 7.7) on average. The female participants have generally distributed a significantly higher score for all prototypes. It should be emphasized here that Prototype 1 was rated slightly better, with 78.1%, than Prototype 2, with 77.1%. Prototypes 3 and 4 received the best rating, with 86.2% each. Among the male participants, Prototype 1 performed worst with 40.0%, followed by Prototype 2 with 59.0%. Prototypes 3 and 4 are close, with 69.2% and 70.8% respectively.

Correlation Matrix for Characteristics

A correlation matrix was used to gain insights into which characteristics have an influence on the acceptance of the various prototypes. No characteristics correlate strongly with the overall STAM scores of the prototypes, but there are several moderate correlations (correlations between |0.3-0.6|). *Age* showed a moderate negative correlation with the results of prototypes 2, 3, and 4 (-0.46, -0.52, and -0.4, respectively). *Gender* showed a moderate correlation only for prototype 1, with a correlation value of 0.48. *Living Conditions* showed a moderate (positive) correlation between 0.36 and 0.47 for all prototypes. *Health* and *Concentration* both showed a positive correlation for all prototypes, with correlations around 0.4. Another notable characteristic is *Tech Experience* (*Digital Literacy*), with moderate correlations around 0.3 for Prototype 1, 3, and 4 and 0.43 for Prototype 2. Characteristics such as *Income*, *Education*, *Region*, *PT Use*, *Support*, and *QOL* appeared to be less significant, as their correlations with the prototypes' STAM scores were generally weak (< |0.3|). The correlation matrix can be seen in Appendix 10.

4.3.2 MAMCA Results

Key Findings
• Prototypes 3 and 4 performed best overall and were rated better than the baseline across all Clusters • Prototype 2 consistently got better score than Prototype 1, nevertheless generally both scored lower than the baseline • Safety, Ease of Use and Improved Mobility have generally emerged as important criteria for older people

In contrast to the STAM approach, the evaluation criteria in the MAMCA are not predefined. The MAMCA allows the stakeholders to define their own criteria, reflecting their specific expectations and needs. The stakeholders then weigh these chosen criteria according to their importance. Using the SMART method, each prototype is then evaluated based on these weighted criteria. In this way, MAMCA allows the comparison of different strategic alternatives (prototypes) and supports decision-makers in their final selection by visualizing the results. Furthermore, the prototypes were compared with an existing solution to provide a baseline reference. This baseline acts as a reference point, demonstrating how the new prototypes measure up against current technologies or practices (see Chapter 2.6.2 for more details).

Due to the different nature of the prototypes, the evaluation was divided into two groups. Prototypes 1 and 2 were grouped as hardware solutions, while Prototypes 3 and 4 formed the software group. Although the baseline chosen for each group is more similar to one prototype than the other, this comparison still provides valuable insights without distorting the overall evaluation. The rollator was chosen as the baseline for the hardware group, as it pursues a similar goal and is widely known. While the Google Maps app serves as the baseline for the software group, as it has a similar goal and is also widely used.

In addition to the three clusters of older people (see Chapter 4.2), the MAMCA process involved other relevant stakeholders in the evaluation process. These include government (senior citizen advisory councils), industry experts (*VentureLab Mobility*), and a representative from academia. The results of the analysis for each stakeholder group are analyzed below, and the defined criteria and their weights are presented. The results reflect the average values of the respective stakeholder groups. An overview of the analysis can be found in the Digital Appendix 2.

Older People

For reasons of research economy and in accordance with the Mass-Participation Decision Making of the MAMCA methodology (Huang et al., 2021), the criteria for the analysis were defined jointly in an initial workshop with two senior citizens' councils and one senior citizen (see participants 2, W1, and W2 in Appendix 9). The defined criteria were then adopted by the three clusters and the stakeholder group 'Seniors' Advisory Council' for evaluation.

As mentioned in Chapter 3.2.2, 30 older people in different group sizes (from one to 14 people per group) took part in the evaluation process of the prototypes. After the first three evaluation rounds, the prototypes were divided into two groups (hardware and software) to create better comparability between the different prototypes. In addition, an existing solution was introduced as a baseline for each of these groups, against which the prototypes were compared. To ensure that the comparative alternatives were evaluated under the same conditions to guarantee a fair and consistent analysis, only the data in which the prototypes were compared with the baseline was used. Therefore, the first 18 results of the evaluation were omitted. In addition, care was taken to ensure that only complete responses from the participants were included in the evaluation, which is why two further results were omitted due to incomplete data.

The sample that was included in the evaluation consists of 9 males between 64 and 82 years old, with an average age of 72.9 (median 71, SD 5.95). The exact composition of the clusters and the respective results are discussed below.

The defined criteria included *Safety*, *Costs*, *Improved Mobility*, *Ease of Use*, *Accessibility*, *Customizability*, *Compatibility*, and *Networkability*. In the hardware group, *Ease of Use* was rated highest, with an average score of 79 out of 100, followed by *Safety* with 76 and *Improved Mobility* with 73. In the software solutions, the criteria were generally weighted higher. The highest average weighting was given to *Safety* with 88 out of 100 points, followed by *Ease of Use* and *Improved Mobility* with 87 and 86 points, respectively. An overview of the weighting broken down by clusters can be found in Appendix 11.

Table 6: MAMCA Results

		Hardware			Software		
		Baseline 1	**Prototype 1**	**Prototype 2**	**Baseline 2**	**Prototype 3**	**Prototype 4**
Older People	**Cluster 1**	70.2%	66.3%	76.0%	69.8%	83.5%	87.7%
Older People	**Cluster 2**	65.7%	58.8%	64.8%	83.5%	77.9%	80.8%
Older People	**Cluster 3**	80.2%	50.6%	71.3%	68.5%	71.7%	81.3%
Older People	**Total**	**74.5%**	**57.2%**	**70.2%**	**68.8%**	**78.2%**	**80.0%**
	SAC	75.7%	83.9%	83.9%	67.4%	87.9%	94.0%
	Industry	60.0%	62.2%	63.7%	72.8%	83.8%	80.4%
	Academia	73.1%	68.7%	68.8%	52.8%	75.9%	75.9%

Cluster 1

The evaluation of three participants was included in this cluster (see participants 36, 37, and 38 in Appendix 9). Their age ranges between 64 and 71 years, with an average age of 67.3 (median 67, SD 3.51). Two-thirds of them live in the city, and most of them drive a car. They have a higher level of digital literacy (average score of 3.0 out of 4) and rate their health as rather good, with an average of 4.0 out of 6.

Baseline 1 achieved a performance value of 70.2%. Prototype 1 scored slightly lower at 66.3%, indicating a slight deterioration in performance compared to the baseline in relation to the defined criteria. However, Prototype 2 showed a slight improvement and achieved a score of 76.0%, suggesting that it could perform better in terms of the defined criteria and better meet the needs of older users in this group and may be favored. In the software group, both prototypes have a better score than the baseline. Prototype 4 has the highest score with 87.7%, while Prototype 3 achieved 83.7% and Baseline 2 69.8%.

In Cluster 1, *Safety*, *Improved mobility,* and *Ease of use* were rated as the most important criteria for the hardware group, all of which were weighted at 80. The *Cost* criterion was weighted at 70. *Customizability* and *Networkability* were both weighted at 67. *Compatibility* was weighted lowest at 60. For the software prototypes, *Accessibility* was the highest-rated criterion, with 93 points. *Ease of use* and *Customizability* were also weighted highly, with 87 points each, closely followed by *Safety* with 85 points. *Improved Mobility* and *Networkability* also received a fairly high weighting of 83 points each, while *Compatibility* was rated at 80. The lowest rated criterion, with 63, was *Cost*.

Cluster 2

In this Cluster, only one older person participated in the evaluation (see participant 32 in Appendix 9). This man is 77 years old and lives alone in a rural area. He still drives a car and a bicycle. He rates his digital literacy as higher (3.0 out of 4) and his health as quite good (5 out of 6).

Baseline 1 scored moderately in the hardware group, with 65.7%. Prototype 1, on the other hand, achieved a lower score of 58.8%. Prototype 2 received a slightly lower score than the baseline, with 64.8%. Similarly, in the software group, the two prototypes performed worse (77.9% and 80.8%) than Baseline 2 (83.5%).

For the hardware solutions, *Networkability* was the highest priority for Cluster 2, scoring 90, followed by *Compatibility* at 80. *Ease of use*, *Cost, Customizability,* and *Accessibility* were given moderate weightings of 60, 50, 50, and 50, respectively. In contrast to Cluster 1, *Safety* and *Improved Mobility* were given the lowest priority at 40 and 10. Cluster 2 showed a more homogeneous distribution of weights for the software solutions. *Cost*, *Improved Mobility*, *Customizability*, and *Networkability* were the most important criteria, weighing 90 each. *Safety*, *Ease of use*, and *Accessibility* followed with weightings of 70. *Compatibility* received the lowest score of 50.

Cluster 3

In this Cluster, five older people participated in the evaluation (see participants 28, 30, 33, 34, and 35 in Appendix 9). Their age ranges between 71 and 82 years, with an average age of 75.4 (median 76, SD 5.40). They all live in a rural area, and still drive a car. They have a moderate level of digital literacy (average score of 2.8 out of 4) and rate their health as rather good, with an average of 3.8 out of 6.

In this cluster, Baseline 1 achieved 80.2 % and was therefore higher than the performance of the two prototypes. Prototype 1 achieved a significantly poorer result of 50.6 %, while prototype 2 achieved a value of 71.3 %. Although Prototype 2 did not perform better than the baseline, it was significantly better than Prototype 1. For the software prototypes, Baseline 2 performs lower than the two prototypes, with 68.5%. Prototype 4 performed better than Prototype 3, with 81.3% and 71.7%, respectively.

For the hardware prototypes, Cluster 3 emphasized *Improved Mobility*, *Ease of use*, and *Accessibility* the most, with 82 each. This was closely followed by *Safety* (80). *Compatibility* was weighted at 74, while *Customizability*, *Costs*, and *Networkability* were only moderately weighted at 62, 54, and 42, respectively. For the software prototypes, *Safety* received the highest weighting (94) and, thus, the highest overall weighting across all clusters. *Ease of use* and *Improved Mobility* were also highly weighted with 91 and 86, respectively, followed by *Compatibility*, *Accessibility*, and *Customizability* with 82, 80, and 78, respectively. *Costs* and *Networkability* received the lowest weighting of 64 and 44.

Government (Seniors' Advisory Council)

A total of four senior citizens' advisory councils were involved in the evaluation of the prototypes. Two councils were involved in defining the evaluation criteria, while the other two were involved in the final evaluation. Representatives from Munich (city) and Neu-Anspach (rural area) participated in the final evaluation.

The two seniors' advisory councils gave all prototypes a high score, with each prototype achieving over 80%. Prototypes 1 and 2 achieved a similar score of 83.9% and 84.1%, respectively, while Baseline 1 achieved 75.7%. Prototype 4 received the highest score of 94.0% (out of all clusters), outperforming Prototype 3 and the Baseline with 87.9% and 67.4%, respectively.

Safety and *Improved Mobility* were the highest priority for the hardware solutions for the Senior Advisory Council, scoring 95, followed by *Ease of use* at 90. *Accessibility and Customizability* were both weighted with 85*,* and *Costs* were given a weighting of 80. *Networkability* and *Compatibility* received lower weightings, with 55 and 50, respectively. *Safety* was also the most important criterion for the software solutions, together with *Ease of use* and *Networkability* (each 95). *Improved Mobility* and *Accessibility* were given 90 each, followed by *Costs*, *Customizability*, and *Compatibility* with 85 each. An overview of the criteria with the respective weighting can be found in Appendix 12.

Industry Experts (*VentureLab Mobility*)

The industry experts' evaluation of the hardware solutions showed a relatively homogeneous picture. The baseline received a score of 60.0%, while Prototype 1 achieved a slightly higher score of 62.2%. Prototype 2 again received a slightly higher score of 63.7%. The Software Group received higher average scores. Baseline 2 received 72.8%, while Prototype 3 received the highest score of 83.8%, and Prototype 4 a slightly lower score of 80.4%.

The scores were calculated based on seven defined criteria. An overview of the criteria with the respective weighting can be found in Appendix 13. The two most highly weighted criteria were *Technological Feasibility* and *Market Potential*, each with a weighting of 90.

Academia

The evaluation of the representative from Academia resulted in a score of 74.1 for Baseline 1 in the hardware group. Prototypes 1 & 2 received approximately the same score with 68.7% and 68.8%. Both score a below the one of the Baseline. The picture looks different for the software solutions. Here, the Baseline scored moderately with 52.8%, while both prototypes received a significantly higher score with 75.9% each.

For the hardware group, seven criteria were defined for the evaluation. The most important criterion was *Safety,* with a weighting of 100%, followed by the *Promotion of Independence* and *Ease of use*, both with a weighting of 95. Five criteria were defined for the software evaluation, with the most important criterion being *Ease of use* with a weighting of 100 and *Customizability* and *Networkability* with 95 each. The complete overview of the criteria and the corresponding weighting can be found in Appendix 14.

Overall – Visualization MAMCA Software

When analyzing the results of all stakeholder groups, several main trends emerge with regard to the performance of the prototypes compared to the basic solutions for both hardware and software.

1. Hardware Prototypes

Across all stakeholder groups, Prototype 2 performed consistently better than Prototype 1. This is particularly clear in the evaluations of the results of older people, where Prototype 2 performed significantly better than Prototype 1 in all clusters. For the non-user stakeholders, the results of both prototypes are almost identical.

However, Baseline 1 (Rollator) generally performed better for older people than both hardware prototypes. Only Cluster 1 rated Prototype 2 better than the baseline. In the case of the non-user stakeholders, the results from both the Seniors' Advisory Council and the Industry Experts show slightly higher values for both prototypes than the baseline. Academia, however, rated the prototypes slightly worse than the baseline. Figure 19 provides a visualization of the results, which ensures good comparability of the prototypes and baselines.

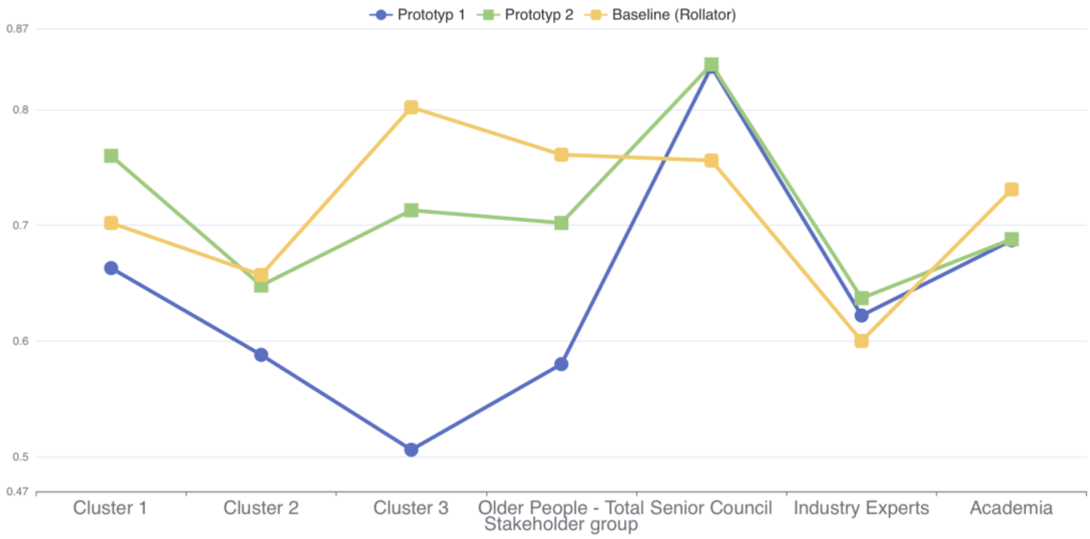


Figure 19: MAMCA Visualization - Hardware Prototypes

2. Software Prototypes

For the software solutions, the results for the prototypes are more positive. Both prototype 3 and prototype 4 scored better than baseline 2 (Google Maps) in all stakeholder groups. Older people in all clusters rated Prototype 4 the highest, with Cluster 1 giving the highest score. The Senior Citizens Advisory Council gave the highest scores for both prototypes across all groups. Similarly, both industry and academia preferred Prototype 3 and Prototype 4, with all stakeholders giving these prototypes higher ratings than Baseline 2. Contrary to the general trend among older people, industry experts rated Prototype 3 higher, while academics rated both prototypes equally. The results are visualized in Figure 20.

