Digital Placemaking and Healthy Ageing

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A USER-CENTRIC APPROACH FOR EMPOWERING SENIOR CITIZENS IN INCLUSIVE DECISION-MAKING OF FUTURE HEALTHY AGEING NEIGHBOURHOODS

Peyman Najafi

Bouwstenen 396

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A user-centric approach for empowering senior citizens in inclusive decision-making of future healthy ageing neighbourhoods

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Digital Placemaking and Healthy Ageing

A User-Centric Approach for Empowering Senior Citizens in Inclusive Decision-Making of Future Healthy Ageing Neighbourhoods

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Summary

Digital placemaking and healthy ageing explore the barriers identified by stakeholder communities to shape environments where individuals are healthier and happier. This inquiry is timely, given the dramatic global increase in the senior citizen population, presenting unique challenges for maintaining inclusive community planning, design, and decision-making. This thesis specifically targets the underexplored dimension of digital placemaking for its integration into the inclusive planning and decision-making processes of future neighbourhoods geared towards healthy ageing, in collaboration with senior citizens. The research challenges existing paradigms in digital placemaking by proposing a user-centric digital placemaking methodology that can be incorporated into the strategic decision-making processes of future neighbourhoods and urban public realms, designed for healthy ageing.

Chapter 2 of this thesis offers a systemic literature review by focusing on the trilogy of placemaking, digital technology, and the involvement of senior citizens during the decision-making process. This chapter includes how digital instruments impact the placemaking process and its role in enhancing the participation of senior citizens in decisions related to urban neighbourhoods and public spaces.

Chapter 3 moves to practical applications, detailing a user-centric digital placemaking prototype tailored for inclusive participation of senior citizens during the neighbourhood decision-making process. This chapter outlines the proposed system architecture of a virtual city information model for digital (twin) placemaking. It also presents the findings from user experience conducted to assess the usability and effectiveness of the prototype in actively involving senior users throughout the decision-making process, setting the stage for empirical investigations.

Chapter 4 focuses on how a healthy ageing neighbourhood can be (re)defined for contemporary ageing communities. It conducts a systematic literature review and convolutional neural network analysis of one of the successful and existing healthy ageing communities, dubbed "the World's Longest-Lived Populations" (Blue Zones), to identify environmental policy guidelines that can be tested for feasibility and incorporated into the decision-making process of future healthy ageing neighbourhoods and urban public realms.

The final chapter, Chapter 5, presents an empirical study by experimenting with a healthy ageing neighbourhood together with senior citizens through user-centric digital placemaking. It also highlights the affordances and considerations of user-centric digital placemaking for future inclusive decision-making in urban design and planning settings.

This thesis underscores the importance of user-centric approaches in digital placemaking, especially in the context of shaping future healthy ageing neighbourhoods. This research aids in guiding community stakeholders by featuring holistic approaches that enhance the involvement of senior citizens in digital placemaking. Furthermore, it introduces a user-centric digital (twin) placemaking that facilitates inclusive decision-making for senior citizens. Meanwhile, it informs community policy-makers by providing practical insights and policy guidelines learned from Blue Zones for digital placemaking, ensuring that the needs and preferences of this ageing population are central to the development of future healthy ageing neighbourhoods and urban public realms.

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List of Abbreviations

3D	3 Dimensional
AFC	Age-Friendly Cities
API	Application programming interface
AR	Augmented Reality
BZN	Blue Zone Neighbourhood
CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment
CIM	City Information Model
CNN	Convolutional Neural Network
CR	Centenarian Rate
DoF	Degree of Freedom
DT	Digital Twin
Eli	Extreme Longevity Rate
FBX	Filmbox
GIS	Geographic Information System
GN	Global North
GS	Global South
GSV	Google Street View
HCI	Human Computer Interaction
HMD	Head Mounted Display
IoU	Intersection over Union
LBGs	Location Based Games
LBSNs	Location Based Social Networks

LiDAR	Light Detection and Ranging
LoD300	Level of Detail 300
LQC	Lighter, Quicker, and Cheaper
PPS	Project for Public Spaces
SKP	SketchUp
SPE	Senior People Exclusively
SPI	Senior People Inclusively
STL	Stereolithography
UDT	Urban Digital Twin
UE	Unreal Engine
UI	User Interface
UV	Ultraviolet
UX	User Experience
VR	Virtual Reality
WHO	World Health Organisation
YOLO	You Only Look Once
glTF	GL Transmission format
mAP	Mean Average Precision
vCIM	Virtual City Information Model

Chapter 1 Introduction

1.1 Population ageing and digital placemaking

The global phenomenon of an ageing population presents unique challenges and opportunities to smart neighbourhood development. This demographic shift, marked by increasing life expectancy and declining birth rates, is transforming urban landscapes worldwide [1]. Particularly in developed countries like the Netherlands, the implications of this change are profound. Recent demographic data indicates a historic shift: As of January 1, 2023, individuals aged 65 and older constituted 20.2% of the Netherlands' population, with projections suggesting an increase to 26% by 2035 [2], [3]. The vast majority of this population prefers to age healthily in their place, within their familiar homes and neighbourhoods, rather than transitioning to care facilities [4]. Their preference aligns with government recognition of the societal and economic value of older individuals remaining active and engaged in their neighbourhood [5], [6].

At the same time, the rise in the proportion of older people in the total population has been accompanied by an increase in digital ageism [7], a new form of digital discrimination [8]. This type of discrimination involves assumptions and stereotypes about the abilities of older people to use and learn digital technologies. Such biases can lead to the exclusion of older individuals from smart neighbourhood developments. In the recent neighbourhood developments, urban scholars have incorporated a variety of interactive technologies—such as 3D city information models, digital twins, and virtual/augmented reality (VR/AR)—to enhance the accuracy, efficiency, and reliability of the decision-makings. To ensure a more equitable and participatory approach to smart neighbourhood development, bridging digital ageism is paramount.

In participatory planning, placemaking – a participatory design approach to collective (re)imagination and (re)shaping the local environments – has long history in neighbourhood

development. Despite the relatively recent introduction of the term "placemaking," the fundamental idea it represents is not novel. Originating in the 1960s and early 1970s, placemaking emerged as a participatory approach advocated by notable urbanists like Jane Jacobs and William H. Whyte, serving as a collective mechanism through which community members can actively shape their neighbourhoods to enhance communal values (more details is provided in Chapter 2). Nowadays, given the increasing interplay of technology and placemaking (often referred to as digital placemaking [9], [10]) for smart neighbourhood developments, developing novel tools that facilitate the participation of vulnerable citizens, particularly older people, is imperative.

There is a growing interest in deploying user-centred design methods in digital placemaking to address the various challenges of older people's participation. Among these methods, the empathic design living lab stands out as a systemic and integrative approach put emphasis on understanding user needs and feelings through exploration, translation, processing, and validation [11]. Integrating such user-centred methods into digital placemaking has not yet contextualised nor embraced a specialised approach to older people's participation.

In the Netherlands, national authorities like the Ministry of Housing and Spatial Planning, local authorities and policymakers such as the Dutch Council for the Environment and Infrastructure, and healthcare organisations have taken proactive steps to address the evolving challenges and opportunities presented by an ageing population and the rise of neighbourhood development in the digital era [12]. The research presented in this dissertation was conducted within this progressive context as part of the "Shaping Smart and Inclusive Environments to Empower Healthy Ageing" (GELIJK) project at Eindhoven University of Technology.

My involvement in the GELIJK project encompassed a range of activities, including utilising an empathic design research method to develop a user-centred (virtual twin) placemaking tool (more details in Chapter 3 and 5) [13]. This tool was designed to facilitate the informed decision-making processes together with older people. Additionally, I contributed to the formulation of a context-based urban design policy advice aimed at promoting healthy ageing within Dutch neighbourhoods [14], [15]. While this dissertation builds upon the valuable insights gained through my work on the GELIJK project, it also contributes more broadly to the academic discourse on participatory planning. This work seeks to bridge the gap between theory and practice, ultimately advancing the field of participatory planning in the digital age.

1.2 Research gap and problem statement:

The advent of interactive technologies in placemaking has been heralded as a transformative force with potential to shape the future of healthy ageing neighbourhoods [16], [17]. To realise this potential, placemaking must be seamlessly integrated with (interactive) technologies and innovations. This integration is crucial to enable the necessary transitions and provide a more reliable and transparent framework for experimentation, optimisation, risk management, learning, and, most importantly, community engagement. In particular, community engagement is the cornerstone of successful digital placemaking [10]. It is essential for informing and continuously improving neighbourhood planning.

While the interplay of technology and placemaking holds potential, the feasibility of such an integrative digital placemaking in participation with older people remains a crucial issue. A significant concern is that this approach may inadvertently exacerbate the digital divide, thereby excluding vulnerable citizens, notably older people,

from democratic decision-making processes [18], [19], [20]. Research indicates that, although older people are becoming more digitally connected, they still lag behind younger generations, particularly in terms of digital skills and confidence[10], [21], [22]. This digital divide is not solely age-based but is influenced by various factors such as socioeconomic status, education level, and geographic location[20]. Nonetheless, studies have shown that older people, on average, tend to have lower levels of digital literacy compared to younger generations [23]. This disparity can be particularly pronounced when it comes to utilising complex or interactive technologies in placemaking initiatives (López Silva & Rodríguez Bolívar, 2021).

With a significant portion of future neighbourhood, residents expected to be older adults, that it is imperative that digital placemaking incorporates new tool or methods that facilitate older people. Many academic publications in recent years have investigated digital placemaking with older people in various contexts[10], [16], [24], [25]. While the knowledge in this field is constantly expanding, there is a noticeable gap in the literature regarding digital placemaking as a collective approach with older adults. To address this gap, a comprehensive analysis of the available literature is required, encompassing both theoretical and practical perspectives. The analysis should provide a comprehensive understanding of how (by which means/methods/tools) digital placemaking can empower older people as active agents of participation.

In practice, successful digital placemaking with older adults requires a shift towards user-centred approaches that prioritise engagement and democratisation. However, many barriers impede this transition and limit the development and implementation of tools for digital placemaking tailored to the needs and capabilities of older adults. Existing literature has identified a range of challenges, including feelings of inadequacy or intimidation, lack of confidence among older adults in their knowledge and skills, declining health conditions, and concerns about security and privacy [21], [26]. Thus,

what is needed is a more agile and user-centred tool/method to digital placemaking, ensuring that older adults feel empowered to actively participate in decision-makings.