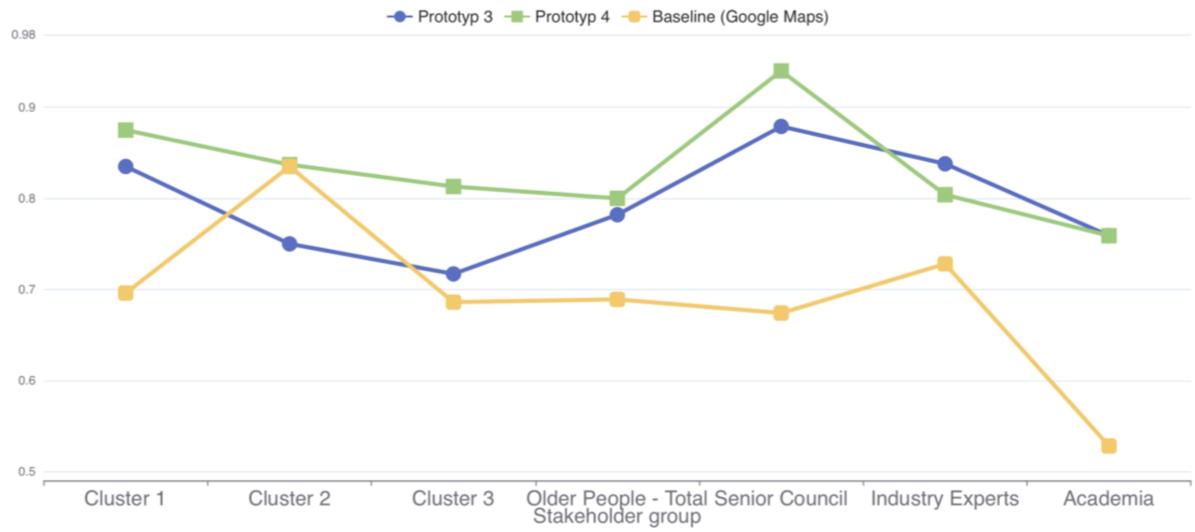


Figure 20: MAMCA Visualization - Software Prototypes

4.3.3 Comparison STAM vs. MAMCA

Key Findings
• STAM & MAMCA generally captured similar trends in preferences of the prototypes across the three clusters, although there are larger differences in magnitude • MAMCA generally resulted in higher values, especially for the lower-rated prototypes such as Prototype 1 • Prototype 4 receives the best scores across both methods, followed by Prototype 3

This chapter compares the results of the two methodological approaches, STAM and MAMCA. The comparison seeks to gain a more comprehensive understanding of the acceptance and evaluation of the developed prototypes by the different clusters of older people. By comparing these two evaluation approaches, consistencies and discrepancies in the results can be identified. Only the participants who completed the STAM questionnaire and the MAMCA evaluation were included in this comparison to ensure a coherent and meaningful analysis and avoid bias in the results.

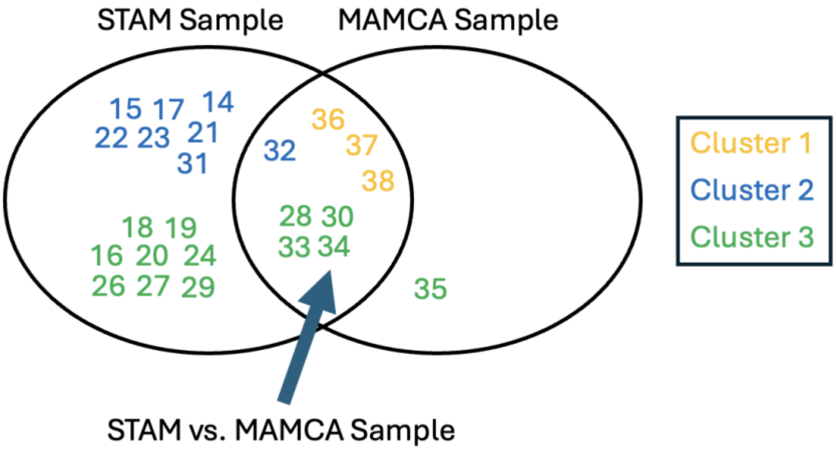


Figure 21: STAM vs. MAMCA Sample

Figure 21 shows the composition of the sample for the comparison of the two methods. The sample consists of a total of eight people. Three of them come from Cluster 1, one from Cluster 2, and four from Cluster 3. The final scores derived from STAM and MAMCA are presented in Table 7.

Table 7: Comparison STAM vs. MAMCA by Cluster

		Hardware		Software	
		Prototype 1	**Prototype 2**	**Prototype 3**	**Prototype 4**
Cluster 1	**STAM**	32.2%	62.2%	72.2%	66.7%
	MAMCA	66.3%	74.7%	83.5%	87.5%
Cluster 2	**STAM**	16.7%	53.3%	63.3%	63.3%
	MAMCA	56.7%	54.9%	77.9%	80.8%
Cluster 3	**STAM**	37.5%	67.5%	74.2%	85.0%
	MAMCA	50.6%	71.3%	75.9%	82.6%
Total	**STAM**	32.9%	63.8%	72.1%	75.4%
	MAMCA	53.3%	67.1%	71.8%	81.3%

Cluster 1

The value derived from the STAM for Prototype 1 in Cluster 1 is 32.2%, which is significantly lower than the value derived 66.3% in the MAMCA evaluation. At 62.2% (STAM) and 74.7% (MAMCA), the values for Prototype 2 are closer between the two methods. For Prototype 3, the STAM rating is 72.2%, and the MAMCA rating is 83.5%. For Prototype 4, the STAM rating is 66.7%, while the MAMCA rating is slightly higher at 87.5%. This indicates that although the overall trend is similar, the prototypes achieve a higher score when evaluated using the defined criteria in MAMCA.

Cluster 2

In this cluster, Prototype 1 has a very low STAM value of 16.7%, which is significantly lower than the MAMCA value of 56.7%. The STAM value for Prototype 2 is 53.3%, compared to a MAMCA value of 54.9%. Although for Prototype 3, both scores are reasonably consistent, the MAMCA score is slightly higher at 77.9%, compared to the STAM score of 63.3%. For Prototype 4, the STAM value is also 63.3%, and the MAMCA value is 80.8%.

Cluster 3

In Cluster 3, Prototype 1 has again a low STAM score of 37.5%, compared to a higher MAMCA score of 50.6%. The STAM score for Prototype 2 is 67.5%, while the MAMCA score is 71.3%. For Prototype 3, the STAM and MAMCA ratings are close together, with 74.2% and 75.9%, respectively. The STAM and MAMCA values for Prototype 4 are also close together, but with a higher STAM (85.0%) than MAMCA (82.6%) score.

Total

The STAM and MAMCA methods show a consistent trend in evaluating the four prototypes for all older people participants but with a different magnitude. In the total results, Prototype 1 has the lowest STAM and MAMCA scores among the four prototypes, with 32.9% and 53.3%, respectively. The total STAM score for Prototype 2 is 63.8%, while the MAMCA score is 67.1%. Prototype 3 shows the closest alignment between the two methods, with a STAM score of 72.1% and a MAMCA score of 71.8%. The highest scores for both Methods received Prototype 4 with a STAM score of 75.4% and a MAMCA score of 81.3%.

5 Discussion

This chapter compares the findings from Chapter 4 with the academic literature presented and further reflects upon it. Section 5.1 discusses the results from the focus groups, followed by a reflection on the personas developed in Section 5.2. Section 5.3 discusses the STAM results, 5.4 the MAMCA results, and 5.5 the comparison of STAM and MAMCA. Section 5.6 outlines the implications and provides recommendations based on the results gathered. Section 5.7 concludes this chapter by identifying and discussing the limitations of this work.

This discussion reflects on the findings of this study from the point of view of current academic literature. This is intended to answer the following research question:

“How do the barriers, needs, and technology acceptance levels vary among different groups of older people, and how can these findings contribute to the development of inclusive (digital) mobility solutions?”

5.1 Focus Groups

In this chapter, the findings from the focus groups on understanding the mobility behavior and digital literacy of older people (Chapter 4.1) are discussed and compared with the literature (Mobility Behavior: Chapter 2.2 and Digital Literacy: Chapter 2.3).

5.1.1 Mobility Behavior of Older People

The focus group discussions provided valuable insights into the mobility behavior, preferences, and barriers of older people. These results are largely consistent with the existing literature on the mobility behavior of older people (as described in Chapter 2.2) but provide more detailed insights into the reasons for their mobility behavior. It became clear from the focus groups that with increasing age (and the associated decline in physical capabilities), mobility is increasingly limited to short and expedient journeys such as shopping or doctor visits. The following section classifies the statements and findings from the focus groups according to the "three-level model of needs and motivations for traveling in older age" as proposed by Musselwhite & Haddad (2010) and (Musselwhite, 2019) (see Chapter 2.2).

1. **Primary Mobility Needs (Practical and Utilitarian Needs)**

With increasing age, older people tend to favor convenience and utility as their physical abilities decline. Thus, many of the older participants mentioned that they use buses and subways, which usually meet practical needs (safe, cheap, and reliable). However, barriers such as the gap between buses and curbs or broken elevators limit their ability to use these modes of transportation, showing that their primary mobility needs are not always met.

2. **Secondary Mobility Needs (Social or Affective Needs)**

The decline in car use with increasing age found in the study by Nobis & Kuhnimhof (2018) was also observed in the focus groups, in which participants over the age of 80 stated that they were more reliant on walking, public transport, or family members, as they had given up their car. This decline in car ownership among older people and their regret at giving up their car highlights the loss of independence and control that are central to social/affective needs. For many participants, the car was an enabler of freedom and spontaneity that they now miss. With other means of transportation, such as the bus or walking, control, and independence are often limited because you are dependent on timetables and the help of others. This is in line with the findings from Musselwhite (2019), according to which older people who are dependent on public transport often miss the opportunity to travel freely.

3. **Tertiary Mobility Needs (Aesthetic Needs)**

Aesthetic needs (enjoyment of travel for its own sake) did not play a role for most participants. Some participants mentioned that they used to simply get in the car to explore new places or experience something else. However, by giving up the car this no longer applies. While some continue to enjoy walking (if they are physically able) to satisfy this need, this aspect of travel is more difficult to achieve for most participants due to physical limitations and less access to convenient, enjoyable travel options. In particular, longer trips were no longer an option for most of the older participants, as they were perceived as too strenuous and time-consuming.

Health-related mobility limitation and travel patterns

As stated by Nobis & Kuhnimhof (2018), health status is the most important component for mobility in later life. Many participants expressed how health issues make walking and public transport less accessible. The deterioration of health directly affects the ability to meet all three mobility needs. The trend towards shorter trips and the move away from cars (as mentioned in the focus groups and the literature) reflects the adjustment older people make with increasing age. Practical barriers, such as the effort required for longer journeys, restrict older people to nearby destinations, often leading to less social engagement. The narrowing of travel distance reduces the ability of older people to satisfy primary, secondary, and tertiary mobility needs. The shorter travel distance means that even practical travel needs become more difficult to meet. As a result, secondary needs like independence are sacrificed because there is more reliable help for traveling (e.g., being driven by family members), and tertiary needs are almost entirely unfulfilled, as the focus groups have shown, traveling becomes an increasing burden in old age and can no longer be enjoyed.

In addition, health restrictions that are not directly related to mobility can also have a negative impact on mobility. For example, people with hearing difficulties avoid noisy places such as restaurants because the background noise makes conversation difficult, leading to older people staying home alone. Health problems such as hearing impairment can also limit older people's activities, indirectly reducing mobility even further. This reflects a marked change in social behavior, where the inconvenience and discomfort of going out becomes a barrier to social contact and mobility. Fear of falling (FOF) exacerbates these limitations by discouraging outings due to safety concerns, further limiting mobility and social interaction. This also affects people, as shown in the focus groups, who have not yet fallen themselves but are afraid of it because they have heard about it from others. This confirms the findings of (Jørstad et al., 2005; Suzuki et al., 2002).

5.1.2 Digital Literacy among Older People

Digital literacy among older people encompasses different levels and perceived barriers. The results of the focus groups show a range of digital competencies characterized by factors such as age, motivation, and support networks. While most younger participants (under 80) showed generally higher levels of digital literacy, older participants were more likely to limit their use of DT to basic tasks, reflecting the findings of Chapter 2.3.

General DT Usage by Older People

Almost all participants used digital technologies. Most of them used a computer or smartphone. The main reason for using DT was to stay connected with family and friends. Among the younger participants (younger than 80 years), digital literacy was relatively high, and they used various forms of DT and digital functions. The older participants used advanced digital functions only to a limited extent. Although many of them owned a smartphone, they mainly used it for basic tasks such as calling or texting, reflecting statements in the literature about the underutilization of the full potential of smartphones. This confirms the statements by Seifert et al. (2021) and van Boekel et al. (2017), who emphasize that although many older adults own smartphones, their use is often limited to simple functions. Only two participants did without DT altogether - one for health reasons and the other for financial reasons.

Barriers od DT Usage among Older People

The barriers to the use of digital technologies identified in the focus groups are discussed below in accordance with the structure from Chapter 2.3.3.

1. **Physical Factors**

Physical factors (such as hearing, sight, or motor changes) were not often cited as a major barrier to DT adaptation or use. Only one person with severe health limitations complained that they could not use a computer or smartphone because they had problems with their fingers. Otherwise, a few times, it was only mentioned that the computer was preferred for Google or writing emails because of the larger screen or fonts. These results confirm the points from the literature (Fisk et al., 2020; Nunes et al., 2010), but physical factors were not a driving force for not using DT in this sample.

2. **Cognitive Factors**

Cognitive barriers were evident in the participants' reluctance to learn new digital systems. Participants explained that learning new technologies is complex and tedious, and some are reluctant to learn new processes and technologies. They prefer to stick with familiar processes. This is in line with the literature on cognitive factors (Fisk et al., 2020), which cites memory deficits and difficulties with multitasking as major barriers to digital literacy in older people. Studies also mention that the complexity of digital interfaces can overwhelm older users (Lamont et al., 2013), who often find it difficult to memorize longer sequences (Harvey et al., 2019; Kim et al., 2016), making learning new functions more difficult, as only simpler functions and systems are often used.

3. **Psychological and Social Factors**

Lack of Self-efficacy:

The lack of confidence in one's own abilities reflects another hurdle to DT utilization. Some participants felt ‘too old’ to learn a new technology, discouraging them from trying. This was particularly true for the older participants, who complained that learning new skills at an older age was simply too strenuous. This self-perception is consistent with the findings of the literature, which emphasizes self-efficacy as a barrier to digital use by older people (Carney & Kandt, 2022; Kärnä et al., 2022; Kim et al., 2016).

Motivation / Lack of Motivation:

Similar to the previous topic, an important aspect is the motivation to engage with digitalization. While some participants were motivated to learn digital technologies, others did not want to adapt to digitalization. They have been reluctant to adopt even when acknowledging the benefits of digitalization and digital technologies. They prefer to do things the traditional way. This confirms the report by Kim et al. (2016) on older people who are set in their ways and no longer want to adopt. They don't want to change something they've been doing all their lives or find the transition too time-consuming or difficult. These results are consistent with the findings of Durand et al. (2022) and Harvey et al. (2019). Again, age played a significant role. Lack of motivation was mainly a problem for the older participants (80+). However, there were also many older participants who were motivated to learn digital technologies. This shows the heterogeneity in this demographic group.