Despite the need for tools to facilitate participation of older adults, one of the paramount ambitions highlighted within the current discourse on ageing is the promotion of healthy ageing neighbourhoods. WHO defines healthy ageing as a functional ability that enables individuals to meet their needs and contribute to society within their environment[3]. Specifically, to achieve healthy ageing, one of the strategic objectives of the global Strategy and Action of the WHO is promoting age-friendly environment to raise awareness about the value of adapting urban environments to the needs and preferences of ageing populations [27]. Promoting such environments through digital placemaking necessitates a continuous cycle of knowledge acquisition and exchange between research and practice. Learning from real-world exemplars of successful healthy communities offers a valuable avenue for knowledge acquisition. Existing literature has highlighted the existence of such neighbourhoods, notably the Blue Zones, renowned in the field of gerontology for their lower rates of chronic disease and longer life expectancies [28], [29]. Digital placemaking could benefit from the age-friendly lessons embedded within these successful examples to realise and generate context-based policy action to promote healthy ageing within neighbourhoods.

In sum, The *problem statement* that informs this dissertation is as follows: Despite significant advancements in (interactive) technologies and their growing application in participatory planning, there remains a notable research gap— there is a significant lack of information and experience when it comes to participation of older people in digital placemaking. This thesis recognises and addresses this gap by challenging the conventional paradigms of placemaking and utilises a user-centred design methodology (empathic design living labs) that actively involves older people throughout the design

and research process. The principal objective is to develop a new inclusive decision-making tool that prioritise the preferences and needs of the ageing population and facilitate their participation within digital placemaking. This endeavour is founded on the conviction that the incorporation of older people's insights and experiences is essential for creating truly inclusive, equitable, democratic neighbourhood development.

In summary, the synthesis of identified gaps leads to the formulation of this *problem statement*: the integration of cutting-edge technology, placemaking, and active participation of older people for shaping healthy ageing neighbourhoods has remained limited in practice. One potential solution is to develop a user-centred digital placemaking tool that facilitate the active engagement of older adult residents in the design and planning of (future) healthy ageing neighbourhoods. However, the question of how such tool should be designed and applied remains largely unexplored.

1.3 Overview of research questions and thesis structure

This study's overarching research question *is:* ***To what extent and how can digital technology and placemaking be combined to shape a healthy ageing neighbourhood with senior citizens?***

The thesis methodological outline for looking at this research question adopts the theoretical framework of empathic design living lab, as developed by Mohammadi (2017) [11], and is structured into four main phases (exploration, translation, realisation, and validation), each corresponding to a sub-research question and presented in individual chapters (see *Figure 1*):

- **Exploration: What is the state of the art on placemaking and digital technology with respect to exploring the active involvement of senior citizens?**

The current literature lacks a holistic view of how digital technology and placemaking can be synergised for the benefit of senior citizens. In Chapter 2, I delve into the first research question by conducting a systematic literature review. The focus is on exploring the active involvement of senior citizens in digital placemaking initiatives. I particularly evaluate the role digital technology has played in placemaking processes, specifically how it has been used to empower senior citizen participation.

- **Translation: How do we create a user-centric digital placemaking system that supports the involvement of older adults during neighbourhood (re)design initiatives?**

There is a significant gap in the practical application of digital placemaking systems that effectively engage senior citizens. In Chapter 3, I address this gap by developing and assessing a user-centred digital placemaking system. This system, inspired by the concept of digital twins, provides a near-exact virtual model of neighbourhoods, integrated with a user-friendly interface to facilitate the active involvement of older adults in neighbourhood design and decision-making. In this chapter, I also evaluate the system architecture of digital placemaking for usability and effectiveness in enhancing participatory decision-making, particularly from the perspective of older adults. I provide insights into how user-friendly digital placemaking can facilitate a collaborative, data-driven decision-making process, empowering older adults as key participants in the design of their living environments.

- **Realisation of a healthy ageing neighbourhood: What specific neighbourhood policies and design principles, derived from successful existing models of healthy ageing communities, can be effectively translated into placemaking strategies for contemporary ageing neighbourhoods?**

Building upon the insights and tools developed in the previous chapters, research specific to realising a healthy ageing neighbourhood remains scarce. Addressing the third research question, the study presented in Chapter 4 involves an empirical study on the age-friendly built environment characteristics of Blue Zones that contribute to healthy ageing in these communities. The aim is to formulate neighbourhood policy and design guidelines that can serve as a foundation for developing actionable strategies to promote healthy ageing neighbourhoods. To achieve this, I employ a mixed-method methodology. I conduct a scoping review to identify the main longevity factors associated with the socio-spatial features of Blue Zones. Additionally, I utilise Convolutional Neural Networks techniques on imagery datasets of these regions to supplement my qualitative analysis by providing empirical evidence.

- **Validation: How do we co-create a healthy ageing neighbourhood in digital placemaking with older adults in the Dutch context?**

Chapter 5 addresses the final research question, presenting and testing the leverage of user-centric digital placemaking in the co-creation of healthy ageing neighbourhoods with older adults in the Dutch context. It culminates in the development of place-based neighbourhood design guidelines and policy action plans that prioritise healthy ageing. These guidelines

and plans serve as valuable resources for local authorities and policymakers, supporting them in the experimentation, optimisation, learning, and, crucially, community engagement processes that underpin successful age-friendly urban development initiatives.

Chapter 6 provides a summary of each study's findings and contributions. Collectively, these four studies address the overarching research question from complementary angles. Overall, this chapter highlights a user-centric approach as a necessary component for the implementation of digital and data-driven placemaking. It provides insights from diverse disciplines, theoretical frameworks, and methodological approaches to aid in participatory urban planning and design. The chapter concludes by discussing the implications of the research findings for policy and practice, highlighting potential avenues for future research and innovation in the field of age-friendly urban development.

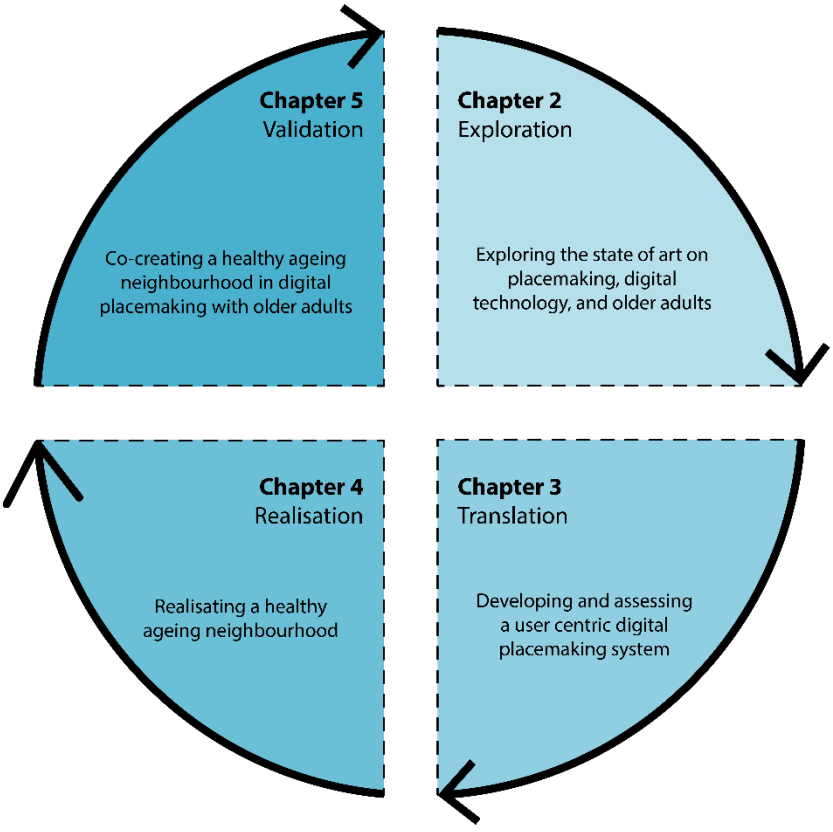

Figure 1. Thesis dissertation's conceptual framewor

Chapter 2 Insights into placemaking, senior people, and digital technology: a systematic quantitative review

Insights into placemaking, senior people, and digital technology:
a systematic quantitative review

This chapter has been published as follows:

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For consistency of the dissertation, some typos are adjusted, and phrases are reworded without changing the content

ABSTRACT

How placemaking involves senior people and implements cutting-edge technology is a question that this review aims to shed light on. This paper provides a systematic quantitative review of 26 original, peer-reviewed research articles on placemaking, digital technology, and senior people. It discusses the scope of the research, the critical concepts cited, the type of senior involvement (inclusive/exclusive), and the type of digital instrument implementation (advanced/simple). In addition, it includes a scatter analysis between (advanced/simple) digital instrument implementation and (inclusive/exclusive) senior people's involvement in placemaking initiatives. This review indicates that

although interest in digital placemaking has increased in the last decade, senior people are underrepresented. This review can open windows for developing a more coordinated research agenda that considers seniors as active players in (advanced) digital placemaking.

2.1 Introduction

Placemaking is a concept coined by Jane Jacobs and William H. Whyte in the 1960s that promises to make cities a better place to live. It refers to creating a place that promotes health, happiness, and well-being by drawing on the community's assets, values, and resources [30]. In the past six decades, the evolution of placemaking has been influenced by a variety of factors. Among these factors are the rapid ageing of society and the advent of digital instruments. As the population of the world ages rapidly – for example, the Netherlands' senior population doubled from 17.9% in 1960 to 34.9% by 2022 [31] – there is a greater need for seniors to play active roles in placemaking. Meanwhile, as the 21st century unfolds, there is a growing interest in incorporating advanced and innovative technologies – such as Artificial Intelligence (AI), big data, the Internet of Things (IoT), the Internet of Behaviours (IoBs), Mixed Realities (MR), and Digital Twins (DTs) – into placemaking. Therefore, placemaking should incorporate seniors and advanced digital technologies effectively. Nevertheless, how placemaking is doing so is a critical question that needs to be addressed.