Fear/Security

When it came to security, the picture was mixed. Data security, in particular, was the subject of many discussions. Data security was a particularly important topic for the Seniors' Advisory Council participants, which they also passed on to their seniors. However, there were also participants for whom the topic was not so important and who explained that they had nothing to hide. In addition to data protection, topics such as radiation protection when using mobile phones and online banking, as well as EC cards (withdrawing money), were also discussed. It should also be noted here that senior citizens generally feel more at risk than their younger counterparts. Even withdrawing money and carrying a debit card alone was considered dangerous by some participants, and sometimes, it was only done with family support.

Social & Support

One of the most important aspects of the focus groups was support from others. A recurring theme was that most participants would not have started using certain digital technologies without the support of others. This applies not only to the older participants but also to the younger ones. Several participants stated that they only used the DT or certain functions/applications because a friend or family member had suggested or introduced it to them. This shows that support from acquaintances plays a central role in older people's use of technology. Although this is not new in the literature, it reinforces the results made by (Harvey et al., 2019; Kärnä et al., 2022) and emphasizes the importance of factors such as support and relationships in the STAM models (Chen & Chan, 2014; Kim et al., 2016).

However, despite the positive role of support networks, there is also a concern about becoming a burden. Many participants expressed their reluctance to constantly ask for help. This feeling of being a burden is a significant emotional barrier to adopting digital technologies and emphasizes the need for learning and training opportunities outside of one's own network.

4. Access to Technology

The barriers to access described in the literature (Carney & Kandt, 2022; Harvey et al., 2019), such as the lack of access to suitable technology, the overwhelming variety of options, and the cost of the devices, were more of a marginal topic in the focus groups. Nevertheless, both 70-year-olds and 80-year-olds were an issue. On the one hand, the need for support when buying devices was discussed because people don't know which device is most suitable. On the other hand, the high costs were mentioned, which make a purchase in old age no longer seem sustainable due to the shorter life expectancy.

5.2 Personas

The cluster analysis and the resulting personas (Chapter 4.2) provide a differentiated understanding of how older people differ regarding their digital literacy, mobility preferences, and support needs. These findings are valuable for developing inclusive mobility solutions that meet the diverse needs of this demographic.

The personas generated from these clusters reflect archetypal user profiles that can guide the development of inclusive (digital) mobility solutions (Mannheim et al., 2019). By modeling each persona's needs and potential barriers, solutions, training programs, and support networks can be tailored to different levels of digital literacy and mobility independence.

For Anna (Cluster 1), offering more complex but personalized digital tools with features such as advanced navigation would cater to her desire for independence, while simplicity is not necessarily required. Physical mobility solutions such as a bike or scooter are also so not attractive to her due to slight mobility impairments and her good adoption of PT.

For Helga (cluster 2), devices with minimal, intuitive functions would minimize her reluctance to technology and reduce her cognitive load. The integration of additional functions into existing systems is a suitable approach here.

For Klaus (Cluster 3), familiar interfaces and customizable settings that consider his functional needs and preference for simplicity are ideal. In principle, he is very open to mobility solutions and is also open to physical mobility solutions such as scooters due to his good health.

This approach also aligns with the principles of inclusive design, where user-centered solutions address specific challenges to support the unique needs of each persona within a broader system.

5.3 STAM

The results of the STAM questionnaire presented in Chapter 4.3.1 provide important insights into the acceptance of the developed prototypes. For further analysis, the results were segmented according to the previously defined clusters and gender. By comparing the results between the different prototypes and clusters, trends in technology acceptance and factors that influence the willingness of older people to accept new mobility solutions can be identified.

As highlighted by (Davis & Venkatesh, 2004) (S)TAM is a good way to predict PU early in technology development. However, PEOU required actual interaction with the system for a reliable assessment, which was not possible for every prototype within the scope of this study. Firstly, some of the prototypes were still at an early stage, and not all functions had been fully developed. In addition, Prototype 2, the e-scooter, could not be taken to the evaluation workshops for logistical reasons. In addition, some of the workshops had too many participants for everyone to be able to test the prototypes in detail. Nevertheless, the results can be used to obtain a general picture of the acceptance of the prototypes and to better understand the potential user group.

General acceptance of the prototypes

A higher score on the STAM questionnaire generally reflects a more positive perception of the technology and, consequently, better acceptance. The percentage score allows a good comparison of the prototypes with each other and indicates which design is the most promising. The findings reveal a strong preference for the digital prototypes (Prototypes 3 & 4), with acceptance rates above 77%. This emphasizes the idea that, despite barriers such as digital literacy (Chapter 2.3), older people are not necessarily opposed to digital solutions from the outset if they are user-friendly and have been developed specifically with the user group in mind. This emphasizes the concepts of PU and PEOU as important factors and strengthens the legitimacy of these factors in STAM (Chen & Chan, 2014; Kim et al., 2016). In contrast, Prototype 1 received the lowest score (53.3%) overall. The feedback from the evaluation workshops and the evaluation from the STAM questionnaire highlighted concerns about PU and PEOU for this prototype. The lower acceptance could also be related to the fact that it visibly shows the need for mobility assistance. This would be in line with the finding by Neves & Mead (2021) that older people do not want to use solutions that directly show that they are old and in need of help. Additionally, the data shows that the participants were more concerned about making mistakes with the hardware prototypes (Prototypes 1 & 2) than with the software prototypes (Prototypes 3 & 4). One explanation for this could be that errors in handling the hardware prototypes can lead to falls and injuries. As the literature (Chapter 2.2) and the focus groups (see Chapter 4.1.1) have shown, FOF represents a serious barrier to the mobility of older people and affects not only those who have already fallen but also those who have not yet suffered a fall. Nevertheless, Prototype 2 received a moderate 67.1% score, although the fear of making mistakes was highest here.

The higher acceptance of the software prototypes could also be due to the degree of familiarity. Most of the participants were familiar with a smartphone and had already used applications such as WhatsApp. On the other hand, it can be concluded from focus groups that older people can be reluctant to adopt new technologies and only use them when a friend or family member suggests using them. This is also consistent with the literature, which states that social relationships positively impact belief in usefulness and influence intention to use (Chen & Chan, 2014). As the participants were not familiar with either Prototype 1 or Prototype 2 and had no recommendations from their social network, it is consistent with the findings from the literature and the focus groups that acceptance of these two prototypes is lower.

Acceptance based on Clusters/Personas

The overall trend remains similar in all three clusters, but the variation in values between the clusters illustrates the heterogeneity of older people (Doh, 2020; Mannheim et al., 2019; van Boekel et al., 2017). The different persona profiles - Anna, Helga, and Klaus (see Chapter 4.2) - give the clusters more depth and enable a more differentiated understanding of why certain prototypes have achieved higher acceptance in a group.

In Cluster 1, Prototype 1 received the lowest STAM score, indicating low acceptance. This result can be connected to Anna’s high independence and good health, whereby she has no use for this mobility aid. The moderate evaluation of Prototype 2 suggests that it may offer some practical benefits but does not fully fulfill the expectations of independence in an urban context. Prototype 3 achieved the highest STAM score within this cluster. This can possibly be explained by the fact that this prototype further promotes independence and facilitates networking. Prototype 4 also received a relatively high STAM score, albeit slightly lower than Prototype 3. This could be due to Anna's already high level of digital literacy. The prototype's simple user interface does not offer Anna any great added value, as she already uses existing navigation tools without having any major problems with them.

In Cluster 2, Prototype 1 received the lowest acceptability score, consistent with Helga’s cautious attitude towards technology and her need for simplicity. Nevertheless, the score shows that Helga sees some benefit in the prototype, as it could improve her limited mobility due to arthritis but may not have met her expectations for ease of use. The moderate rating of Prototype 2 suggests that it offers some practical benefits. It fulfills Helga's basic mobility needs better than prototype 1 but may also lack usability and accessibility. The fear of making mistakes (or FOF) was relatively high with this prototype, reflecting her sense of safety and reducing her overall acceptance. Prototypes 3 and 4 both received the highest acceptance scores in Cluster 2, suggesting that the digital solutions better fit Helga's cautious, user-friendly approach to technology. These prototypes probably offered more familiarity, as she can already operate simple interfaces on a smartphone or tablet (like WhatsApp), which led to a higher level of acceptance overall.

Cluster 3 shows the highest overall acceptance for all prototypes. Prototype 1, in particular, has a comparatively high level of acceptance compared to the other clusters. As Klaus is still quite fit, he doesn't need the walking aid at the moment, but the higher score shows that he recognizes the benefits of the prototype and could imaging using it in later life. The higher acceptance of Prototype 2 could be due to the fact that Klaus is still very fit and, therefore, less worried about making mistakes while using it. It also offers a good alternative for short journeys in his rural setting, where the prototype can be a good alternative to his car. Prototypes 3 and 4 both have high acceptance rates of over 80%. This shows that the prototypes are not a completely new challenge for Klaus due to his fairly solid digital skills. At the same time, the simple user interface is appreciated, and the functionalities are seen as useful, as they help him to network further and navigate more easily.

Acceptance based on Gender

One striking result is the gender-specific difference in the acceptance of the prototypes. The female participants gave consistently higher scores for all prototypes, with prototypes 3 and 4 receiving the highest ratings (both 86.2%). Interestingly, the female participants rated Prototype 1 with 78.1% significantly higher than the total sample and especially significantly higher than the male participants (43.3%). In addition, the score is even slightly higher than that of Prototype 2, which contradicts the general trend in the overall sample. The higher score for the walking aid is in line with the results of Gell et al. (2015), according to which women generally use a walking aid more often than their counterparts, which suggests that the acceptance of such a solution is also generally higher among women.

When analyzing the fear of making mistakes by gender, interesting differences emerge. While the average of the values is quite similar across all prototypes, with the score for women being slightly higher than that for men, it becomes clear when looking at the individual prototypes that women are more afraid of making mistakes in the two hardware prototypes (1 & 2), while the picture is exactly the opposite in the software prototypes (3 & 4). On average, women are slightly less worried about making mistakes in both prototypes.

Characteristics influence scores of prototypes / Correlation Matrix

Analyzing the correlation matrix in Chapter 4.3.1 sheds light on how the different characteristics of the participants influenced the acceptance of the prototypes. While there were no strong correlations between background characteristics and overall STAM results, several moderate correlations were present in the analysis (like Age, Gender, Living Status, Health, and Concentration). This shows some of the characteristics used for the persona creation were more influential than others and provides initial starting points for investigating exactly which characteristics really influence the acceptance of mobility aids. However, the small sample size (n=23) limits the statistical power to identify important relationships between characteristics and prototype acceptance.

5.4 MAMCA

The results of the MAMACA outlined in Chapter 4.3.2 provide important insights into the factors influencing the acceptance of the developed prototypes. The weighting of the defined criteria offers a comprehensive understanding of the considerations of older people regarding hardware and software mobility aids. It highlights how older people prioritize different aspects of technology and how these prioritizations differ across this heterogeneous group.

Older People

Overall, the MAMCA shows a consistent ranking pattern to the STAM results: Prototype 1 received the lowest score, followed by Prototype 2, while Prototype 3 was rated better, and Prototype 4 achieved the highest score across all three clusters. The results are discussed in more detail below, and possible conclusions are drawn from the defined criteria. The discussion is divided into two groups, hardware and software, as a specific baseline was used for both prototypes of a group during the evaluation

1. **Hardware Prototypes**

While the weightings of the criteria in Clusters 1 and 3 are similar and criteria such as *Safety*, *Improved Mobility*, and *Ease of Use* have crystallized as the most important factors, a different picture emerges for Cluster 2. Here, the greatest importance is placed on *Networkability*. However, no generalization is possible here due to the small sample size. Nevertheless, the weighting indicates that *Costs*, *Customizability,* and *Compatibility* play a rather subordinate role for older people regarding the hardware mobility aids.

Almost all results are lower than the baseline assessment. Only in Cluster 1 Prototype 2 was rated better than the baseline. This shows that older people find the rollator more useful than the two prototypes presented. However, this contradicts the possible explanation from Chapter 5.3 that Prototype 1 was rated lower partly because it is immediately recognizable as a mobility aid. After all, the rollator (Baseline 1) is also clearly recognizable as a mobility aid. However, the widespread use and high level of acceptance of the rollator could help mitigate these concerns and positively influence its evaluation. As Chen & Chan (2014) found, familiarity with a solution increases both perceived usefulness and ease of use, which could further explain why the rollator performed better. In addition, Harvey et al. (2019) discuss the role of older ‘champions’. This refers to peers who have adopted technology and from whom others learn and subsequently adopt it themselves. This peer influence could be another reason for the popularity and acceptance of the rollator. In general, peers and confidants play an important role in accepting and adapting new technologies, which was also confirmed in the focus groups. However, the lack of recommendations from their own network also makes it difficult for older people to accept such new solutions. As became clear in the focus groups, the usefulness of a solution is not always recognized by the older people themselves, but only after someone close to them has suggested the use of this solution.

2. **Software Prototypes**

The software evaluation clarifies the importance of *Safety*, *Improved Mobility*, and *Ease of use*. Again, they are among the most heavily weighted criteria. They are even weighted significantly higher than for the hardware prototypes. On the one hand, this confirms the conclusions drawn in Chapter 5.3 about the importance of PEOU, but it also highlights the safety concerns of older people.

For the software solutions, the prototypes generally performed better than the baseline (Google Maps). This shows how important it is to develop software with interfaces that are simple and intuitive. It also confirms the generally higher acceptance of solutions that seniors are familiar with, as was already deduced from the STAM results. Cluster 2 is an exception again, although the rating for both prototypes is also high (around 80%) but slightly below Baseline 2 with 83.5%. The high acceptance of the baseline shows that the person from this cluster has few problems with *Google Maps* and that the solutions do not bring much added value in comparison.

Other Stakeholder

The evaluation by non-users provides additional insights into the perceived usefulness and practicability of the prototypes. The evaluation of the non-user stakeholders partly reflects different priorities. In general, however, it is clear that the prototypes are seen as useful, and, with the exception of the hardware solutions (in the eyes of the expert from academia), all prototypes were rated better than the baselines by all three non-user stakeholder groups.

- **Senior Citizens' Advisory Council and Academia**

The evaluation with members from the senior citizens' advisory council and academia confirms the importance of *Safety*, *Improved Mobility*, and *Ease of use*. Both groups rated these criteria highly, which validates the conclusion that these criteria are generally valued and important to older people for both hardware and software mobility aids.

- **Industry experts**

The industry experts had a slightly different focus. They were interested in criteria like *Technological Feasibility*, *Market Potential*, and *User Experience*. This shows a different perspective and relates more to the general scalability and suitability of the prototypes for the broader market.

5.5 STAM vs. MAMCA

The comparison of the STAM and MAMCA results for the four prototypes shows consistent trends in the overall rating of the prototypes. Still, in some cases, there are differences in the order of magnitude of the scores. Both methods generally agree that Prototype 1 has the lowest acceptance, while Prototypes 3 & 4 receive the highest score across all clusters. However, important differences exist in how the two methods evaluate the prototypes and the insights they provide, which are discussed in detail below.

Discussion Results STAM vs. MAMCA

The consistency in the trend between the prototypes measured with both methods emphasizes the robustness of the results. It shows that the preferences of the interest groups remain fairly stable, regardless of whether it is a question of general technology acceptance or more detailed, criteria-based evaluations. Nevertheless, on average, the MAMCA method achieves higher values than STAM. This is particularly noticeable for Prototype 1. The difference is most extreme in cluster 2, where prototype 1 achieves 56.7% in the MAMCA evaluation and is significantly higher than the 16.7% of STAM. However, this extreme deviation may also be due to the small sample size in this cluster, as only the result of one participant was included here. Nevertheless, this trend can be seen in Prototype 1 across the entire sample with a STAM result of 32.9% and a MAMCA result of 53.3%. For the other prototypes, the difference between the two methods is quite small, usually less than 10 percentage points.