As noted by Webb (2014), today's placemaking represents a comeback for community and people empowerment [32]. "Empowerment" expands the scope of placemaking for people's active involvement [6]. However, in today's placemaking, empowerment requires specific considerations. Among the key considerations are "age" and "technology." As a homogeneous

community group, senior people might be different from their younger counterparts in dynamics and technology-related skills [33], [34], [35]. According to Duplaga and Szulc (2019), although the generation gap is narrowing, technology use is still the lowest among the oldest age groups (over 65s), and they are far more likely to be "offline" in comparison to the younger generations [36]. There is a body of research addressing the topic of age and technology as the "grey digital divide" (e.g. [37]). The digital divide refers to the gap between those who have access to technology, the internet, and digital literacy and those who do not. The attached term – grey – indicates that one group experiencing marginalisation in the first-level digital divide is seniors [37]. The research on the grey digital divide emphasises bridging the digital divide for senior people [21], [37]. Bridging the digital divide argues that although the gap between technology and seniors exists, it is steadily narrowing, and aged people embrace technology more than ever. Furthermore, it shows that as more seniors use technology, senior-friendly technology - for example, social apps like Facebook and Pillboxie [38] - is being created to support their daily lives, communications, and community activities [39], [40]. In this sense, the advancement of digital technology is not only a catalyst for seniors' active participation but also a means of support and empowerment.

In addition to taking demographic changes into account and bridging the digital divide, innovative technologies are essential for placemaking. Technology enhances placemaking in a variety of ways. It creates a deeper understanding of the relationships between people and the places they inhabit. For example, location-specific social media such as Twitter, Facebook, and Instagram offer people more extensive communication, sharing thoughts and experiences about their place [25], [41], [42]. Furthermore, they can lead to greater public participation. Online mapping platforms like Participatory GIS (PGIS) can involve people – in coming up with scenarios to solve issues that emerge

from the analysis – at broad scales [43]. Digital technologies can also support placemaking by facilitating people's activities when the interventions are implemented. Location-Based Game (LBG) apps like Pokémon G.O. are such an example making it possible to book certain places for shared activities [44], [45]. Thus, digital technologies have contributed to placemaking towards creating a more collective approach, establishing digital urban commons, and building community; however, only when sufficient attention is paid to the digital literacy of participants – what is called "empowerment." To this end, it is still an open question in the areas relating to neighbourhood planning, design, and healthy ageing as to how – by which digital instrument – and to what extent technology has empowered seniors to take part in placemaking.

Therefore, this review aims to provide an overview of what is known in the placemaking literature about digital technology implementation and empowerment of senior people using a systematic quantitative review. A better understanding of this issue is essential because as technology advances and the senior population grows, seniors' desire for digital placemaking and active participation will increase. By conducting a systematic review on this topic, we could determine which digital instruments have successfully enabled the active participation of seniors in placemaking. This article first presents an overview of the placemaking approach, its process, and its types (Section 2.2). Then, it reviews the most recent literature on placemaking, digital technology, and senior people (Sections 2.3 and 2.4). Previous experiences of co-authors, consultations and references from experts in neighbourhood planning and design, healthy ageing, gerontology, and innovation science are used to complete the literature review. The inquiry into the literature has focused mainly on the following questions: (1) who has conducted the research? (2) when was it published? (3) what type of placemaking is approached? (4) In what way were the seniors involved (exclusive

or inclusive)? (5) what digital instrument(s) are used? (6) what key theories, concepts, or perspectives underpinned the research? and (7) what correlation(s) exist between digital instrument implementation and seniors' involvement in placemaking? This paper concludes by demonstrating the inquiry results, providing a scattergram, and revealing the correlations between digital instrument implementation and senior people's involvement in placemaking.

2.2 Placemaking defined

> *"When a space becomes more than the sum of its parts, it becomes a place [46]."*

Placemaking is the process of transforming public spaces into vital places that inspire revitalisation, showcase local assets, and meet citizens' needs [30]. In addition, it is not just about creating a new space but also about how to create new uses and meanings for space and establish relationships between people and spaces [47]. The founder of the placemaking concept, Project for Public Spaces (PPS), defines a five-step process (Figure 2) to involve people in observing, planning, and shaping a place [1]:

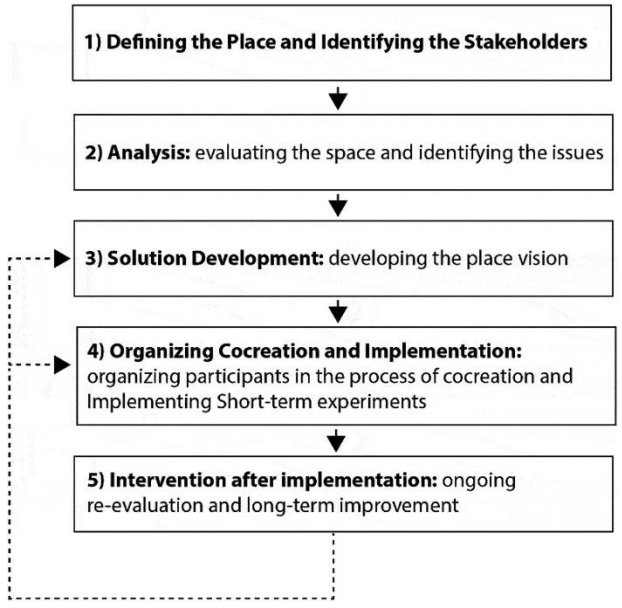

Figure 2. The placemaking five-step functionalities, source: [48]

According to Figure 2, the first step starts with selecting the right site and involving the stakeholders. The stakeholder involvement may vary depending on the central issue the placemaking effort is focused on. Stakeholders can be chosen from the public, private, and civic sectors. The second step involves understanding how space operates. Therefore, planning time to spend on-site, evaluating the space, and recognising the assets or challenges are crucial parts of this step. In the third step, the key stakeholders develop a place vision. This document can contain several components: a statement of goals, a definition, a description, a concept plan, successful examples, and an action plan. The fourth step is recognised as the critical step in the placemaking process. Through this step, stakeholders are organised in co-creation to implement short-term experiments and put the vision into action. This step informs the creation of a vision for the place. The final step is the intervention and ongoing evaluation of implementation, leading to long-term improvements for the space.

2.2.1 Types of placemaking

Understanding the different types of placemaking can help us sort the placemaking literature into the options. Further, it will help us better understand which placemaking has the most significant potential to assist with digital technology implementation and senior people empowerment. According to MSU Land Policy Institute, there are four types of placemaking [49]. Figure 3 shows the relationship of three specialised types of placemaking included in the broader "standard" form.

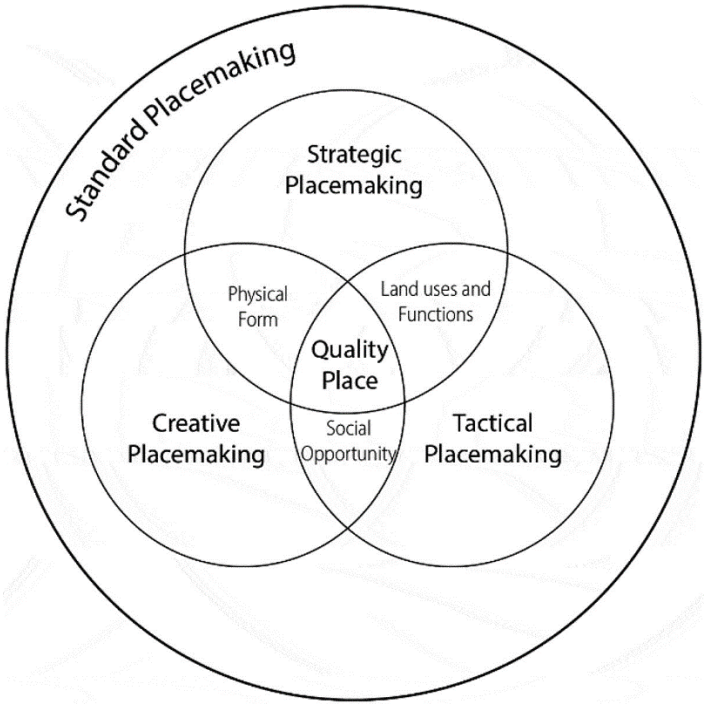

Figure 3. The four types of placemaking; the relationships associated with the specialised types of placemaking from the border standard form, source: [49].

The other three specialised types of placemaking are:

- **Strategic Placemaking** involves projects or activities in specific locations like corridors, nodes, or defined centres

that result in economic prosperity, social and cultural well-being, and the creation of quality places [49]. Examples of strategic placemaking can be mixed-use developments at defined centres, along key corridors, or activities such as cyclical events targeted to arts, culture, and recreational activities that add vitality to quality places.

- **Creative Placemaking** aims at forming the physical and social character of space around arts and cultural activities to rejuvenate structures, improve the local economy, and gather diverse people together to celebrate, inspire, and be inspired [50]. Examples of creative placemaking are public art displays, transit stations with art themes, chalk art projects, outdoor playing activities, and movies in the park.
- **Tactical Placemaking** can be described based on two separate approaches. First, as Mike Lydon et al. (2015) describe it in their book "Tactical Urbanism", it targets to test new concepts before making political and fiscal commitments [51]. Second, what PPS calls: a set of activities "Lighter, Quicker, and Cheaper (LQC)" (see www.pps.org). LQC describes quick and cheap events and intervention projects or activities that support development strategies for long-term change. Examples of tactical placemaking include complete street projects, road diets (reducing a four-lane road to a three-lane road with bicycle paths), or activities such as new design alternatives like park enlargements, self-guided historical walks, before/after photo rendering to remove or add buildings in certain places, etc.

2.2.2 Research objectives and methods

After defining the placemaking approach, process, and types, the systematic review was conducted using the Scopus database, Google Scholar, PubMed, ProQuest, Science Direct, Sage, and hand search (snowball method). We retrieved and analysed

academic citations published in English language scholarly journals on placemaking, digital technology, and senior people using the Publish or Perish software program. In the search engines, the terms used were “placemaking” and a combination of the following words: “senior people,” “older people,” “older adults,” “ageing,” “digital,” “smart,” “hybrid,” “online,” “ICT,” “technology.” Non-peer-reviewed publications (e.g. reports, books, book chapters, conference proceedings) were excluded and used as “grey literature” in addition to hand-selected relevant resources. The systematic quantitative assessment of literature review results was documented, framed, and coded in ATLAS.ti and quantitatively analysed in SPSS 26. The coded information included: the author’s year of publication, type of placemaking approach, the realm (Senior People Inclusively (SPI) or Senior People Exclusively (SPE)) that the stakeholder involved, the digital instruments (e.g. A.R., V.R., DT, LBSNs, and LBGs) implemented, and the critical theories, concepts, and approaches cited or applied.

The coding framework was built based on a discussion between the authors and the decision logic developed by Wyckoff (2014) to ensure choosing the best-suited framework for placemaking, digital technology, and senior people [49] (Figure 4). The type of placemaking implemented in each article was coded as standard, strategic, creative, or tactical as categorised by MSU. The stakeholders’ realm was defined and classified into Senior People Exclusively (SPE) and Senior People Inclusively (SPI). This classification helps better define the levels of senior people empowerment. SPI means that senior people are involved and studied with other stakeholders in placemaking. SPE means that senior people are involved and studied in placemaking exclusively without other stakeholders. We classified and coded the digital instruments used in placemaking according to the last four steps – analysis, solution development, co-creation and implementation, and intervention after implementation – of the placemaking process proposed by PPS. The placemaking theories, concepts, and

approaches were tracked, recorded, and analysed in a scattergram. The scatter analysis is used to evaluate the correlation(s) between the digital technology implementation and senior people's involvement in the theories, concepts, or perspectives applied in placemaking literature.

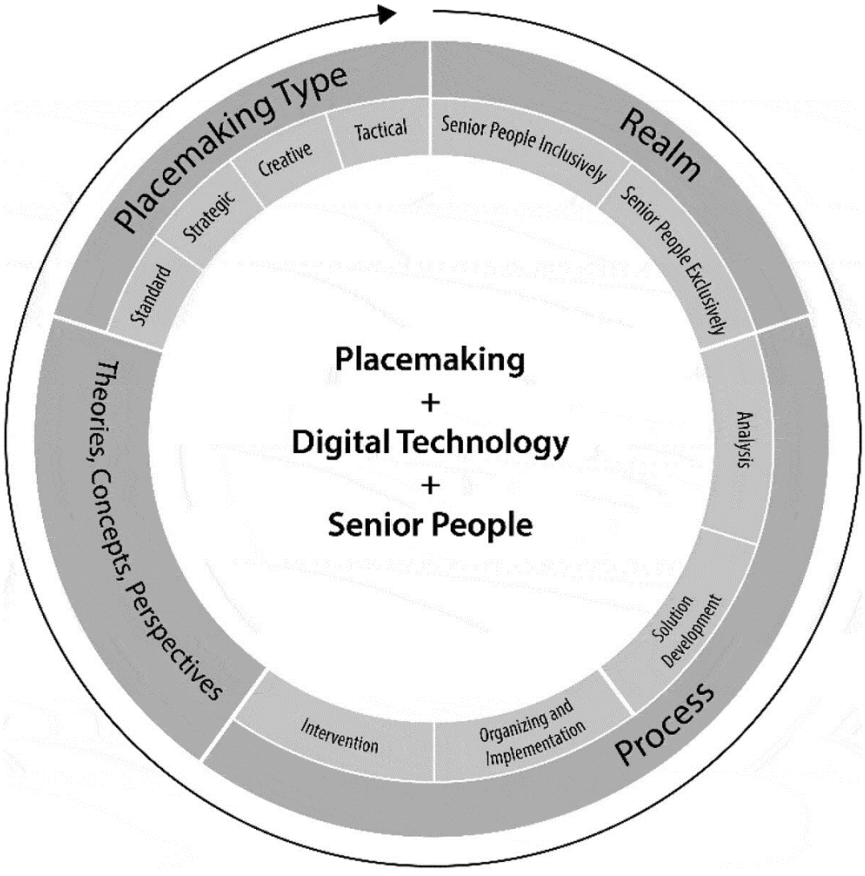

Figure 4. The coding framework on placemaking, digital technology, and senior people was built based on discussions between the authors and the decision logic developed by [49].

2.3 Results

The systematic literature review eventually yielded a total of 26 peer-reviewed research articles and 21 non-peer-reviewed publications on placemaking, digital technology, and senior people

published between 2011 and 2020 (Appendix A). Peer-reviewed research information is reported in terms of (1) the scope of research (year published and field of publication); (2) placemaking type; (3) stakeholder realm; digital instruments used; and (4) key theories, concepts, and perspectives underpinned in the literature of placemaking, digital technology, and senior people; and (5) the correlations between digital technology implementation and senior people involvement in placemaking.

2.3.1 Scope of research

To determine trends, publications reviewed within this article were divided into three periods of approximately equal duration (2011–2014, 2015–2017, and 2018–2020). The first published article was penned by Cornelio and Ardévol (2011), who performed placemaking through locative media artworks. Then, there was a decrease in the number of studies on placemaking, digital technology, and senior people from the first interval with six publications (23% of the total) to the second interval with three publications (11.5% of the total). Finally, there was a marked acceleration in the last interval, as 17 publications (65.3%) were published from 2018 to 2020 (Figure 5).

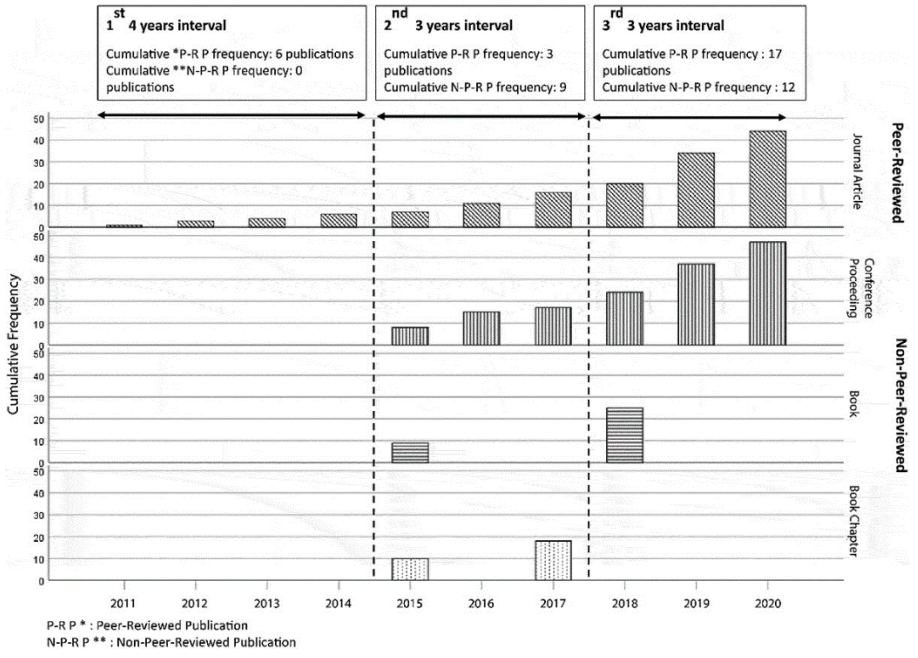

Figure 5. Cumulative frequency of peer-reviewed articles examining placemaking, digital technology, and senior people by years published.

Across the four types of placemaking, 25 different journals published articles on placemaking, technology, and senior people (see Table 1). In addition, these journals published 13 studies on standard placemaking (50%), seven studies on strategic placemaking (29.6%), four studies on creative placemaking (15.4%), and two studies on tactical placemaking (7.6%). Except for the Journal of Urbanism, which had published two articles on this topic, the contribution of every other journal was one article.

Table 1. Placemaking type and journal distribution of peer-reviewed articles on placemaking, digital technology, and senior people.

Placemaking Type	Journal Title	Journal Frequency	Approach Frequency (%)
Standard Placemaking	Journal of Urbanism	2	13 (50)[a]
	Journal of Urban Technology	1	
	Journal of Planning Education and Research	1	
	Sustainable Cities and Society	1	
	Feminist Review	1	
	Journal of Space and Culture	1	
	Journal of Environmental Practice	1	
	Communications in Computer and Information Science	1	
	Journal of Working with Older People	1	
	Digital Creativity	1	
	European Spatial Research and Policy	1	
	Journal of Communications	1	
Strategic Placemaking	Journal of Sustainability	1	7 (26.9)
	Journal of Media International Australia	1	
	Journal of City, Culture and Society	1	
	International Journal of Architectural Research	1	
	Journal of Asian Architecture and Building Engineering	1	
	Journal of Health and Place	1	
	Journal of Australian Library	1	
Creative Placemaking	Journal of Hospitality and Tourism Research	1	4 (15.4)
	Energies	1	
	World Leisure Journal	1	
	Journal of Behaviour and Information Technology	1	
Tactical Placemaking	Journal of Action Research	1	2 (7.6)
	Journal of Australian Planner	1	
Total			26 (100)

[a]Does not add to 100% due to rounding.

2.3.2 Research in the global north and global south: sociocultural context

Analysing studies on the socio-cultural contexts of digital placemaking with senior people reveals a division between the

Global North and the Global South (Figure 6). The Global North represents high-income countries, whereas the Global South represents developing nations [52]. These terms do not necessarily refer to a particular region of the world. For instance, many of the nations in the Global South are located in the Northern Hemisphere. Specifically, the Global North comprises the developed countries located in Western Europe and North America and Australia, Israel, Japan, South Korea, and New Zealand. In contrast, the Global South includes the developing countries located in Africa, Latin America, and the Caribbean (among others). Often, the two groups are categorised according to their levels of wealth, democratic systems, economic prosperity, income inequality, and political freedom [53].