Advantages/Disadvantages of STAM

STAM is particularly suitable for measuring general acceptance and users' initial attitudes and reactions, especially for prototypes in the early phase, where participants can only test the prototypes to a limited extent (Davis & Venkatesh, 2004). STAM applies a set of standardized criteria based on perceived usefulness (PU), ease of use (PEOU), and fear of technology (gerontechnology anxiety) to determine the acceptance of technology (see Chapter 2.5.2).

Although these criteria cover important aspects of technology acceptance, they leave little room for further findings, e.g., on what other factors could influence acceptance, which could then be used to develop the prototype further. Nevertheless, possible conclusions can be drawn from the other factors, such as the health status of the participants or the support network, which are captured by the STAM questionnaire. These factors could be investigated by comparing the STAM results of the participants and analyzing whether there are correlations between these aspects and the evaluation of the prototypes (for example, with a correlation analysis as seen in Chapter 4.3.1). This could show whether, for example, a better state of health or a strong support network positively influences the evaluation of the prototypes.

Advantages/Disadvantages of MAMCA

The results indicate that MAMCA generally gets higher scores, which is particularly noticeable in the hardware group. This could be due to the flexibility of the MAMCA process, which allows participants to define and prioritize criteria according to their specific priorities (see Chapter 2.6.2). Further, additional perspectives can be incorporated into the evaluation by including other stakeholders in addition to the users. This is particularly interesting in this study, as the sample size of older people is quite small, and the results are difficult to generalize. The involvement of other stakeholders, such as academics and senior citizens' councils, who are intensively involved with the user group, its needs, and requirements, can add additional depth to the evaluation. Their results can also be used to validate the user group(s) results and contribute to a better understanding of the needs of older people. In addition, the various stakeholders contribute further aspects to the evaluation that go beyond user acceptance or were not considered by the user group when defining the criteria.

However, if a technology is rated well in all the defined criteria, it is still possible the target users will not accept or adopt it. MAMCA does not record the acceptance of a solution but compares different solutions with each other to determine which stakeholders favor which solution (alternative). It, therefore, enables good comparability for the prototypes, but the acceptance cannot be derived from this alone. This is particularly evident in the results of Prototype 1. The values for the MAMCA evaluation are significantly higher and show at least a moderate evaluation. This could suggest that older people would adopt this solution, at least to a certain extent. However, acceptance, measured with STAM, is significantly lower, indicating that acceptance is generally very low.

5.6 Implication and Recommendations

The discussion of the results from Chapter 4 shows the different needs and barriers to mobility solutions for older people. When comparing the qualitative results of this study with research in the relevant areas, many overlaps can be identified. The study helps to better disaggregate these findings by providing a nuanced understanding of how barriers, needs, and acceptance vary across different groups of older people. It also highlights the importance of developing personalized, adaptable solutions considering different levels of digital literacy and independence.

Practical, social, and aesthetic mobility needs and the use of DT change with age and other factors such as health status. But by adhering to certain rules, the inclusiveness of (digital) mobility solutions in general can be improved. By addressing primary mobility needs through real-time accessibility features and routing options, physical barriers such as steps can be reduced. In addition, social and emotional independence should be promoted by offering flexible, needs-based transport options and community-based travel networks. Ultimately, greater use should also be made of integrating confidence-building support systems and technological aids, especially for users with a high FOF or health restrictions, to reach more people that would fit into Cluster 2.

Further, the insights on digital literacy reveal that while physical barriers must be addressed, they are less influential. Cognitive, psychological, and social factors, on the other hand, significantly influence DT usage among older people. Understanding these diverse factors and barriers is essential for developing inclusive digital mobility solutions that not only consider accessibility and ease of use but also provide external support resources and community engagement to address the unique needs and concerns of older people. This can be done by leveraging tools that older people know and are familiar with, as we saw with Prototype 3.

The access and usage of DT will strongly grow among older people (see Chapter 2.3), but the level of engagement will continue to be limited in this demographic (Harvey et al., 2019). To overcome this, new DTs should be developed so that they initially only display the basic functions, and additional functions only become visible when they are actively requested. This reduces complexity and keeps the barrier to entry as low as possible (for people from Cluster 2 & 3), while users with a higher level of digital expertise (Cluster 1) can have access to advanced functions. The evaluation further suggests that features that promote social interaction and navigation while ensuring a high level of safety and ease of use are generally well-received and perceived as useful by all clusters. In general, it has been shown that ergonomic aspects, including an easy-to-understand and easy-to-use interface, are very important (especially for Clusters 2 & 3).

Learning from older 'champions' (Harvey et al., 2019) and providing support networks can help with the adoption of new technologies and mobility solutions. This is an important component in increasing the uptake of new solutions among older people. This is particularly important when solutions that older people have not previously encountered (as was the case with the hardware prototypes). This is where ambassadors or learning groups, such as the PC groups where two of the evaluation workshops were held, could be used to promote these solutions and familiarize older people with them.

Combination of STAM & MAMCA

The joint application of STAM and MAMCA for the evaluation of (different) prototypes provides a useful framework for an early assessment of the acceptance and potential of the prototypes. STAM is used to better assess the overall acceptability of a technology/prototype, while

MAMCA provides a customized, context-specific understanding of stakeholder priorities. Important conclusions can be drawn from the defined criteria, and adjustments can be made to the prototype. Together, these methods provide a solid framework for evaluating and improving the design of mobility aids for older adults, as they complement each other and can be used to validate each other's findings.

5.7 Limitations

Although this study provides several insights into the acceptance of different mobility aids to support an active life and overcome digital barriers among older people, several methodological limitations must be addressed to contextualize the results and enable further research.

Sample Size and Representativeness

One of the main limitations of this study is the small sample size. Although the study took care to involve an overall heterogeneous group of participants, it does not fully represent the diversity of older people. For example, the recruitment strategy chosen limited the sample to relatively independent and active older people who still participate in social events in senior centers or assisted living facilities. This means the study does not include immobile or isolated population groups. The results cannot be generalized because of the relatively small sample size in the focus groups and evaluation workshops. Nonetheless, the interviews and evaluation workshops were conducted to gain deep insights into people's lives and to identify and compare opportunities for acceptance evaluation, thus expanding the knowledge base on the research and use of mobility aids for older people (Boerema et al., 2017; Kylberg et al., 2013).

These limitations mean that while the analysis provides valuable insight into older people's requirements for mobility aids and factors that impact their acceptance of them, the results should still be interpreted cautiously. Further research should address these limitations by studying larger, more diverse samples and going into more depth, both quantitatively and qualitatively, to gain a broader understanding of technology acceptance by older people and thus validate the findings presented in this study.

Validation of Results

Ideally, the results should have been validated with participants for both the persona creation and MAMCA to ensure reliable and accurate results (Gonzalez de Heredia et al., 2018). However, this was not possible due to practical constraints, including research economics, geographical factors, and the structure of the study. The methods were conducted with different groups in different locations and on different days. Furthermore, as the results had to be analyzed first, it was not possible to return to the participants for validation once the assessments were completed.

Baseline in the STAM Evaluation

Including a baseline in the STAM analysis could allow for a more accurate comparison of the prototypes presented, as it provides a familiar reference point and helps contextualize the scores. It would also allow a more direct comparison with the MAMCA results and contribute to a better interpretation of the ratings.

6 Conclusion

Various factors like digital literacy, mobility habits, and health status influence older people's acceptance and adoption of new (digital) mobility solutions. Despite the complexity, efforts to improve mobility through the use of (digital) technologies are seen as crucial to prevent the exclusion of older people in the mobility sector.

6.1 Research Question and Key Findings

This study investigated the mobility behavior of older people and their use of DTs, identifying specific needs and requirements for inclusive mobility solutions that can serve as a basis for future research and development. Furthermore, a framework for evaluating the acceptance of such solutions was examined to promote innovations that fulfill the expectations and requirements of this user group. The research question was, therefore, as follows:

“How do the barriers, needs, and technology acceptance levels vary among different groups of older people, and how can these findings contribute to the development of inclusive (digital) mobility solutions?”

For this study, three focus groups were conducted with a total of 12 older people, and four co-created mobility prototypes were evaluated with 27 older people and five other relevant stakeholders. It provides detailed insights into the needs and barriers that different groups of older people face regarding mobility and DT. Further, it sheds light on the acceptance of the newly developed mobility aids among these groups by leveraging two evaluation methods (STAM and MAMCA).

The first part of the research question was addressed through focus groups and questionnaires. The participants were clustered into three groups based on demographic and socio-economic data. For each group, a distinct persona was created, further detailed with the insights from the focus groups. While the small sample size limits the generalizability of the results, this approach provides new insights into unique sets of needs and attitudes toward mobility and DT.

- **Persona 1: The Independent Urban Explorer**

This persona represents the group with the greatest digital experience. They placed a high value on mobility aids that improve their social engagement and enable real-time information, as well as optional add-ons that increase customizability but do not necessarily require a simple interface. Physical mobility aids were not particularly attractive to this group.

- **Persona 2: The Careful Suburb Resident**

The group belonging to this persona had the lowest level of digital literacy and a cautious attitude towards DT. In addition, health issues limit mobility and the modes of transport that can be used. Their most important requirements were simplicity and intuitive design. As a result, they favored mobility aids that were integrated into existing systems with which they were familiar. Further, a support network played an important role in their adoption.

- **Persona 3: The Fit Rural Spouse**

Participants represented by this persona were moderately familiar with DT and still relatively fit. Their needs included customizable features that enable step-by-step learning and support, such as user-friendly interfaces and customizable settings. This group also showed higher acceptance of physical mobility aids like e-scooters.

Answering the second part of the research question, the evaluation of the four mobility prototypes was analyzed according to the three clusters. This research clearly illustrates a higher acceptance of digital mobility aids (Prototype 3 & 4) that indirectly support mobility by providing information for networking events or navigation. These prototypes embody ease of use and are integrated into applications that are familiar to most older people. The hardware prototypes (Prototype 1 & 2), which directly support mobility, generally had a lower level of acceptance. Among other things, this can be attributed to a lower perceived usefulness and higher complexity. However, this raises the question of the extent to which unfamiliarity of the solutions played a role here. Nevertheless, the evaluation indicated that Cluster 1 & 3 still showed a moderate to higher interest in this prototype. It is worth noting that there were significant gender differences, with female participants generally showing higher acceptance of all prototypes, particularly prototype 1.

This analysis revealed several important factors from which recommendations for future mobility solutions for older people can be derived.

Personalization and simplicity are important features in developing inclusive mobility solutions. The functions offered should be adaptable to different digital competencies and physical abilities to ensure effective use and broad acceptance. Safety and social engagement are crucial and should be given special consideration when designing mobility solutions. The provision of real-time information on accessibility, the promotion of community-based travel networks, and the introduction of confidence-building support systems can help to promote independence. Combined with an intuitive and simple user interface, this has led to a high acceptance of Prototype 4. Utilizing familiar technologies by integrating new functionalities can increase acceptance, as shown by the positive response to Prototype 3. Furthermore, promoting networks and learning resources are important to facilitating technology adoption.

The role of ambassadors or learning groups, such as PC groups, should be emphasized. Providing support networks where older people can learn from peers or ‘champions’ can significantly increase confidence and technology uptake.

6.2 Outlook / Further Research

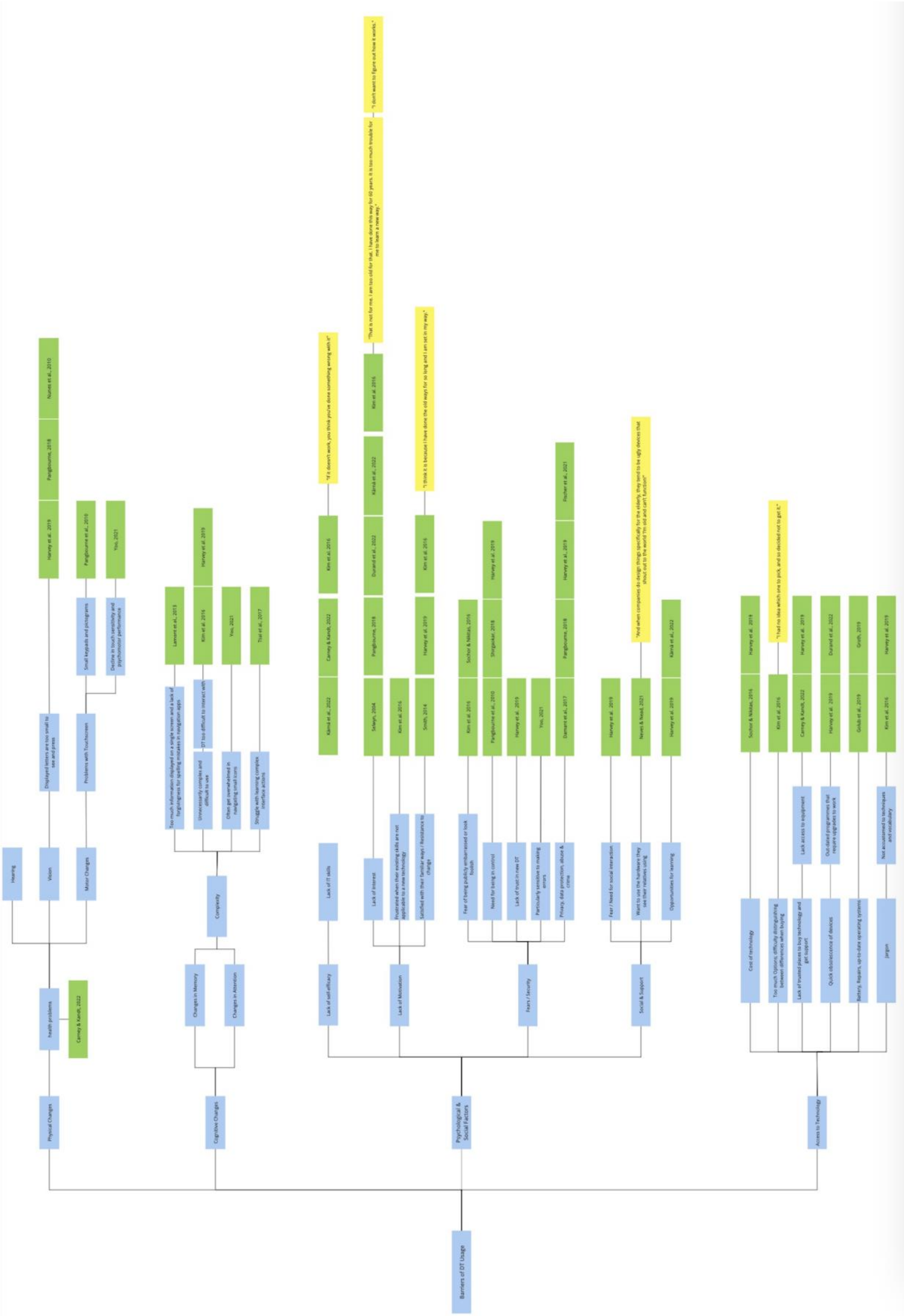
The results of this work make an important contribution to understanding older people's perception and acceptance of (digital) mobility technologies in connection with the use of MaaS and integrated mobility services.

An important area for future research is the investigation and validation of existing stereotypes (or clusters), barriers, and needs of older people in relation to MaaS and other integrated mobility services. A better understanding of their perceptions and possible misconceptions about these services is essential for developing inclusive solutions that older people accept.

In addition, MaaS has the potential to fundamentally change the mobility of this demographic group by breaking down various physical, spatial, temporal, and informational barriers to mobility. However, a remaining research gap concerns the question of whether the introduction of MaaS could unintentionally penalize older people instead of breaking down these barriers. While initial aspects of this have been explored in this research, this risk should be explored in more detail in future studies.