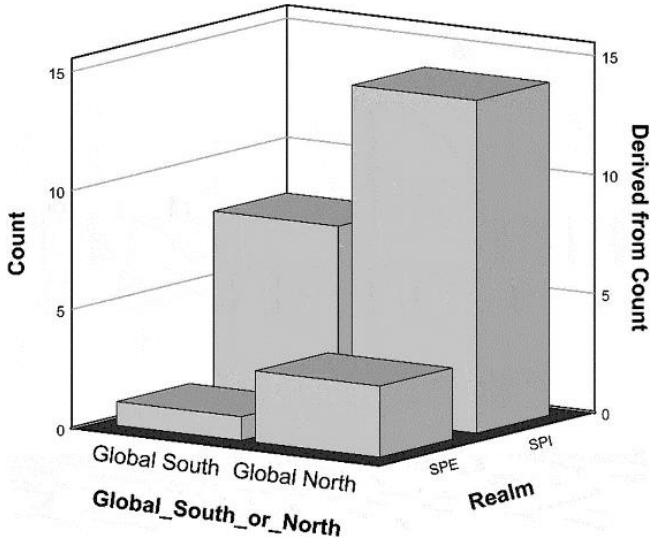

Figure 6. A classification of digital placemaking studies based on the global North and global South. SPE (Senior People Exclusively) and SPI (Senior People Inclusively) represent how seniors are involved in placemaking initiatives.

Our review shows that the Global North countries were more inclined to involve seniors in their digital placemaking initiatives, with 18 articles (69%), compared to eight publications (31%) in the Global South (Figure 6). Of these countries, Australia, the United States, and Canada contributed the most to this

research area. However, Canada and the United Kingdom were the only countries that studied seniors exclusively in their digital placemaking initiatives with one and two articles, respectively (Table 2). In terms of socioeconomics, most studies did not mention the economic class of the seniors; those that did mainly concerned low-income residents living in shared apartments. Overall, the Global North studies primarily emphasised the importance of building partnerships with seniors in digital placemaking studies. However, in light of the rapidly ageing population of their countries, the focus was more on deploying digital literacy as a way to enable seniors to age well in the right place with high-quality (in)formal care and treatment [54], [55], [56]. They used digital instruments to gather data about the sense of place experienced by seniors, which led to improvements in architectural scenarios and care service delivery.

Table 2. The socio-cultural and economic context of studies on digital placemaking and senior people, categorised by the Global South and Global North

Reference		Topic	Context	Nationalities	Economic class	Agency of older adult	Year
Global South	Garay and Morales (2020)	User Engagement in Festival Virtual Brand Communities: The Cases of SÃ³nar and Primavera Sound (Barcelona)	Spain	Spaniards	NMa	I[b]	2020
	Canepa ro and Bonave ro (2016)	Neighbourhood regeneration at the grassroots participation: Incubatorsâ€™ co-creative process and system.	Italy	Italian	Low-income inhabitants	I	2016
	Kotus and Rzeszewski (2020)	Online Mapping Platforms: Between Citizen-Oriented and Research-Focused Tools of Participation?	Poland	Polish	NM	I	2020

Reference		Topic	Context	Nationalities	Economic class	Agency of older adult	Year
	Wang (2019)	A Study of Digitally Enhanced Peopleâ€“Space Interaction: A Place-Centric Perspective.	Hong Kong	Chinese	NM	I	2019
	Stupar et al. (2019)	Participative placemaking in Serbia: The use of the limitless GIS application in increasing the sustainability of universal urban design.	Serbia	Serbs	NM	I	2019
	Nenko and Petrova (2018)	Emotional geography of St. Petersburg: Detecting emotional perception of the city space.	Russia	East Slavic	NM	I	2018
	Cornelio and ArdÃ© vol (2011)	Practices of place-making through locative media artworks.	Spain	Spaniards	NM	I	2011
	Qi and Gu (2020)	Older people and placemaking in post-disaster community rebuilding: An interdisciplinary action research in Sichuan, China.	China	Chinese	Low-income inhabitants	E[b]	2020
	N	8	8	8			8
Global North	Breek, Eshuis, and Hermes (2020)	Sharing feelings about neighbourhood transformation on Facebook: Online affective placemaking in Amsterdam-Noord	The Netherlands	Dutch, Germans	NM	I	2020

Reference	Topic	Context	Nationalities	Economic class	Agency of older adult	Year
Budge (2020)	Museum Visitors, Instagram, and the City. Journal of Urban Technology	Australia	NM	NM	I	2020
Chen, Song, and Li (2020)	Where do people tweet? The relationship of the built environment to tweeting in Chicago	United States	NM	NM	I	2020
Han, Lee, and Leem (2019)	Modelling interaction decisions in smart cities: Why do we interact with smart media displays?	Australia	mixed	mixed	I	2019
Meenar (2019)	Integrating placemaking concepts into Green Stormwater Infrastructure design in the City of Philadelphia.	United States	Latinx culture	NM	I	2019
Glover (2019)	The transformative (and potentially discriminatory) possibilities of animating public space.	Canada	NM	NM	I	2019
Pang et al. (2020)	The role of a location-based city exploration game in digital placemaking	Canada	Mixed	Mixed	I	2019
Tarr and Alvarez LeÃ³n (2019)	Will Review for Points: The Unpaid Affective Labour of Placemaking for Googleâ€™s Local Guides.	United States	Non-white labour	Low-income	I	2019

Reference	Topic	Context	Nationalities	Economic class	Agency of older adult	Year
Yu and Blain (2019)	Tongzhi on the move: Digital/social media and placemaking practices among young gay Chinese in Australia	Australia	Chinese gay migrants	NM	I	2019
Fredericks et al. (2018)	Blending pop-up urbanism and participatory technologies: Challenges and opportunities for inclusive city-making	Australia	NM	NM	I	2018
Fang et al. (2016)	Place-making with older persons: Establishing sense-of-place through participatory community mapping workshops.	Canada	Mixed	NM	E	2017
Houghton, Foth, and Miller (2015)	Urban Acupuncture: Hybrid Social and Technological Practices for Hyperlocal Placemaking.	Australia	Mixed	NM	I	2015
Hanlon et al. (2014)	Place integration through efforts to support healthy ageing in resource frontier communities: The role of voluntary sector leadership.	Canada	Mixed	Low-income	E	2014
Kim, Cho, and Chae (2014)	A smart community for placemaking in housing complexes.	Korea	Korean	Mixed	I	2014
Bilandzic and Johnson (2013)	Hybrid placemaking in the library: Designing digital technology to enhance users on-site experience.	Australia	NM	NM	I	2013

Reference		Topic	Context	Nationalities	Economic class	Agency of older adult	Year
	Van Hoven and Douma (2012)	â€™We make ourselves at home wherever we are â€“ Older peopleâ€™s placemaking in newton hall.	United Kingdom	Older in-migrants	Low-income	E	2012
	Brunnberg and Frigo (2012)	Placemaking in the 21st-century city: Introducing the funfair metaphor for mobile media in the future urban space.	Japan	Japanese	Mixed	I	2012
	Hollander et al. (2019)	Seeing the city: Using eye-tracking technology to explore cognitive responses to the built environment.	United States	NM	NM	I	2019
Total	N 18	18	18				18
Total	N 26	26	26				26
a Not Mentioned; b Inclusive; c Exclusive							

In the Global South, Spain, China, Hong Kong, Poland, Serbia, Russia, and Italy have included seniors in their digital placemaking studies. Out of these countries, only China (with one article) exclusively studied seniors in its digital placemaking practice (Table 2). Similarly to the Global North, most Global South studies did not mention the socioeconomic status of seniors. However, those that did were about low-income residents living in shared apartments. Overall, the Global South studies remarked on the importance of the senior population as active cultural assets rather than passive recipients in placemaking decisions. According to them, “placemaking with senior people” is a way of building partnerships that reinforce place-activation and active ageing [57], [58], [59]. In these studies, digital literacy plays a minor role. The priority is to demonstrate the importance of involving the senior

population in community rebuilding rather than explaining how digital technology can effectively accomplish this.

2.3.3 The implemented digital instruments

The first published article on placemaking, digital technology, and senior people employed a case study method to describe and analyse the mediation of digital technologies in different placemaking approaches [60]. Then, a range of diverse digital instruments contributed to this topic in 26 published articles (Table 2).

Cross-tabulation of the digital instrument and stakeholder realm (Table 3) illustrates how far digital technology has contributed to placemaking with the partnership of seniors. In most articles, seniors were studied alongside other stakeholders (SPI) (22 articles or 84.6%). In comparison, only four articles have focused exclusively on seniors (SPE) (15.4%).

Table 3. Placemaking process and stakeholder realm crosstabulation table.

Stakeholder realm		Placemaking Process				Total
		Analysis	Solution Development	Organising Co-creation and Implementation	Intervention after Implementation	
[a]SPI	Count	13	2	4	3	22
	% within Realm	59.1%	9.10%	18.20%	13.60%	100.00%
	% of Total	50.0%	7.70%	15.40%	11.50%	84.60%
[b]SPE	Count	2	1	1	0	4
	% within Realm	50.00%	25.00%	25.00%	0.00%	100.00%
	% of Total	7.70%	3.80%	3.80%	0.00%	15.40%

[a] Senior People Inclusively; [b] Senior People Exclusively

Further, the cross-tabulation shows how far seniors are involved in digital placemaking. 59.1% of articles involved SPI only in analysis, 9.1% in solution development, 18.2% in the co-creation

and implementation, and 13.6% in intervention after implementation. Two articles involved SPE in analysis [54], [56], one in the solution development [61], and one in organising co-creation and implementation [58]. According to the review, no article involved SPE in the last step of the placemaking process: intervention after implementation.

The results of this cross-tabulation indicate that the active participation of seniors in SPE has been downgraded as soon as digital instruments are incorporated in placemaking. One factor for this issue could be the agency of senior people. The term agency is frequently used in social sciences, referring to the capacity of individuals to fulfil their potential [62]. However, according to our review, only a limited number of publications (n = 3 out of 26) squarely addressed senior's agency as active agents in place development activities [56], [58], [61]. This part of the literature argued that despite the unavoidable physical decline, seniors are still productive social capital and advocate extending the age of labour participation. Therefore, they reinforced promoting "active ageing" to encourage seniors to increase their social involvement and support the idea that society should make good use of senior people and maximise their human capital.

Nevertheless, based on the majority of literature (n = 23 out of 26), despite not acknowledging ageing as a process of frailty, infirmity, and vulnerability, seniors are often excluded from the placemaking process, or they are studied inclusively with other stakeholders, primarily due to the technology necessities. Hence, to better understand this issue, we detailed and cross-tabulated the digital instruments along the placemaking process. This cross-tabulation can help identify what type of digital instrument is used in each step of the placemaking process (*Table 4*). To crosstab the digital instruments and the placemaking process, the digital instruments were categorised into four main categories: survey, online mapping platform, digital observation, and media

architecture (Table 4). The cross-tabulation revealed that 61.5% of digital instruments were used for analysis, 7.6% for solution development, 19.2% for organising co-creation and implementation, and 11.5% for intervention after implementation. The dominant digital instruments used along the placemaking process were online mapping platforms with 46.1% and surveys with 30.6%, respectively. Digital observation and media architecture were used far less, with 15.3% and 7.6%, respectively.

Table 4. Digital instrument and placemaking process cross-tabulation table of 26 articles relating to placemaking, digital technology, and senior people

Digital Instrument		Placemaking Process				Total
		Analysis	Solution Development	Organising Co-creation and Implementation	Intervention after Implementation	
Survey	Count	5	1	2	0	8
	% of Total	19.20 %	3.80%	7.60%	0.00%	30.60 %
Online Mapping Platform	Count	10	0	2	0	12
	% of Total	38.40 %	0	7.60%	0.00%	46.10 %
Digital Observation	Count	1	1	0	2	4
	% of Total	3.80%	3.80%	0.00%	7.60%	15.30 %
Media Architecture	Count	0	0	1	1	2
	% of Total	0.00%	0.00%	3.80%	3.80%	7.60 %
Total	Count	16	2	5	3	26
	% of Total	61.5%	7.6%	19.2%	11.5%	100%

As the digital instruments used at each step varied significantly, we included them in another table (Table 5). Crosstabs show that involving seniors through surveys was frequently investigated in SPI, but it was used as the dominant instrument in SPE (n = 4 out of 4). In the SPI, online and on-site surveys were used to analyse the stakeholders' preferences in place activations [63], [64]. "Engagement channels" were used for organising stakeholders for co-creation and implementation. For

the first time, this instrument was introduced by [65]. Joel Fredericks et al. expressed engagement channels through novel interfaces combining emerging digital practices – such as selfies – with traditional data-gathering techniques such as paper surveys. According to them, engagement channels helped organise co-creation and implementation more effectively. In the SPE realm, surveys (n = 3) were run through a design charrette for analysing, developing solutions, and organising seniors for co-creation and implementation. Mental mapping (n = 1) [56], photo-voice sessions (n = 1) [55], and photo-video diaries (n = 1) [58] were the most used techniques during the design charrette to involve seniors in an intense period of design and planning activity. The design charrette lets researchers understand senior people's unique needs and desires. It also empowered the overall placemaking process of developing an ageing community [56].

Table 5. The cross-tabulation of the stakeholder realm, detail of digital instruments, and placemaking process

Realm	Digital Instrument	Detail of Digital Instrument	Placemaking Process: Analysis	Solution Development	Organising Cocreation and Implementation	Intervention after Implementation	N
[a]SPI	Survey	Online/on-site Survey	3	N/A	N/A	N/A	3
		Engagement Channels		N/A	1	N/A	1
		N	3		1		4
	Online Mapping Platform	LBSNs	9	N/A	N/A	N/A	9
		LBGs	N/A	2	N/A	N/A	2
		Geo-questionnaire	"1"	N/A	N/A	N/A	1
		N	10		2		12
	Digital Observation	Eye-tracking	1	N/A	N/A	N/A	1
		AR	N/A	1	N/A	N/A	1
		Digitally Enabled Place	N/A	N/A	N/A	1	1
		Locative-media Artworks	N/A	N/A	N/A	1	1
		N	1	1	A	2	4
	Media Architecture	Media Facade	N/A	N/A	N/A	1	1
		Pop-up Animation	N/A	N/A	1	N/A	1
		N			1	1	2
[b]SPE	Survey	Design Charrette	2	1	1	N/A	4
		N	2	1	1		4

[a] Senior People Inclusively; [b] Senior People Exclusively

Data in online mapping platforms were gathered through Location-Based Social Networks (LBSNs) (n = 9) and geo-questionnaire (n = 1) for analysis and Location-Based Games (LBGs) (n = 2) for solution development. LBSNs like popular social media, including Facebook, Twitter, and Instagram, and the less popular media, like Imprecity, were used to collect the relevant information. This information was used to understand the

stakeholders' behaviours and preferences in the physical space through communication and participation [66]. The geo-questionnaire was another standard instrument used to provide stakeholders with spatial information. Further, it was used to build collaborative thinking about the design process and create a place. Kotus and Rzeszewski (2020) implemented a geo-questionnaire to integrate sketchable maps with questions to elicit place preference, land allocations, and services [43]. LBGs were used to involve stakeholders in exploring alternative solutions to place-centric issues [67]. LBG apps – such as Pokémon G.O., Dérive, and Sankofa Says – were among the most popular game apps used for solution development during the placemaking process[68] [69] [70].

The digital observation instruments were used during the analysis, solution development, and the intervention after implementation. In the SPI, researchers employed advanced digital instruments such as Augmented Reality (AR) (n = 1), eye-tracking systems (n = 1), digitally enabled place (n = 1), and locative-media artworks (n = 1). These instruments mainly sourced data by empirically testing the variations in the stakeholders' activities [71], perceptions and demands [24], and emotions and feelings of a place [72].

Media Architecture was identified in articles published after 2019, with two articles in the SPI and no article in the SPE realm. The use of media architecture largely supported placemaking by experimenting with the stakeholders' experiences of how a place is entertaining, pleasing, and imaginary [67]. The strategies that embraced media architecture mainly revolved around media façades [73] and pop-up animations [74]. Media façades, such as large-medium scale screens, were used to shift the stakeholder's involvement process into a more interactive and tangible interaction. Pop-up animations were employed to animate

the public space temporarily (e.g. in festivals, events, pop-up activities, etc.) to animate space and stage public life.

2.3.4 Theories, concepts or perspectives underpinned

The theories, concepts, or perspectives underpinning each peer-reviewed article were identified and coded where possible. The two terms "cited" and "applied" were used in this section. "Cited" conveys that the study discussed the theory, concept, or perspective, but no evidence was seen that the study examined the cited theory. "Applied" conveys that the study explicitly discussed and mentioned the theory and researched it expressly through research design and methods in the article.

Theories on placemaking, digital technology, and senior people were cited 21 times in 18 peer-reviewed research articles and applied 11 times in 10 research articles. Approximately one-fourth of the research articles (23.07%) neither cited nor applied any specific theory or concept. A few authors cited more than one concept (Table 6). The concept of co-creation [43], [58], [63] and age-in-place [54], [55], [58] were the most cited or applied concepts in five articles. "Online affective placemaking" [25], [72], "transformative placemaking" [74], [75], "urban emotion" [72], [76], and "hyperlocal placemaking" [60], [67] were each referred to twice. The remaining approaches were either cited or applied in only one of the reviewed articles. These include "virtual brand communities" [77], "engagement channels" [65], "self-organisation" [63], "urban acupuncture" [64], "gamification" [78], "place-centric perspective" [71], "universal urban design" [59], and "smart paradigm" [24].

Table 6. Theories, concepts, or approaches used in the peer-reviewed articles

Theories, Concepts, Approaches	[a]Cited	[b]Applied
Online Affective Placemaking [25], [72]	2	2
Virtual Brand Communities [77]	1	1
Engagement Channels (Fredericks et al. 2018)	1	-
Co-creation (Caneparo and Bonavero 2016; Hanlon et al. 2014; Kotus and Rzeszewski 2020; Qi and Gu 2020)	3	2
Self-organization (Caneparo and Bonavero 2016)	1	-
Urban Acupuncture (Houghton, Foth, and Miller 2015)	1	1
Transformative Placemaking (Glover 2019; Yu and Blain 2019)	2	1
Urban Emotion (Hollander et al. 2019; Nenko and Petrova 2018)	1	-
Gamification (Pang et al. 2020)	1	1
Place-Centric Perspective (Wang 2019)	1	-
Universal Urban Design (Stupar et al. 2019)	1	1
Smart Paradigm (Kim, Cho, and Chae 2014)	1	-
Hyperlocal Placemaking (Bilandzic and Johnson 2013; Cornelio and ArdÃ©vol 2011)	2	1
Age-in-place (Hanlon et al. 2014; Qi and Gu 2020; Sixsmith et al. 2017)	3	1
[c]Total	21c	11c

[a]Cited: the theory, concept, or perspective is discussed and mentioned in the article but not evidently assessed.
[b]Applied: a sub-group of Cited and conveys that the theory, concept, or perspective is explicitly researched through methods in the article.
[c]Total<26. A total of 6 articles neither applied nor cited specific theory, concept, or perspective

2.3.5 The correlation between digital instrument implementation and senior people's involvement in placemaking concepts

The scattergram in Figure 7 demonstrates how implementing digital instruments has been correlated with seniors' involvement in the concepts/theories applied in placemaking. Codes on the vertical axis represent the digital instruments used. They range from simple digital instruments like photo-video diaries and online/on-site surveys to advanced digital instruments such as LBGs, LBSNs, and AR. The horizontal axis represents the extent to which seniors were involved. It ranges from inclusively

with the other stakeholders (Low) to exclusively senior people (High). To make it easier to interpret the results, the scattergram has been divided into four scatter zones: Scatter zone (A) shows the concepts that correlate with advanced-digital instrument implementation and low-senior involvement; scatter zone (B) shows the concepts that correlate with advanced-digital instrument implementation and high senior involvement; scatter zone (C) shows the concepts that correlate with simple-digital instrument implementation and high senior involvement; and scatter zone (D) shows the concepts that correlate with simple-digital instrument implementation and low-senior involvement. The weight of each concept (as shown in different circles) indicates the extent to which the theory/concept is applied in placemaking.