Finally, determining the willingness to pay (WTP) for different MaaS features is another topic for future research. The WTP values could be derived from a discrete choice model considering different MaaS features by conducting a stated preference experiment. This could provide valuable insights and extend this study by further investigating which features are particularly important to older people and which they would be willing to pay for.

Appendix



Appendix 1: Barriers of DT Usage

Constructs	Items		Sources
Attitude towards using (AT)	AT1	Using technology is a good idea	Davis, Bagozzi, and Warshaw (1989)
	AT2	You like the idea of using technology	
Perceived usefulness (PU)	PU1	Using technology would enhance your effectiveness in life	Davis, Bagozzi, and Warshaw (1989)
	PU2	Using technology would make your life more convenient	
	PU3	You would find technology useful in your life	
Perceived ease of use (PEOU)	PEOU1	You would find technology is easy to use	Davis, Bagozzi, and Warshaw (1989)
	PEOU2	You could be skilful at using technology	
Gerontechnology self-efficacy (SE)	SE1	You could complete a task using technology if there is someone to demonstrate how	Venkatesh et al. (2003)
	SE2	You could complete a task using technology if you have just the instruction manual for assistance	
Gerontechnology anxiety (ANX)	ANX1	You feel apprehensive about using the technology	Venkatesh et al. (2003)
	ANX2	You hesitate to use the technology for fear of making mistakes you cannot correct	
Facilitating conditions (FC)	FC1	You have the knowledge necessary to use the system	Ryu,Kim, and Lee (2009) and
	FC2	A specific person (or group) is available for assistance with technology difficulties	Venkatesh et al. (2003)
	FC3	Your financial status does not limit your activities in using technology	
	FC4	When you want or need to use technologies, they are accessible for you	
	FC5	Your family and friends think/support that you should use technology	
Self-reported health conditions	General health	How are your general health conditions?	McDowell (2006, 619)
	Health compared to others	How is your health conditions compared with the same-age groups?	
	Hearing	How good is your hearing?	
	Vision	How well can you see?	
	Movement	How well are you able to move around?	
Cognitive ability	Memory	How would you rate your memory?	Leung et al. (2005) and
	Learning	How satisfied are you with your ability to learn new information?	McDowell (2006, 619)
	Concentration	How well are you able to concentrate?	
	Thinking	How satisfied are you with your ability to make decisions?	
Social relationships	Relaion1	How satisfied are you with your personal relationships?	Leung et al. (2005) and
	Relation2	How satisfied are you with the support you get from your friends and family?	McDowell (2006, 619)
	Relation3	Do you participate in social or community activities?	
Psychological function	Attitude to ageing	Do you feel that as you get older you are less useful?	Wong et al. (2004)
	Life satisfaction	How satisfied are you with your quality of life?	
Physical function	IADL1	Ability to use telephone	Leung, Leung, and Chi (2011)
	IADL2	Grocery shopping	
	IADL3	Food preparation	
	IADL4	Doing housework or handyman work	
	IADL5	Laundry	
	IADL6	Getting to places beyond walking distance	
	IADL7	Taking medications	
	IADL8	Managing money	

Appendix 2: Modified STAM 38-item questionnaire (Chen & Chan, 2014)

Focus Group Guide

A. Introduction

- Introduce myself (+ assistant)
- Introduce research, motivation & purpose
- Ask for consent

"All data collected will be anonymized and used for research purposes only. Would you be okay with us recording the audio?"

- Round of Introduction (participants), including Icebreaker

B. Fill in questionnaire

- Explain the reason for the questionnaire

C. Group Discussion (encourage discussion between participants)

1. **Topic: Digital Technology**
   - What digital tools do you use in your everyday life?
     - What hurdles do you have to overcome?
     - How did you acquire it?
     - Does anyone help you with the operation?
2. **Topic: Mobility habits and transport modes**
   - What means of transport do you use in everyday life?
     - What obstacles do you face?
     - Would you exercise more if you had better access to information?
3. **Topic: Digital Technology & Mobility**
   - What digital aids do you use for mobility?
     - What obstacles do you face?
     - What stops you from using digital tools?
     - What could a better solution look like?

D. Presentation of prototypes (Introduce TechChallenge participants if present)

- Introduce and explain prototypes
- Let participants test prototypes and gather feedback

E. Fill out STAM Questionnaire

- Explaining questionnaire

F. Expressing gratitude and saying goodbye

Appendix 3: Focus Group "Interview" Guide

Technische Universität München

Fragebogen zum Thema: Digitale Hilfsmittel von Senioren

1. Welcher Nationalität gehören Sie an?

☐ ______________________

2. Welchem Geschlecht gehören Sie an?

☐ Männlich ☐ Weiblich ☐ Divers

3. Wie alt sind Sie?

☐ _____________________

4. Was ist Ihr höchster Bildungsgrad?

☐ Ausbildung ☐ Mittlere Reife ☐ Universität ☐ ______________________

5. Was ist Ihr aktueller Lebensstatus?

☐ Allein ☐ Partner ☐ Betreutes Wohnen ☐ Pflegeheim ☐______________________

6. Was ist Ihr Berufsstatus?

☐ Berufstätig Vollzeit ☐ Berufstätig Halbtags ☐ Ruhestand ☐______________________

7. Wie hoch ist Ihr aktuelles monatliches Einkommen?

☐ < 1.000€ ☐ 1.000€-2.000€ ☐ 2.000€-3.000€ ☐ > 3.000€

8. Wie bewerten Sie ihren Erfahrungen im Umgang mit digitalen Geräten wie Smartphones und Tablets?

Keine Erfahrung	Schlecht	Mittel	Gut	Sehr gut
☐	☐	☐	☐	☐

9. Welche Verkehrsmittel nutzen Sie primär?

☐ Auto ☐ Auto Beifahrer ☐ Taxi ☐ Bus ☐ Straßenbahn ☐ U-Bahn
☐ S-Bahn ☐ Fahrrad ☐ Carsharing ☐ Laufen ☐______________________

Vielen Dank für Ihre Teilnahme!

Appendix 4: General Questionnaire

STAM Fragebogen

Fragen	Stimme gar nicht zu	Stimme nicht zu	Stimme eher nicht zu	Neutral	Stimme eher zu	Stimme zu	Stimme voll zu
Diese Technologie wird Ihnen in Ihrem Leben nützlich sein.	○	○	○	○	○	○	○
Die Verwendung dieser Technology würde Ihre Effektivität im Leben verbessern.	○	○	○	○	○	○	○
Ihnen gefällt die Idee, diese Technologie zu verwenden.	○	○	○	○	○	○	○
Sie könnten diese Technologie geschickt einsetzen.	○	○	○	○	○	○	○
Sie könnten eine Aufgabe mithilfe dieser Technologie erledigen, wenn es jemanden gibt, der das vorführt.	○	○	○	○	○	○	○
Sie zögern, diese Technologie zu verwenden, weil Sie befürchten, Fehler zu machen, die Sie nicht korrigieren können.	○	○	○	○	○	○	○

Fragen	Sehr schlecht	Schlecht	Eher schlecht	Neutral	Eher gut	Gut	Sehr gut
Wie steht es um Ihren allgemeinen Gesundheitszustand?	○	○	○	○	○	○	○
Wie gut können Sie sich bei der Verwendung dieser Technologie konzentrieren?	○	○	○	○	○	○	○
Wie zufrieden sind Sie mit Ihren persönlichen Beziehungen?	○	○	○	○	○	○	○
Wie zufrieden sind Sie mit der Unterstützung, die Sie von Ihren Freunden und Ihrer Familie erhalten?	○	○	○	○	○	○	○
Wie zufrieden sind Sie mit der Qualität Ihres Lebens?	○	○	○	○	○	○	○

Appendix 5: STAM Questionnaire

Kriterium	Gewichtung	Prototyp (Bewertung 1-10)		
	1-100	BAU*	1	2
Sicherheit Verbessert der Prototyp die Sicherheit?				
Kosten Steht der Nutzen im Verhältnis zum Preis? Kann man sich den Prototyp leisten?				
Verbesserung der Mobilität Verbessert der Prototyp die Bewegungsfreiheit und Unabhängigkeit?				
Leichte Bedienbarkeit Lässt sich der Prototyp einfach bedienen?				
Barrierefreiheit Ist der Prototyp einfach zugänglich und nutzbar?				
Individualisierbarkeit Ist es möglich den Prototypen an die eigenen Bedürfnisse anzupassen?				
Kompatibilität Kann der Prototyp mit bereits vorhandenen Geräten, Technologien oder Infrastruktur zusammenarbeitet?				
Vernetzbarkeit Hilft der Prototyp dabei soziale Kontakte zu pflegen oder neue Netzwerke zu knüpfen?				

*BAU – Baseline (Grundlinie): Existierende Lösung

Appendix 6: MAMCA Evaluation Form (Older People)

Technische Universität München

TUM

UNTERNEHMER TUM

WORKSHOP

ENTWICKLUNG DIGITALER LÖSUNG ZUR UNTERSTÜTZUNG DER MOBILITÄT VON SENIOREN

Wir laden Sie herzlich ein, an einem spannenden Workshop teilzunehmen! Beteiligen Sie sich an der Entwicklung neuer digitaler Technologien zur Erleichterung und Verbesserung der Mobilität von Senioren.

Die enge Zusammenarbeit mit Ihnen ist essentiell, um maßgeschneiderte Lösungen zu entwickeln. Deshalb brauchen wir Sie! Werden Sie Teil der Lösung und helfen Sie dabei, die Technologien und Hilfsmittel zu entwickeln, die Sie wirklich benötigen und nutzen wollen.

DISKUSSION

Teilen Sie Ihre Meinung und Diskutieren Sie mit anderen Senioren über Ihre Erfahrungen.

ENTWICKLUNG

Helfen Sie bei der Entwicklung neuer digitaler Hilfsmittel mit und bringen Sie die Forschung mit Ihren Ideen voran

TESTEN

Testen Sie aktuelle Prototypen, die von unserer Forschungsgruppe entwickelt wurden

Melden Sie sich einfach telefonisch oder per E-Mail für einen der folgenden Termine an:

Wann?

Wo?

0151 26876845 lennart.mueller@tum.de

Appendix 7: Flyer Focus Group Acquisition

Appendix 8: Codebook Focus Groups

Main Categories	Sub Categories	Codes	Definition	Examples
DT Usage & Barriers	Technology	Apps	Usage and familiarity with different apps	"And when I go hiking in the countryside, I use this MapsMe app. I find it really useful, so I only really use Google Maps on my computer at home [...]" - FG1
		WhatsApp	High familiarity with WhatsApp	"And I like using WhatsApp. If we have problems, we talk to each other. How do
		Online Banking / Paying	Usage & Barriers of online banking services	"DKB only works online. And at the beginning there are sometimes really
		Tech Requirements	Perceived or actual technology specifications	"That's quite useful because the screen is bigger. Because then I can cope
		Technology Hurdle	General barriers/challenges with DT	"These are certainly not significant changes. But for me, it's a completely
DT Usage & Barriers	Psychological Factors	Privacy	Concerns regarding the protection of personal data	"I do have WhatsApp in my private life, but I actually use Signal more for
		Fears/Worries	General fears in connection with the use of DT	"However, I had resisted the use of smartphones for a long time; for reasons of
		Attitude towards Tech	General attitude towards DT	"I have a mobile phone, yes.But I just don't get on with it at all. And I don't like it
		Motivation / Lack of Motivation	Drive or willingness to engage with DT	"Apart from that, the whole digitalisation thing, I'm too old for that, I'm not
		Self-efficacy	Confidence in your own ability to use DT	„[...] this is now a tedious business for us older people and that we no longer want to do it, so I'd rather do less and do what I know." - FG9
		Personal Contact	Preference for in-person interaction over digital interaction	"I'd rather do my things in person or over the phone or something. And not be
DT Usage & Barriers	Cognitive & Perceptual	Memory Impairment	Memory problems when using DT	"It's dangerous because sometimes you don't remember what you've done. You've already done it a long time ago" - FG11
		Health	Physical or cognitive health condition that impact DT use	""So I don't have WhatsApp or a smartphone, nor do I have a computer, because
DT Usage & Barriers	Access to Technology	Don't be a burden	The desire not to cause inconvenience to others	"And I mean, I have a lot of support from my daughter and son-in-law here in Garching, but they are also so busy at work that I don't want to burden them
		Tech Support	Role of support for technical questions	"So I really need support there too. I haven't yet found anyone who does online
		Reason for Tech	Reason for using DT	I have the mobile phone, but I don't like it. I actually bought it just to talk to my grandchildren via WhatsApp to the USA to talk to my daughter." - FG4
		Exclusion through Digitalisation	Feeling of being left out due to increasing digitalization	"Even the supermarkets only give discounts if you use the app. I think that's anti-consumer behaviour towards older people who can't use it now." - FG3
Mobility Needs & Barriers	Transport Modes	Car	Use of and barriers to a personal vehicle	"I'm also often sorry that I sold my car.But unfortunately that's the way it is." -
		Bus	Use of and barriers of public bus	"I go shopping, everything with the rollator and everything that is a bit further
		Bicycle	Use of and barriers of bicycles	"And I don't like cycling any more. You have to recognise your limits." - FG7
		Subway	Use of and barriers of subway	"Due to my state of health, it is no longer possible to go on such long tours. So travelling by bus and so on is out of the question. The only thing left is the
		Walking	Walking as a mode of mobility	"[...] one disadvantage is of course that there is no lift.It's on the third or fourth floor without a lift. And then, of course, all the senior citizens said it was dead
Mobility Needs & Barriers	Travel Distance	Habitat / radius of movement	Usual places and distances when travelling	"So I'm still reasonably mobile, I realise that the circle of life, the space is
		Long Trips	Capacity and willingness to travel longer distances	"Due to my state of health, it is no longer possible to go on such long tours" -
Mobility Needs & Barriers	Mobility Barriers	Planning / Waiting Time	Dealing with planning and waiting times	„... [the train] drives to Salzburg every hour. And my God, if I can't reach one of them, I'll take the next one. I've got time to wait." - FG4
		Mobility Hurdles	General/Others barriers that hinder mobility	"I have severe osteoarthritis in my knees, bones and fingers. It just comes with
		Risk of Injury	Concern of potential injuries; FOF	"And with the bus, I'm afraid to move, I've heard too many experiences from others who have fallen and broken all sorts of things and the hassle with the
		Navigation	Usage & Challenges with navigation	"So I mainly use the MVGO for orientation [...]. So actually whenever I have a new address, because it shows me exactly how to get there and also the side of

#	Age	Gender	Region	Education	Income	Digital Literacy	Total	Living Status	PT Usage
1/FG1	72	Female	City	2	1	4	21	1	1
2/FG2	75	Male	City	1	2	4	25	1	0
3/FG3	75	Female	City	2	2	2	10	1	1
4/FG4	85	Female	Rural	1	2	2	26	1	1
5/FG5	86	Female	Rural	0	3	2	23	1	1
6/FG6	92	Female	Rural	0	2	2	19	1	0
7/FG7	87	Female	Rural	2	1	1	25	2	0
8/FG8	88	Female	Rural	0	1	2	25	0	1
9/FG9	86	Female	Rural	0	1	2	22	0	0
10/FG10	92	Female	Rural	0	1	1	26	0	0
11/FG11	84	Female	Rural	2	3	1	23	2	0
NA/FG12	75	Female	Rural	-	-	-	-	-	-
NA/W1	67	Male	City	-	-	-	-	-	-
NA/W2	66	Female	City	-	-	-	-	-	-
12	65	Male	Rural	2	2	4	27	0	0
13	79	Female	Rural	0	2	1	26	2	1
14	82	Male	Rural	0	2	2	20	2	1
15	85	Male	Rural	0	1	0	14	2	1
16	67	Female	Rural	0	1	3	25	0	0
17	89	Male	Rural	0	3	3	26	0	1
18	67	Male	Rural	0	2	2	24	0	0
19	73	Female	Rural	0	0	2	21	2	0
20	69	Male	Rural	0	2	2	19	0	0
21	81	Female	Rural	0	1	3	26	2	0
22	68	Female	Rural	2	1	2	24	2	1
23	84	Female	Rural	0	3	3	28	2	0
24	64	Female	Rural	0	0	3	25	2	0
25	81	Female	Rural	1	1	2	25	1	0
26	69	Female	Rural	2	3	4	30	1	0
27	71	Male	Rural	2	3	3	25	1	0
28	82	Male	Rural	2	2	2	20	1	0
29	79	Male	Rural	1	2	2	25	2	0
30	76	Male	Rural	2	3	3	19	2	0
31	85	Male	Rural	1	1	2	14	2	1