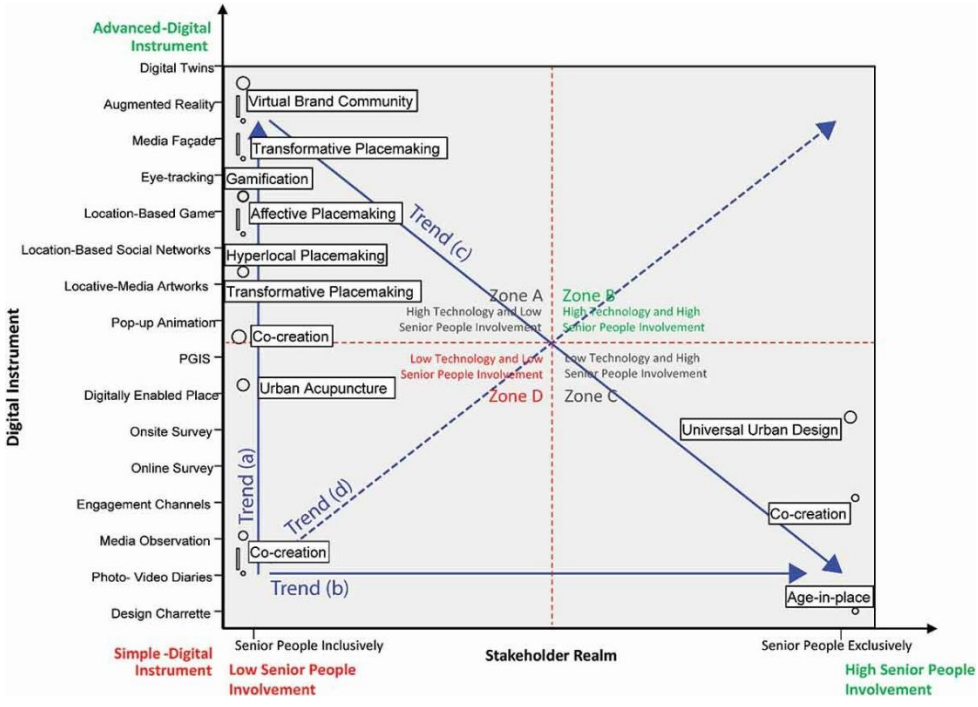

Figure 7. Placemaking, digital technology, and senior people scattergram.

According to the scatter zones, the correlations between digital instrument implementation and senior people's

involvement across the placemaking concepts reveal four significant trends:

> ***Trend (a)*:** a strong positive correlation between seniors' inclusively (SPI) involvement and advanced digital instrument implementation.

Trend (a) started in the scatter zone (D) and ended in the scatter zone (A). Seven concepts, including "virtual brand community," "gamification," "online affective placemaking," "hyperlocal placemaking," "transformative placemaking," "urban acupuncture," and "co-creation", were scattered in these two zones. The first five concepts were applied in the scatter zone (A), while the last two were applied in the scatter zone (D). The "urban acupuncture" was cited or applied in both scatter zones.

The articles that applied these concepts mostly reinforced place activation and communication empowerment – or similar terms used interchangeably, such as social networking, social interaction, and co-engagement.

- **Online effective placemaking:** social media platforms such as Facebook and Instagram allow for the practical expression of what is happening in a place [25].
- **Virtual brand communities:** technologies like augmented realities combined with social networks to extend people's interactions in virtual worlds towards shaping collective intelligence communities [24].
- **Gamification:** LBGs produced alternatives to let people engage with each other and explore the city or community in more pleasing and entertaining ways [78].
- **Hyperlocal placemaking:** the affordance of social, spatial, and digital spaces was combined in interactive exhibitions to facilitate people's social interactions in a particular place [67].

- **Transformative placemaking:** technology like media architecture supports people to become co-creators – e.g., the co-creator of a digital art object – in a particular place [79].
- **Hyperlocal placemaking** is also used interchangeably with "urban acupuncture." Urban acupuncture – as a hyper-localised healing treatment – involves people, designers, and planners in place activation and rejuvenation [64].
- **Co-creation:** Online/on-site surveys and Participatory GIS (PGIS) supported the concepts of sharing ideas and improving the place together [63].

In placemaking, digital technology, and senior people, the trend (a) can be stated as an If(p)-then(q) statement. The If-then statement shows a hypothesis followed by a conclusion:

p→q:

If the senior' involvement was low (p), **then** the implementation of the advanced-digital instrument was/would be high (q).

Trend (a) shows that advanced digital instruments (such as AR, LBGs, and LBSNs) that are used in virtual brand communities, gamification, and hyperlocal placemaking have less empowered seniors' active participation than digital instruments such as photo and video diaries that are used in urban acupuncture and co-creation. The two-pronged reason(s) mentioned in the concepts for low-senior people involvement: First, the authors decided to less/inclusively involve senior people in the placemaking because of the low capability of senior people in terms of dynamics, competency, and technology-related skills [80]. Second, the senior people decided to be less/inclusively involved mainly because of feelings of inadequacy, lack of confidence in their knowledge – e.g. how to use a digital property such as a game application [78], –

Lack of interest in wearable gadgets – e.g. gadgets for eye-tracking, poor health conditions, and security concerns [54].

Trend (b): no correlation between senior inclusively (SPI) or exclusively (SPE) involvement and simple-digital instrument implementation.

Four concepts of "urban acupuncture," "co-creation," "universal urban design," and "age-in-place" were scattered across the trend (b). The first two concepts were defined earlier. Therefore, we skip them here. In the last two concepts:

- The authors applied the concept of age-in-place emphasising the importance of shaping places that enable senior people to maintain a sense of belonging, autonomy, independence, safety, and security [80]. To achieve the age-in-place, seniors investigated how they experience the place (sense of place) and what needs and expectations they have from the place. The non- or low-digital instruments such as online surveys, photo and video diaries, and online mapping exercises were used in the age-in-place concept.

- The authors applied the concept of "universal urban design (UUD)" – also called "design for all" – outlining a way to enable the higher usability of the place for all people regardless of their age and (dis)abilities. UUD used digital instruments such as online/on-site surveys, geo-questionnaires, and GIS apps to outline the way by involving senior people. However, the involvement of seniors was only achieved when a facilitator was employed. The facilitator – also known as the voluntary sector [54] or social work educators [80] – played a role in helping the seniors use/implement the digital instruments in the placemaking process.

Overall, trend (a) began with low senior involvement (inclusively) – in scatter zone (D) – and ended with high senior involvement (exclusively) in scatter zone (C). However, the digital instruments implemented were constant as non- or simple digital. As a result, the seniors could participate predominantly or exclusively in placemaking as the contribution of the digital instrument was low.

Trend (c): negative correlation between advanced-digital instrument implementation and high senior involvement.

Trend (c) started in scatter zone (A) and ended in scatter zone (C). All the concepts that belonged to these scatter zones were defined earlier. Therefore, their definition will be skipped here. The concepts in scatter zones (A) and (C) were opposing positions. This indicates that concepts such as virtual brand community and gamification implement advanced-digital instruments involving SPI, while concepts like age-in-place implement simple-digital instruments by applying SPE. According to the trend, as the contribution of technology in implementation lessened, the involvement of senior people increased:

p→q:

If the contribution of a digital instrument in placemaking lessons, **then** the senior involvement increases.

Trend (d): by increasing the exclusively senior involvement (SPE), no concept was cited or applied in placemaking to implement advanced digital instruments.

Because of the evidence deficiency in concepts relating to advanced digital instrument implementation and high senior involvement, trend (d) was illustrated as a

dashed line and differentiated from the other trends. Trend (d) highlights that seniors' empowerment in placemaking concepts has yet to be discussed. Yet, seniors are marginalised when advanced digital instruments are applied to placemaking, such as Digital Twins and Augmented Reality.

Overall, the seniors' empowerment for active involvement in placemaking mainly was achieved through non- or simple digital instruments. The seniors' empowerment through advanced-digital instruments such as Digital Twins remained vague since evidence of deficiency existed in the literature on placemaking, digital technology, and senior people.

2.4 Discussion

This review aimed to overview what is known in the placemaking literature about digital technology implementation and seniors' empowerment for active involvement. A systematic quantitative literature review was performed to identify the scope, the digital instruments implemented, the theories, concepts, or perspectives underpinned, and the correlations between digital instrument implementation and senior involvement from the first published article in 2011 to those at the end of 2020. The review highlighted several key findings, which may indicate future venues for necessary research in this field: 1) Twenty-six peer-reviewed research articles on the topic of placemaking, digital technology, and senior people have been published from 2011 to 2020 by 25 journal titles across the four types of placemaking; 2) The topic of placemaking, digital technology, and senior people has rapidly caught the research attention over the last three years with almost two-thirds of the 26 reviewed articles being published between 2018 and 2020; 3) In many placemaking studies, senior people are underrepresented and the number of placemaking studies exclusively involving seniors is very rare (n = 4 out of 26); 4) The

empowerment of seniors for exclusive involvement in placemaking mainly occurred through employing a facilitator; 5) Online mapping platforms and its strategies such as Location-Based Social Networks, Location-Based Games, and Participatory GIS were the most frequently used digital instruments; 6) Age-in place and co-creation were the most frequently cited or applied concepts 7) There was a positive correlation between advanced digital instrument implementation and low senior involvement; 8) There was no correlation between simple-digital instrument implementation and high/low senior involvement; 9) There was a negative correlation between advanced digital instrument implementation and high senior involvement; and 10) No study was found to cite or apply advanced digital instruments such as Digital Twins to involve senior people exclusively in the placemaking.

2.4.1 The rapid increase in placemaking research towards senior people involvement and digital technology implementation

Placemaking research has a history of six decades, dating back to the 1960s. However, the research on digital placemaking with the contribution of senior people is relatively young, with the first identified article published in 2011[60]. As shown by published peer-reviewed articles in Section 2.3, interest in this research has increased rapidly since 2018 after a few years of relatively slow but steady increase. In part, it may be correlated to the drastic increase in the world's senior population and the desire for seniors to become more involved in decisions that affect their lives. Further, the advancement of technology solutions in health and neighbourhood planning fields is indicative of the current big-data era and a prerequisite for shaping future smart and active ageing neighbourhoods. Such trends open windows for developing a more coordinated research agenda that stimulates considering seniors as active creators/contributors to digital placemaking. In addition, better use of the limited resources for placemaking,

digital technology, and senior people research will enable rapid and coherent advancement of the body of knowledge.