32	77	Male	Rural	1	3	3	27	0	1
33	69	Male	Rural	2	1	4	20	2	1
34	71	Male	Rural	1	1	2	23	2	1
35	79	Male	Rural	1	1	3	23	0	0
36	64	Male	City	2	2	2	19	2	1
37	67	Male	City	2	1	2	17	2	1
38	71	Male	City	2	3	2	20	2	1
39	71	Male	City	2	2	4	26	0	0

Appendix 9: Overview Participants

Note: FG = Focus Groups; NA = not included in Cluster Analysis or Evaluation; For Label Encoding see Table 3

	Age	Gender	Income	Education	Region	PT	Living	Health	Concentration	Realtionships	Support	QOL	Total	Experience_Tech	Prototype_1	Prototype_2	Prototype_3	Prototype_4
Age	1.00	-0.14	0.23	-0.36	-0.32	-0.49	-0.56	-0.30	-0.30	[illegible]	-0.06	-0.07	-0.17	-0.27	-0.18	-0.46	-0.52	-0.40
Gender		1.00	-0.34	-0.32	-0.27	-0.10	-0.10	0.50	0.32	0.40	0.14	0.52	0.43	0.21	0.48	0.24	0.26	0.22
Income			1.00	0.29	0.09	-0.02	0.02	0.14	0.14	0.29	0.52	0.31	0.36	0.28	-0.09	-0.10	-0.10	-0.09
Education				1.00	0.46	0.24	0.24	0.08	0.11	-0.18	-0.05	0.02	-0.02	0.31	-0.09	[illegible]	0.09	0.16
Region					1.00	0.58	0.11	-0.11	-0.29	-0.22	-0.07	-0.11	-0.19	-0.03	-0.11	0.05	[illegible]	-0.12
PT						1.00	0.24	0.07	-0.06	-0.22	-0.27	-0.13	-0.16	-0.19	0.18	0.21	0.24	0.12
Living							1.00	0.21	0.21	0.16	0.03	0.14	0.18	0.21	0.36	0.43	0.47	0.47
Health								1.00	0.57	0.47	0.35	0.68	0.72	0.64	0.46	0.27	0.39	0.42
Concentration									1.00	0.62	0.60	0.51	0.80	0.64	0.39	0.41	0.40	0.44
Realtionships										1.00	0.79	0.74	0.89	0.48	0.25	0.07	0.12	0.07
Support											1.00	0.64	0.85	0.50	0.02	0.11	0.14	[illegible]
QOL												1.00	0.85	0.58	0.33	0.20	0.22	0.16
Total													1.00	0.68	0.33	0.24	0.30	0.25
Experience_Tech														1.00	0.29	0.43	0.30	0.32
Prototype_1															1.00	0.63	0.46	0.48
Prototype_2																1.00	0.69	0.62
Prototype_3																	1.00	0.93
Prototype_4																		1.00

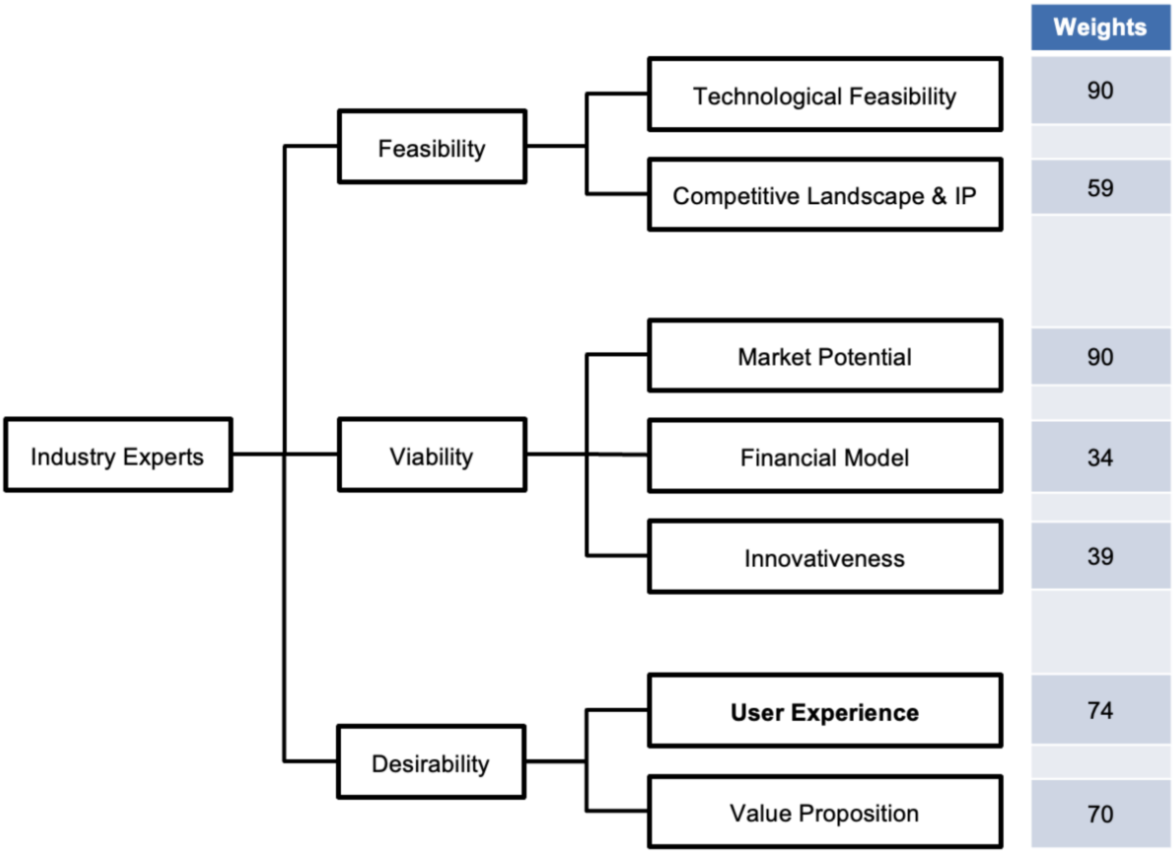
Appendix 10: Correlation Matrix

Older People	Hardware				Software			
	Cluster 1	Cluster 2	Cluster 3	Total	Cluster 1	Cluster 2	Cluster 3	Total
Safety	80	40	80	76	85	70	94	88
Costs	70	50	54	59	63	90	64	67
Improved Mobility	80	10	82	73	83	90	86	86
Ease of use	80	60	82	79	87	70	91	87
Accessibility	50	50	82	68	93	70	80	83
Customizability	67	50	62	62	87	90	78	82
Compatibility	67	80	42	54	83	50	44	58
Networkability	60	90	74	71	80	90	82	82

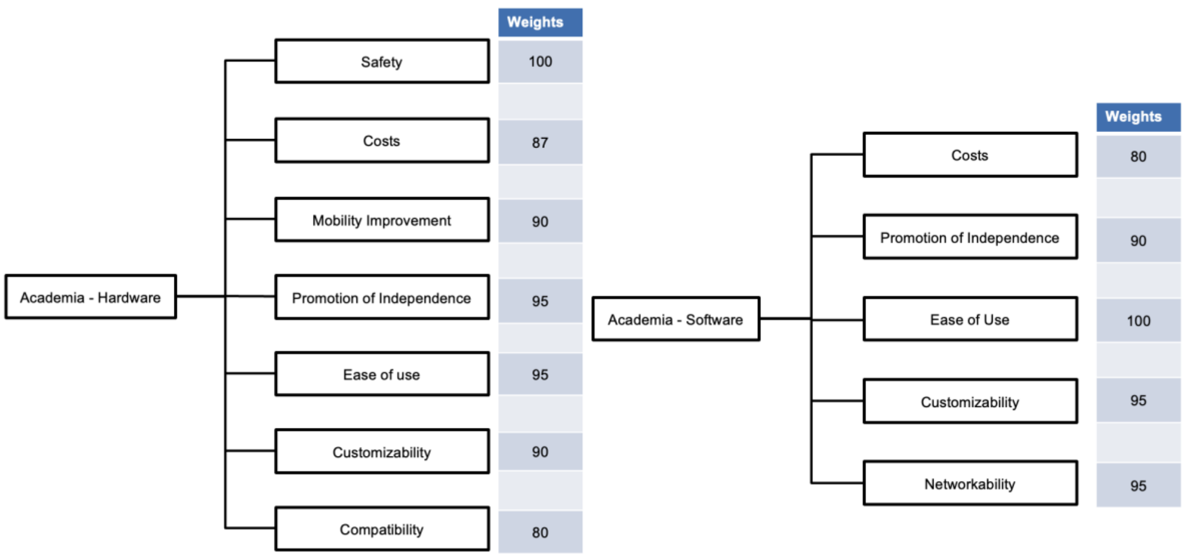
Appendix 11: MAMCA Criteria Weighting Older People

Senior Advisory Council	Hardware	Software
Safety	95	95
Costs	80	85
Improved Mobility	95	90
Ease of use	90	95
Accessibility	85	90
Customizability	85	85
Compatibility	55	95
Networkability	50	85

Appendix 12: MAMCA Criteria Weighting Senior Advisory Counci



Appendix 13: MAMCA Criteria Weightings Industry Experts



Appendix 14: MAMCA Criteria Weightings Academia

Digital Appendix

Digital Appendix 1: STAM Results.xlsx

Digital Appendix 2: MAMCA Results.xlsx

Digital Appendix 3: Focus group transcriptions with coding

Digital Appendix 4: Hierarchical Clustering.R

Digital Appendix 5: STAM Evaluation.R

Digital Appendix 6: Hierarchical Clustering Data 6.xlsx

Digital Appendix 7: Hierarchical Clustering Data 8.xlsx

Digital Appendix 8: Sample Characteristics.xlsx

References

Abdullah, F., & Ward, R. (2016). Developing a General Extended Technology Acceptance Model for E-Learning (GETAMEL) by analysing commonly used external factors. *Computers in Human Behavior*, *56*, 238–256. https://doi.org/10.1016/j.chb.2015.11.036

Aguiar, B., & Macário, R. (2017). The need for an Elderly centred mobility policy. *Transportation Research Procedia*, *25*, 4355–4369. https://doi.org/10.1016/j.trpro.2017.05.309

Almeida, F., Duarte Santos, J., & Augusto Monteiro, J. (2020). The Challenges and Opportunities in the Digitalization of Companies in a Post-COVID-19 World. *IEEE Engineering Management Review*, *48*(3), 97–103. https://doi.org/10.1109/EMR.2020.3013206

Azasoo, J., & Boateng, K. (2015). *A Retrofit Design Science Methodology for Smart Metering Design in Developing Countries*. https://doi.org/10.1109/ICCSA.2015.23

Bandura, A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, *37*(2), 122.

Banister, D., & Bowling, A. (2004). Quality of life for the elderly: the transport dimension. *Transport Policy*, *11*(2), 105–115.

Bartholomew, D. J., Steele, F., Galbraith, J., & Moustaki, I. (2008). *Analysis of multivariate social science data*. CRC press.

Beaton, D. E., Wright, J. G., Katz, J. N., & Group, U. E. C. (2005). Development of the QuickDASH: comparison of three item-reduction approaches. *JBJS*, *87*(5), 1038–1046.

Bengtsson, M. (2016). How to plan and perform a qualitative study using content analysis. *NursingPlus Open*, *2*, 8–14. https://doi.org/10.1016/j.npls.2016.01.001

Betts, L. R., Hill, R., & Gardner, S. E. (2019). "There's Not Enough Knowledge Out There": Examining Older Adults' Perceptions of Digital Technology Use and Digital Inclusion Classes. *Journal of Applied Gerontology*, *38*(8), 1147–1166. https://doi.org/10.1177/0733464817737621

Bhattacherjee, A. (2012). Social Science Research: principles, methods, and practices. In *Book 3.* http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1002&context=oa_textbooks

Bloom, D. E., & Luca, D. L. (2016). The global demography of aging: facts, explanations, future. In *Handbook of the economics of population aging* (Vol. 1, pp. 3–56). Elsevier.

Boerema, S. T., van Velsen, L., Vollenbroek-Hutten, M. M. R., & Hermens, H. J. (2017). Value-based design for the elderly: An application in the field of mobility aids. *Assistive Technology*, *29*(2), 76–84.

Bundesministerium für Familie Senioren Frauen und Jugend. (2020). *Achter Altersbericht*. https://www.achter-altersbericht.de/fileadmin/altersbericht/pdf/aktive_PDF_Altersbericht_DT-Drucksache.pdf

Butler, L., Yigitcanlar, T., & Paz, A. (2020). How can smart mobility innovations alleviate transportation disadvantage? Assembling a conceptual framework through a systematic review. *Applied Sciences*, *10*(18), 6306.

Butler, L., Yigitcanlar, T., & Paz, A. (2021). Barriers and risks of Mobility-as-a-Service (MaaS) adoption in cities: A systematic review of the literature. *Cities*, *109*, 103036.

Caiati, V., Rasouli, S., & Timmermans, H. (2020). Bundling, pricing schemes and extra features preferences for mobility as a service: Sequential portfolio choice experiment.

Transportation Research Part A: Policy and Practice, *131*, 123–148.
Carney, F., & Kandt, J. (2022). Health, out-of-home activities and digital inclusion in later life: Implications for emerging mobility services. *Journal of Transport and Health*, *24*(December 2021), 101311. https://doi.org/10.1016/j.jth.2021.101311
Carp, F. M. (1988). Significance of mobility for the well-being of the elderly. *Transportation in an Aging Society: Improving Mobility and Safety of Older Persons*, *2*(2), 1–20.
Chen, K., & Chan, A. H. S. (2014). Gerontechnology acceptance by elderly Hong Kong Chinese: a senior technology acceptance model (STAM). In *Ergonomics* (Vol. 57, Issue 5, pp. 635–652). Taylor & Francis. https://doi.org/10.1080/00140139.2014.895855
Chen, K., & Lou, V. W. Q. (2020). Measuring senior technology acceptance: Development of a Brief, 14-Item Scale. *Innovation in Aging*, *4*(3), 1–12. https://doi.org/10.1093/geroni/igaa016
Choi, N. G., & DiNitto, D. M. (2013). Internet use among older adults: association with health needs, psychological capital, and social capital. *Journal of Medical Internet Research*, *15*(5), e2333.
Cooper, A. (1999). *The inmates are running the asylum*. Springer.
Damant, J., Knapp, M., Freddolino, P., & Lombard, D. (2017). Effects of digital engagement on the quality of life of older people. *Health and Social Care in the Community*, *25*(6), 1679–1703. https://doi.org/10.1111/hsc.12335
Davis, F. D. (1985). *A technology acceptance model for empirically testing new end-user information systems: Theory and results*. Massachusetts Institute of Technology.
Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, *35*(8), 982–1003.
Davis, F. D., & Venkatesh, V. (2004). Toward preprototype user acceptance testing of new information systems: implications for software project management. *IEEE Transactions on Engineering Management*, *51*(1), 31–46.
Doh, M. (2020). *Auswertung von empirischen Studien zur Nutzung von Internet , digitalen Medien und Informations- und Kommunikations-Technologien bei älteren Menschen Expertisen zum Achten Altersber ... Auswertung von empirischen Studien zur Nutzung von Internet , digital*. *September*, 96.
Döring, N., & Bortz, J. (2016). Forschungsmethoden und evaluation. *Wiesbaden: Springerverlag*.
Durand, A., Zijlstra, T., van Oort, N., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2022). Access denied? Digital inequality in transport services. *Transport Reviews*, *42*(1), 32–57. https://doi.org/10.1080/01441647.2021.1923584
Edwards, W. (1977). How to use multiattribute utility measurement for social decisionmaking. *IEEE Transactions on Systems, Man, and Cybernetics*, *7*(5), 326–340.
Erber, J. T. (2012). *Aging and older adulthood*. John Wiley & Sons.
Eurostat. (2024). Population structure and ageing. *Eurostat*, *February 2024*, 1–11. http://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing
Everitt, B. S., Landau, S., Leese, M., & Stahl, D. (2011). *Cluster Analysis* (5th ed.). Wiley. https://books.google.de/books?id=w3bE1kqd-48C
Evitt, C. P., & Quigley, P. A. (2004). Fear of falling in older adults: a guide to its prevalence, risk factors, and consequences. *Rehabilitation Nursing*, *29*(6), 207.
Fang, M. L., Canham, S. L., Battersby, L., Sixsmith, J., Wada, M., & Sixsmith, A. (2019). Exploring Privilege in the Digital Divide: Implications for Theory, Policy, and Practice. *Gerontologist*, *59*(1), E1–E15. https://doi.org/10.1093/geront/gny037

Fioreze, T., De Gruijter, M., & Geurs, K. (2019). On the likelihood of using Mobility-as-a-Service: A case study on innovative mobility services among residents in the Netherlands. *Case Studies on Transport Policy*, *7*(4), 790–801.

Fischer, B., Östlund, B., Dalmer, N. K., Rosales, A., Peine, A., Loos, E., Neven, L., & Marshall, B. (2021). Co-design as learning: The differences of learning when involving older people in digitalization in four countries. *Societies*, *11*(2), 1–16. https://doi.org/10.3390/soc11020066

Fisk, A. D., Czaja, S. J., Rogers, W. A., Charness, N., & Sharit, J. (2020). *Designing for older adults: Principles and creative human factors approaches*. CRC press.

Fitt, H. (2018). Exploring how older people might experience future transport systems. *Geographies of Transport and Ageing*, 199–225.

Fobker, S., & Grotz, R. (2006). Everyday Mobility of Elderly People in Different Urban Settings: The Example of the City of Bonn, Germany. *Urban Studies*, *43*(1), 99–118. https://doi.org/10.1080/00420980500409292

Francis, J., Ball, C., Kadylak, T., & Cotten, S. R. (2019). *Aging in the Digital Age: Conceptualizing Technology Adoption and Digital Inequalities BT - Ageing and Digital Technology: Designing and Evaluating Emerging Technologies for Older Adults* (B. B. Neves & F. Vetere (eds.); pp. 35–49). Springer Singapore. https://doi.org/10.1007/978-981-13-3693-5_3

Fuglerud, K. S., Schulz, T., Janson, A. L., & Moen, A. (2020). Co-creating persona scenarios with diverse users enriching inclusive design. *International Conference on Human-Computer Interaction*, 48–59.

Gallistl, V., Rohner, R., Seifert, A., & Wanka, A. (2020). Configuring the older non-user: Between research, policy and practice of digital exclusion. *Social Inclusion*, *8*(2), 233–243. https://doi.org/10.17645/si.v8i2.2607

Gell, N. M., Wallace, R. B., LaCroix, A. Z., Mroz, T. M., & Patel, K. V. (2015). Mobility device use in older adults and incidence of falls and worry about falling: Findings from the 2011–2012 national health and aging trends study. *Journal of the American Geriatrics Society*, *63*(5), 853–859.

Gibbs, G. R. (2018). *Analyzing qualitative data*.

Gilster, P. (1997). *Digital literacy*. Wiley Computer Pub. New York.

Glaser, B., & Strauss, A. (2017). *Discovery of grounded theory: Strategies for qualitative research*. Routledge.

Golub, A., Satterfield, V., Serritella, M., Singh, J., & Phillips, S. (2019). Assessing the barriers to equity in smart mobility systems: A case study of Portland, Oregon. *Case Studies on Transport Policy*, *7*(4), 689–697.

Gonzalez de Heredia, A., Goodman-Deane, J., Waller, S., Clarkson, P. J., Justel, D., Iriarte, I., & Hernández, J. (2018). *Personas for policy-making and healthcare design*.

Grissemann, U. S., & Stokburger-Sauer, N. E. (2012). Customer co-creation of travel services: The role of company support and customer satisfaction with the co-creation performance. *Tourism Management*, *33*(6), 1483–1492.

Groth, S. (2019). Multimodal divide: Reproduction of transport poverty in smart mobility trends. *Transportation Research Part A: Policy and Practice*, *125*, 56–71.

Grudin, J., & Pruitt, J. (2002). Personas, participatory design and product development: An infrastructure for engagement. *PDC*, 144–152.

Grundy, E. M., & Murphy, M. (2017). Population ageing in Europe. *Oxford Textbook of Geriatric Medicine*, *11*.

Guner, H., & Acarturk, C. (2020). The use and acceptance of ICT by senior citizens: a comparison of technology acceptance model (TAM) for elderly and young adults.

Universal Access in the Information Society, *19*(2), 311–330. https://doi.org/10.1007/s10209-018-0642-4
Guo, W., Harvey, J., & Edwards, S. (2017). *Older travellers and technology engagement*.
Hardill, I., & Olphert, C. W. (2012). Staying connected: Exploring mobile phone use amongst older adults in the UK. *Geoforum*, *43*(6), 1306–1312. https://doi.org/https://doi.org/10.1016/j.geoforum.2012.03.016
Harvey, J., Guo, W., & Edwards, S. (2019). Increasing mobility for older travellers through engagement with technology. *Transportation Research Part F: Traffic Psychology and Behaviour*, *60*, 172–184. https://doi.org/10.1016/j.trf.2018.10.019
Heikkinen, R.-L. (2004). The experience of ageing and advanced old age: a ten-year follow-up. *Ageing & Society*, *24*(4), 567–582.
Heinz, M., Martin, P., Margrett, J. A., Yearns, M., Franke, W., Yang, H.-I., Wong, J., & Chang, C. K. (2013). Perceptions of technology among older adults. *Journal of Gerontological Nursing*, *39*(1), 42–51.
Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, 75–105.
Hietanen, S. (2014). Mobility as a Service. *The New Transport Model*, *12*(2), 2–4.
Ho, C. Q., Hensher, D. A., Mulley, C., & Wong, Y. Z. (2018). Potential uptake and willingness-to-pay for Mobility as a Service (MaaS): A stated choice study. *Transportation Research Part A: Policy and Practice*, *117*, 302–318.
Huang, H., Lebeau, P., & Macharis, C. (2020). The Multi-Actor Multi-Criteria Analysis (MAMCA): New Software and New Visualizations. In *Lecture Notes in Business Information Processing: Vol. 384 LNBIP*. Springer International Publishing. https://doi.org/10.1007/978-3-030-46224-6_4
Huang, H., Mommens, K., Lebeau, P., & Macharis, C. (2021). *The Multi-Actor Multi-Criteria Analysis (MAMCA) for Mass-Participation Decision Making*. https://doi.org/10.1007/978-3-030-73976-8
Hunsaker, A., & Hargittai, E. (2018). A review of Internet use among older adults. *New Media & Society*, *20*(10), 3937–3954.
Ind, N., & Coates, N. (2013). The meanings of co-creation. *European Business Review*, *25*(1), 86–95. https://doi.org/10.1108/09555341311287754
Jittrapirom, P., Caiati, V., Feneri, A. M., Ebrahimigharehbaghi, S., Alonso-González, M. J., & Narayan, J. (2017). Mobility as a service: A critical review of definitions, assessments of schemes, and key challenges. *Urban Planning*, *2*(2), 13–25. https://doi.org/10.17645/up.v2i2.931
Jørstad, E. C., Hauer, K., Becker, C., Lamb, S. E., & Group, P. (2005). Measuring the psychological outcomes of falling: a systematic review. *Journal of the American Geriatrics Society*, *53*(3), 501–510.
Kallio, H., Pietilä, A., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, *72*(12), 2954–2965.
Kammerer, K., Falk, K., Herzog, A., & Fuchs, J. (2019). *How to reach 'hard-to-reach' older people for research: The TIBaR model of recruitment | Survey Methods: Insights from the Field (SMIF)*. *01*, 1–15. https://doi.org/10.13094/SMIF-2019-00012
Kärnä, E., Aavikko, L., Rohner, R., Gallistl, V., Pihlainen, K., Müller, C., Ehlers, A., Bevilacqua, R., Strano, S., Maranesi, E., Cerna, K., Hengl, L., Kolland, F., Waldenberger, F., Naegele, G., Park, S., Hess, M., Reuter, V., Frewer-Graumann, S., & Korjonen-Kuusipuro, K. (2022). A Multilevel Model of Older Adults' Appropriation of ICT and Acquisition of Digital Literacy.

International Journal of Environmental Research and Public Health, *19*(23). https://doi.org/10.3390/ijerph192315714

Kaufman, L., & Rousseeuw, P. J. (2009). *Finding groups in data: an introduction to cluster analysis*. John Wiley & Sons.

Kim, S., Gajos, K. Z., Muller, M., & Grosz, B. J. (2016). Acceptance of mobile technology by older adults: A preliminary study. *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI 2016*, 147–157. https://doi.org/10.1145/2935334.2935380

Kristensson, P., Matthing, J., & Johansson, N. (2008). Key strategies for the successful involvement of customers in the co-creation of new technology-based services. *International Journal of Service Industry Management*, *19*(4), 474–491. https://doi.org/10.1108/09564230810891914

Krueger, R. A. (2014). *Focus groups: A practical guide for applied research*. Sage publications.

Kubicek, H., & Lippa, B. (2017). *Nutzung und Nutzen des Internets im Alter: empirische Befunde zur Alterslücke und Empfehlungen für eine responsive Digitalisierungspolitik*. Vistas.

Kylberg, M., Löfqvist, C., Phillips, J., & Iwarsson, S. (2013). Three very old men's experiences of mobility device use over time. *Scandinavian Journal of Occupational Therapy*, *20*(5), 397–405.

Lamont, D., Kenyon, S., & Lyons, G. (2013). Dyslexia and mobility-related social exclusion: the role of travel information provision. *Journal of Transport Geography*, *26*, 147–157.

Leaning, M. (2019). An approach to digital literacy through the integration of media and information literacy. *Media and Communication*, *7*(2 Critical Perspectives), 4–13. https://doi.org/10.17645/mac.v7i2.1931

Lee, J. H., Kim, Y. M., Rhiu, I., & Yun, M. H. (2021). A persona-based approach for identifying accessibility issues in elderly and disabled users' interaction with home appliances. *Applied Sciences*, *11*(1), 368.

Legters, K. (2002). Fear of falling. *Physical Therapy*, *82*(3), 264–272.

Lesnoff-Caravaglia, G. (2007). *Gerontechnology: Growing old in a technological society*. Charles C. Thomas.

Levin, L. (2019). How may public transport influence the practice of everyday life among younger and older people and how may their practices influence public transport? *Social Sciences*, *8*(3). https://doi.org/10.3390/socsci8030096

Li, H., Raeside, R., Chen, T., & McQuaid, R. W. (2012). Population ageing, gender and the transportation system. *Research in Transportation Economics*, *34*(1), 39–47.

Lindberg, M., Lindgren, M., & Packendorff, J. (2014). Quadruple Helix as a Way to Bridge the Gender Gap in Entrepreneurship: The Case of an Innovation System Project in the Baltic Sea Region. *Journal of the Knowledge Economy*, *5*, 94–113. https://doi.org/10.1007/s13132-012-0098-3

Lode, M. L. (2020). Transition management and multi-actor multi-criteria analysis intertwined: how MAMCA supports transition management and its political potential. *Proceedings from the IST2020: 11th International Sustainability Transitions Conference*, 624–639.

Lu, Y., Valk, C., Steenbakkers, J., Bekker, T., Visser, T., Proctor, G., Toshniwal, O., & Langberg, H. (2017). Can technology adoption for older adults be co-created? *Gerontechnology, Journal*, *16*(3), 151–159.

Lutz, W., Sanderson, W., & Scherbov, S. (2008). The coming acceleration of global population ageing. *Nature*, *451*(7179), 716–719.

Macharis, C. (2005). The importance of stakeholder analysis in freight transport: the MAMCA methodology. *European Transport*, *25–26*, 114–126.

Macharis, C., & Baudry, G. (2018). *Decision-making for sustainable transport and mobility: multi actor multi criteria analysis*. Edward Elgar Publishing.

Macharis, C., Verbeke, A., & De Brucker, K. (2004). The strategic evaluation of new technologies through multicriteria analysis: the ADVISORS case. *Research in Transportation Economics*, *8*, 443–462.

Mannheim, I., Schwartz, E., Xi, W., Buttigieg, S. C., McDonnell-Naughton, M., Wouters, E. J. M., & van Zaalen, Y. (2019). Inclusion of older adults in the research and design of digital technology. *International Journal of Environmental Research and Public Health*, *16*(19). https://doi.org/10.3390/ijerph16193718

MAXQDA. (2024). *MAXQDA*.

Metz, D. (2017). Future transport technologies for an ageing society: practice and policy. In *Transport, travel and later life* (Vol. 10, pp. 207–220). Emerald Publishing Limited.

Miaskiewicz, T., & Kozar, K. A. (2011). Personas and user-centered design: How can personas benefit product design processes? *Design Studies*, *32*(5), 417–430.

Mihelj, S., Leguina, A., & Downey, J. (2019). Culture is digital: Cultural participation, diversity and the digital divide. *New Media and Society*, *21*(7), 1465–1485. https://doi.org/10.1177/1461444818822816

Mitzner, T. L., Fausset, C. B., Boron, J. B., Adams, A. E., Dijkstra, K., Lee, C. C., Rogers, W. A., & Fisk, A. D. (2008). Older adults' training preferences for learning to use technology. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *52*(26), 2047–2051.

Mollenkopf, H. (2004). *Ageing and outdoor mobility: A European study* (Vol. 13). IOS Press.

muenchen.de. (n.d.-a). *Informationen für Seniorinnen und Senioren in München*. Retrieved March 9, 2024, from https://www.muenchen.de/themen/informationen-fuer-senioren-muenchen

muenchen.de. (n.d.-b). *Statistische Daten zur Münchner Bevölkerung*. Retrieved November 4, 2024, from https://stadt.muenchen.de/infos/statistik-bevoelkerung.html#:~:text=Zum 30.06.2023 waren in,für München ungewöhnlichen niedrigen bzw.

Mulley, C., Nelson, J. D., & Wright, S. (2018). Community transport meets mobility as a service: On the road to a new a flexible future. *Research in Transportation Economics*, *69*, 583–591.

Musselwhite, C. (2019). Older people's mobility, new transport technologies and user-centred innovation. *Towards User-Centric Transport in Europe: Challenges, Solutions and Collaborations*, 87–103.

Musselwhite, C., & Haddad, H. (2010). Mobility, accessibility and quality of later life. *Quality in Ageing and Older Adults*, *11*(1), 25–37.

Neu-Anspach. (n.d.). *ZAHLEN DATEN FAKTEN*. Retrieved November 4, 2024, from https://www.neu-anspach.de/leben-in-neu-anspach/stadtportrait/zahlen-daten-fakten/

Neves, B. B., & Mead, G. (2021). Digital Technology and Older People: Towards a Sociological Approach to Technology Adoption in Later Life. *Sociology*, *55*(5), 888–905. https://doi.org/10.1177/0038038520975587

Neves, B. B., Waycott, J., & Malta, S. (2018). Old and afraid of new communication technologies? Reconceptualising and contesting the 'age-based digital divide.' *Journal of Sociology*, *54*(2), 236–248. https://doi.org/10.1177/1440783318766119

Nobis, C., & Kuhnimhof, T. (2018). Mobilität in Deutschland – MiD Ergebnisbericht. *Studie von Infas, DLR, IVT Und Infas 360 Im Auftrag Des Bundesministers Für Verkehr Und Digitale Infrastruktur (FE-Nr. 70.904/15)*, 136. http://www.mobilitaet-in-deutschland.de/

Nunes, F., Silva, P. A., & Abrantes, F. (2010). Human-Computer Interaction and the older adult: An example using user research and personas. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/1839294.1839353

O'Fallon, C., & Sullivan, C. (2003). Older people's travel patterns and transport sustainability in New Zealand cities. *Proceedings of the 26th Australasian Transport Research Forum, Wellington, New Zealand*, 1–3.

Ofcom. (n.d.). *Share of smartphone users in the United Kingdom (UK) 2012-2023, by age [Graph]*. Statista. Retrieved October 9, 2024, from https://www.statista.com/statistics/300402/smartphone-usage-in-the-uk-by-age/

Oh, S. S., Kim, K. A., Kim, M., Oh, J., Chu, S. H., & Choi, J. Y. (2021). Measurement of digital literacy among older adults: Systematic review. *Journal of Medical Internet Research*, *23*(2), 1–15. https://doi.org/10.2196/26145

Olsen, G. (2004). *Persona creation and usage toolkit*. *25*, 2014.

Ørngreen, R., & Levinsen, K. (2017). Workshops as a research methodology. *Electronic Journal of E-Learning*, *15*(1), 70–81.

Paiva, S., Ahad, M. A., Tripathi, G., Feroz, N., & Casalino, G. (2021). Enabling technologies for urban smart mobility: Recent trends, opportunities and challenges. *Sensors*, *21*(6), 2143.

Pangbourne, K. (2018). Mobility and ageing: A review of interactions between transport and technology from the perspective of older people. *Geographies of Transport and Ageing*, 51–71.

Pangbourne, K., Aditjandra, P. T., & Nelson, J. D. (2010). New technology and quality of life for older people: Exploring health and transport dimensions in the UK context. *IET Intelligent Transport Systems*, *4*(4), 318–327. https://doi.org/10.1049/iet-its.2009.0106

Pangbourne, K., Mladenović, M. N., Stead, D., & Milakis, D. (2020). Questioning mobility as a service: Unanticipated implications for society and governance. *Transportation Research Part A: Policy and Practice*, *131*, 35–49.

Pangbourne, K., Stead, D., Mladenović, M., & Milakis, D. (2018). the Case of Mobility As a Service: a Critical Reflection on Challenges for Urban Transport and Mobility Governance. *Governance of the Smart Mobility Transition*, 33–48. https://doi.org/10.1108/978-1-78754-317-120181003

Parviainen, P., Tihinen, M., Kääriäinen, J., & Teppola, S. (2017). Tackling the digitalization challenge: How to benefit from digitalization in practice. *International Journal of Information Systems and Project Management*, *5*(1), 63–77. https://doi.org/10.12821/ijispm050104

Patton, M. Q. (2014). *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77.

Pew Research Center. (2024). *Share of adults in the United States who owned a smartphone from 2015 to 2023, by age group [Graph]*. Statista. https://www.statista.com/statistics/489255/percentage-of-us-smartphone-owners-by-age-group/

Prensky, M. (2001a). Digital Natives, Digital Immigrants Part 1. *On the Horizon*, *9*(5), 1–6. https://doi.org/10.1108/10748120110424816

Prensky, M. (2001b). Digital natives, digital immigrants part 2: Do they really think differently? *On the Horizon*, *9*(6), 1–6.

Ramsetty, A., & Adams, C. (2020). Impact of the digital divide in the age of COVID-19. *Journal* *of the American Medical Informatics Association*, *27*(7), 1147–1148. https://doi.org/10.1093/jamia/ocaa078

Recker, J. (2013). Scientific Research in Information Systems. In *Scientific Research in Information Systems*. https://doi.org/10.1007/978-3-642-30048-6

Recker, J. (2021). *Scientific research in information systems: a beginner's guide*. Springer Nature.

Reeder, B., Zaslavksy, O., Wilamowska, K. M., Demiris, G., & Thompson, H. J. (2011). Modeling the oldest old: personas to design technology-based solutions for older adults. *AMIA ... Annual Symposium Proceedings / AMIA Symposium. AMIA Symposium*, *2011*, 1166–1175.

Renaud, K., & Van Biljon, J. (2008). Predicting technology acceptance and adoption by the elderly: A qualitative study. *ACM International Conference Proceeding Series*, *338*(October), 210–219. https://doi.org/10.1145/1456659.1456684

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83–98.

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-Design*, *4*(1), 5–18.

Satre, D. D., Knight, B. G., & David, S. (2006). Cognitive-behavioral interventions with older adults: Integrating clinical and gerontological research. *Professional Psychology: Research and Practice*, *37*(5), 489.

Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research Methods for Business Students* . Pearson Deutschland. https://elibrary.pearson.de/book/99.150005/9781292208794

Schade, W., Krail, M., & Kühn, A. (2014). New mobility concepts: myth or emerging reality. *Transport Research Arena-TRA 2014, 5th Conference-Transport Solutions: From Research to Deployment*.

Scheffer, A. C., Schuurmans, M. J., Van Dijk, N., Van Der Hooft, T., & De Rooij, S. E. (2008). Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. *Age and Ageing*, *37*(1), 19–24.

Schejter, A., Ben Harush, O. R., & Tirosh, N. (2015). Re-theorizing the "digital divide": Identifying dimensions of social exclusion in contemporary media technologies. *FACE Conference: European Media Policy 2015: New Contexts, New Approaches*.

Schwanen, T., Lucas, K., Akyelken, N., Cisternas Solsona, D., Carrasco, J. A., & Neutens, T. (2015). Rethinking the links between social exclusion and transport disadvantage through the lens of social capital. *Transportation Research Part A: Policy and Practice*, *74*, 123–135. https://doi.org/10.1016/j.tra.2015.02.012

Schwanen, T., & Páez, A. (2010). The mobility of older people: an introduction. *Journal of Transport Geography*, *18*(5).

Seifert, A. (2020). The digital exclusion of older adults during the COVID-19 pandemic. *Journal of Gerontological Social Work*, *63*(6–7), 674–676.

Seifert, A., Cotten, S. R., & Xie, B. (2021). A Double Burden of Exclusion? Digital and Social Exclusion of Older Adults in Times of COVID-19. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *76*(3), E99–E103. https://doi.org/10.1093/geronb/gbaa098

Seifert, A., Hofer, M., & Rössel, J. (2018). Older adults' perceived sense of social exclusion from the digital world. *Educational Gerontology*, *44*(12), 775–785. https://doi.org/10.1080/03601277.2019.1574415

Selwyn, N. (2004). Reconsidering political and popular understandings of the digital divide. *New Media & Society*, *6*(3), 341–362.

Shaukat, M. M., Gonzalez, R., & Saltou, K. (2014). Co-design: Product type and demographics.

IDSA Education Symposium.

Sheahan, J., Hjorth, L., Figueiredo, B., Martin, D. M., Reid, M., Aleti, T., & Buschgens, M. (2023). Co-Creating ICT Risk Strategies with Older Australians: A Workshop Model. *International Journal of Environmental Research and Public Health*, *20*(1). https://doi.org/10.3390/ijerph20010052

Shirgaokar, M. (2020). Expanding seniors' mobility through phone apps: Potential responses from the private and public sectors. *Journal of Planning Education and Research*, *40*(4), 405–415.

Sixsmith, A., Horst, B. R., Simeonov, D., & Mihailidis, A. (2022). Older people's use of digital technology during the COVID-19 pandemic. *Bulletin of Science, Technology & Society*, *42*(1–2), 19–24.

Sochor, J., & Nikitas, A. (2016). Vulnerable users' perceptions of transport technologies. *Proceedings of the Institution of Civil Engineers-Urban Design and Planning*, *169*(3), 154–162.

Solomon, J. (2009). Social exclusion and the provision of public transport. *London, UK: Department for Transport.*

Sourbati, M., & Behrendt, F. (2021). Smart mobility, age and data justice. *New Media & Society*, *23*(6), 1398–1414.

Statistisches Bundesamt (Destatis). (n.d.). *Number of people aged 67 or over will grow 22% by 2035*. Retrieved October 9, 2024, from https://www.destatis.de/EN/Press/2021/09/PE21_459_12411.html

Stein, M., Meurer, J., Boden, A., & Wulf, V. (2017). Mobility in later life: Appropriation of an integrated transportation platform. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 5716–5729.

Stewart, D. W., & Shamdasani, P. N. (2014). *Focus groups: Theory and practice* (Vol. 20). Sage publications.

Stratton, S. J. (2021). Population Research: Convenience Sampling Strategies. *Prehospital and Disaster Medicine*, *36*(4), 373–374. https://doi.org/10.1017/S1049023X21000649

Stuart-Hamilton, I. (2011). *An introduction to gerontology*. Cambridge University Press.

Suri, H. (2011). Purposeful sampling in qualitative research synthesis. *Qualitative Research Journal*, *11*(2), 63–75.

Suzuki, M., Ohyama, N., Yamada, K., & Kanamori, M. (2002). The relationship between fear of falling, activities of daily living and quality of life among elderly individuals. *Nursing & Health Sciences*, *4*(4), 155–161.

Thoring, K., Mueller, R., & Badke-Schaub, P. (2020). *Workshops as a research method: Guidelines for designing and evaluating artifacts through workshops*.

Tran, T., & Park, J. Y. (2015). Development of a strategic prototyping framework for product service systems using co-creation approach. *Procedia CIRP*, *30*, 1–6. https://doi.org/10.1016/j.procir.2015.02.102

Tsai, H. S., Shillair, R., & Cotten, S. R. (2017). Social support and "playing around" an examination of how older adults acquire digital literacy with tablet computers. *Journal of Applied Gerontology*, *36*(1), 29–55.

Tu, N., He, Q., Zhang, T., Zhang, H., Li, Y., Xu, H., & Xiang, Y. (2010). Combine quanlitative and quantitative methods to create persona. *Proceedings - 3rd International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2010*, *3*, 597–603. https://doi.org/10.1109/ICIII.2010.463

Tun, P. A., & Lachman, M. E. (2010). The association between computer use and cognition across adulthood: use it so you won't lose it? *Psychology and Aging*, *25*(3), 560.

TurboScribe. (2024). *TurboScribe*. https://turboscribe.ai/de/

United Nations. (2019). World Population Ageing 2019. In *Department of Economics and Social Affairs*. https://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2019-Report.pdf

Universitätsstadt Garching. (n.d.). *Die Stadt Garching*. Retrieved November 4, 2024, from https://www.garching.de/stadtporträt-leben/stadtporträt/die-stadt-garching#:~:text=Die Stadt Garching mit ihren,direkt an den Münchner Norden.

Vallet, F., Puchinger, J., Millonig, A., Lamé, G., & Nicolaï, I. (2020). Tangible futures: Combining scenario thinking and personas-A pilot study on urban mobility. *Futures*, *117*, 102513.

van Boekel, L. C., Peek, S. T. M., & Luijkx, K. G. (2017). Diversity in older adults' use of the internet: Identifying subgroups through latent class analysis. *Journal of Medical Internet Research*, *19*(5), 1–11. https://doi.org/10.2196/JMIR.6853

Van Dijk, J. (2020). *The digital divide*. John Wiley & Sons.

Vanolo, A. (2014). Smartmentality: The smart city as disciplinary strategy. *Urban Studies*, *51*(5), 883–898.

Vargo, S. L., Maglio, P. P., & Akaka, M. A. (2008). On value and value co-creation: A service systems and service logic perspective. *European Management Journal*, *26*(3), 145–152. https://doi.org/10.1016/j.emj.2008.04.003

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences*, *39*(2), 273–315.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, *46*(2), 186–204.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 425–478.

Venkatesh, V., Thong, J. Y. L., & Xu, X. (2016). Unified theory of acceptance and use of technology: A synthesis and the road ahead. *Journal of the Association for Information Systems*, *17*(5), 328–376.

Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. *Journal of Business Research*, *122*(November 2019), 889–901. https://doi.org/10.1016/j.jbusres.2019.09.022

Verma, N., Shiroma, K., Rich, K., Fleischmann, K. R., Xie, B., & Lee, M. K. (2021). Conducting Quantitative Research with Hard-To-Reach-Online Populations: Using Prime Panels to Rapidly Survey Older Adults During a Pandemic. In *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 12646 LNCS*. Springer International Publishing. https://doi.org/10.1007/978-3-030-71305-8_32

VuMA. (n.d.). *Share of smartphone users in Germany in 2021, by age group [Graph]*. Statista. Retrieved October 9, 2024, from https://www.statista.com/statistics/469969/share-of-smartphone-users-in-germany-by-age-group/

Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association*, *58*(301), 236–244.

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, *26*(2), xiii–xxiii. https://doi.org/10.1.1.104.6570

Weil, D. N. (1997). The economics of population aging. *Handbook of Population and Family Economics*, *1*(PART B), 967–1014. https://doi.org/10.1016/S1574-003X(97)80009-8

Westerlund, B. (2007). A workshop method that involves users talking, doing and making.

Proceedings of International Conference on Human-Machine Interaction, Human07, IEEE.
Windasari, N. A., & Visita, L. (2019). User engagement mechanisms of online co-design service: does user innovativeness matter? *Asian Academy of Management Journal*, *24*(1).
Wöckl, B., Yildizoglu, U., Buber, I., Aparicio Diaz, B., Kruijff, E., & Tscheligi, M. (2012). Basic senior personas: a representative design tool covering the spectrum of European older adults. *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility*, 25–32.
World Health Organization. (2018). The Global Network for Age-friendly Cities and Communities. *Who*, 48. https://apps.who.int/iris/bitstream/handle/10665/278979/WHO-FWC-ALC-18.4-eng.pdf?sequence=1
World Health Organization. (2024). *Ageing and health*. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health
Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, *39*(1), 93–112. https://doi.org/10.1177/0739456X17723971
Xie, B., & Bugg, J. M. (2009). Public library computer training for older adults to access high-quality Internet health information. *Library and Information Science Research*, *31*(3), 155–162. https://doi.org/10.1016/j.lisr.2009.03.004
Yigitcanlar, T. (2016). *Technology and the city: Systems, applications and implications*. Routledge.
Yigitcanlar, T., & Kamruzzaman, M. (2018). Does smart city policy lead to sustainability of cities? *Land Use Policy*, *73*, 49–58.
Yigitcanlar, T., & Kamruzzaman, M. (2020). Smart cities and mobility: Does the smartness of Australian cities lead to sustainable commuting patterns? In *Smart Cities and Innovative Urban Technologies* (pp. 21–46). Routledge.
Yoo, H. J. (2021). Empowering Older Adults: Improving Senior Digital Literacy. *American Association for Adult and Continuing Education*.
Yu-Huei, C., Ja-Shen, C., & Ming-Chao, W. (2019). Why do older adults use wearable devices: a case study adopting the Senior Technology Acceptance Model (STAM). *2019 Portland International Conference on Management of Engineering and Technology (PICMET)*, 1–8.
Zmud, J., Green, L., Kuhnimhof, T., Vine, S. Le, Polak, J., & Phleps, P. (2017). *Still going and going: the emerging travel patterns of older adults*. https://www.ifmo.de/files/publications_content/2017/2017_ifmo_senior_generation_mobility_en.pdf

Declaration of Authorship

I herewith formally declare that I have authored the submitted thesis independently. I did not use any outside support except for the declared literature and other sources mentioned in the paper.

I clearly marked and separately listed all of the literature and all of the other sources which I employed when producing this academic work, either literally or in content.

I am aware that the violation of this regulation will lead to failure of the thesis.

Munich, 05.11.2024 Müller

Place, Date, Signature