2.4.2 The empowerment in placemaking, digital technology, and senior people

Although advanced digital instruments such as Digital Twins, 3R and LBSNs can manage to perform placemaking at wider scales, they have yet to implement a truly collaborative approach with the stakeholders such as seniors, who usually experience marginalisation. This argument does not negate the importance of digital technology in placemaking empowerment for senior involvement but instead emphasises finding solutions to adopt technology for the use of senior people. For example, in peer-reviewed research such as Hanlon et al. (2014), Webb (2014), and Qi and Gu (2020), a facilitator/social network educator was employed to support seniors along with the digital instrument implementation in placemaking [32], [54], [80]. These studies convey the competency of digital technology towards achieving a more collaborative form of placemaking with seniors. In addition, if such solutions are adopted in future placemaking studies, they may gradually empower seniors' involvement so that seniors can be involved and act independently in the end. Adopting such solutions is primarily due to the profound impacts of digital technologies on placemaking empowerment. In this sense, the review confirms these impacts at least in two ways:

> First, advanced-digital instruments implemented in placemaking can improve the precision and richness of traditional placemaking – or placemaking using non- or simple digital instruments. For example, location-tagged media contents – such as photos, videos, and texts – which are mainly collected throughout the LBSNs, provided non-digital instruments, such as photo surveys, mental mapping, etc., with more detailed and place-based information. Further, the information gathered throughout

the LBSNs was more accurate than what was collected in traditional placemaking [42], [64], [66]. Consequently, the placemaking results were more accurate, and the placemakers could make more targeted interventions. Thus, advanced digital instruments can enable traditional placemaking to act more accurately, effectively, and comprehensively.

As a second point, in some instances, advanced digital instruments can offer completely new possibilities compared to traditional placemaking. For example, thanks to IoT and big data advancements, Digital Twins (DT) can be a digital representation of placemaking. They enable comprehensive data exchange and can use algorithms and machine learning to help 3D simulations and algorithms to describe their physical equivalents in the real world [81]. In addition, by incorporating DT. and immersive Augmented Reality (AR), stakeholders can be more involved in placemaking [15]. Therefore, the outcome of these advanced instruments enables placemaking to take on a much more tangible, dynamic, and multi-sensory form than simple visualisation, as can be achieved by simple tools such as design charrettes, photos, or videos in the traditional sense. (Section 2.3.3- Table 5, and Section 2.3.5).

This review confirms the impact of digital technology on placemaking. Nevertheless, the literature deficiency still exists on senior people empowerment and their role as key players in placemaking. As shown in *Table 4*, a limitation in the peer-reviewed research has been the involvement of senior people in placemaking and digital technology implementation. For example, less than 16% of the reviewed articles involved seniors exclusively (Sections 2.3.2, 2.3.3, and 2.3.4). Further, no research in placemaking has yet studied or tested advanced digital instruments

with senior people exclusively (*Figure 7*). This literature deficiency points out that bridging the grey digital divide for senior people has yet to be discussed. Despite all this, senior people are marginalised whenever advanced digital instruments are implemented in placemaking. Thus, considering the rapid growth of the senior population resulting from demographic changes, future research should develop policies or frameworks to contrast the seniors' marginalisation in advanced placemaking activities.

2.5 Conclusion

The systematic quantitative review demonstrated that 26 peer-reviewed research articles on placemaking, digital technology, and senior people had been published from 2011 to 2020. This topic has rapidly increased over the last three years, with almost two-thirds of the 26 reviewed articles published between 2018 and 2020. Moreover, this review found that seniors are not adequately considered as active participants in digital placemaking. This issue was the most apparent gap in the scattergram presented in Section 2.3.5. Nevertheless, this review confirmed the profound impacts of advanced digital instruments such as Digital Twins on shaping future smart and healthy ageing places. Therefore, this review may open windows for developing a more coordinated research agenda that considers seniors as active players and creators of digital placemaking. Further, the literature review recommends that future studies develop a framework to address seniors' marginalisation in advanced digital placemaking activities.

Chapter 3 Developing a user-centred virtual CIM for inclusive placemaking with older adults: state-of-art

Developing a user-centred virtual CIM for inclusive placemaking with older adults:

state-of-art

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For consistency of the dissertation some typos are adjusted and phrases are reworded without changing the content

ABSTRACT

The concept of placemaking has evolved with the advancement of technology. City information models (CIM), urban digital twin (UDT), and the proliferation of communication technologies have transformed the way society operates and has led to the modernisation of traditional methods of inclusive decision-making. However, creating a CIM that effectively aligns the diverse interests and capabilities of (non-expert) users like local inhabitants for active participation can be challenging. In this study, we aim to develop a virtual CIM (vCIM) and explore the immersive behaviours of (non-expert) users in the context of community design and policy

decision-making. To do this, we use a combination of multi-objective programming and mixed-media prototyping to create the CIM, which includes LOD 300 spatial representation, what-if scenario implementation, geo-tagging feedback, and easy communication and exploration by stakeholders. The vCIM was tested in a real-life urban community design exercise in The Netherlands, the Blue Zone Malvalaan, in two phases by both expert and non-expert stakeholders. We evaluated the user experience through quantitative and qualitative data analysis, focusing on ease-of-use, usefulness, immersion, mental and physical comfort, and satisfaction. Our research shows how the vCIM can help local stakeholders contribute to community design optimisation and strengthen policy decision-making outcomes.

3.1 Introduction

In recent years, city information modelling (CIM) and urban digital twins (UDT) have gained significant attention in urban design, planning, and policy studies [82]. CIM involves creating a virtual representation of a city that can be used to visualise and predict the evolution of a space over time [83]. UDT, a newer approach to CIM, involves simulating and analysing scenarios such as traffic patterns, energy consumption, and emergency response in order to inform smart cities for complex planning and decision-making systems [84],[85]. Both CIM and UDT utilise digital models and data to represent and understand complex systems in urban environments [86]. These technologies offer a powerful toolkit for conceptualising, visualising, and optimising user-centric decision-making and inclusive placemaking [87].

While CIM and UDT have the potential to offer numerous benefits, they have also faced challenges that have hindered their widespread adoption and use. One significant challenge is the difficulty that stakeholders have in understanding and using these technologies [88]. The existing urban digital twins (e.g.,([81], [89],

[90]) tend to be highly specialised and complex, requiring specialised skills and knowledge to be utilised effectively. This complexity can be a barrier for non-specialist stakeholders, such as citizens, who may not have the necessary expertise to fully comprehend and use these systems [91]. This is particularly relevant in the context of user-centred community design efforts, such as inclusive placemaking, where many participants may be non-technical stakeholders[92]. The lack of understanding and ability to use urban digital twins can limit their potential impact and utility for community decision-making initiatives. Moreover, it may limit the participation of certain groups or individuals within the community, for example, senior citizens, from the optimisation and decision-making processes.

To address issues related to the understandability and usability of CIMs for non-specialist users, it is necessary to advance the methodology. This advancement can improve the accessibility and usability of CIMs for a wide range of stakeholders, including community members, government officials, and other stakeholders. A user-friendly CIM can make it easier for these stakeholders to understand and use the model, which can increase the model's effectiveness in informing decision-making and planning processes. In addition, it can increase the participation and engagement of community members in the design and planning process. If the model is easy to understand and use, it is likely that more people will be willing to contribute their ideas and feedback, leading to more inclusive and representative decision-making. Furthermore, a user-friendly CIM can help to build trust and confidence in the model and the planning process. When people feel that the model is transparent and easy to understand, they may be more likely to trust the results and recommendations it produces. To advance the methodology of user-friendly CIMs, it may be necessary to improve data management practices [93], develop standardised data protocols and formats [94], and invest in training and resources to

improve the technical skills and knowledge of users [95]. It may also be necessary to design and implement more user-friendly and intuitive interfaces and tools, and to seek input and feedback from users to identify and address any usability issues [96].

The aim of this study is to introduce a state-of-the-art vCIM that non-expert stakeholders can use for community design and inclusive placemaking. The goal is to create a user-centred CIM as a roadmap for an inclusive urban digital twin ambition. To achieve this, we developed a vCIM and examined its immersive behaviour from the perspective of non-expert users in a real-life urban neighbourhood design optimisation exercise.

The outline for the paper is as follows: in Section 3.2, we highlight common materials and methods for developing CIMs in the context of urban digital twins and policy decisions. This section also presents an overview of currently available UDTs, and their deficiencies for user-centred CIMs, and introduces a novel vCIM as a potential solution. Section 3.3, presents the method and the prototype development process for vCIM. Section 3.4, discusses the user experience test and evaluation of the vCIM by both expert and non-expert users. Section 3.5, highlights considerations for future research, and the conclusions are presented in Section 3.6.

3.2 Material

3.2.1 City Information Model - digital twin in urban design and policy decisions

CIM is a digital representation of the physical and functional characteristics of a city [82]. This model typically involves creating a digital representation of a city's physical and functional features, such as buildings, roads, utilities, and other infrastructure [97]. Because such models are supposed to represent reality as realistically as possible, they require a high level of detail and information [91]. Models of this type can be used as a framework for

digitising urban design and planning practices and manageing data about cities [86]. They can serve the purpose of supporting decision-making and collaboration among city officials and stakeholders very well in most cases [98]. They can provide high-quality information and solid spatial visibility, making them valuable tools for planning for future growth and development, and coordinating the work of different departments and agencies [97], [99].

The recent focus of CIM is on utilising digital twin technology to optimise complex decision-making systems [100]. Digital twin goes beyond geometry and information modelling and involves creating digital copies of real-world cities in order to plan, analyse, and simulate them. Urban Digital Twins (UDT) are created as digital/vCIMs using a combination of data sources, such as maps, sensor data, and other information, and are typically interactive and highly detailed [101]. UDTs can help urban designers identify and address potential usability issues before building a physical urban environment, saving time and resources [102]. Additionally, UDTs can be used for community infrastructure resilience by allowing stakeholders to engage with and provide feedback in a realistic and intuitive way [92]. UDTs can also help cities plan for future growth, manage resources more efficiently, and improve the quality of life for their citizens [83].

The concept of UDT continues to be a subject of confusion, and simple definitions often do not adequately capture the scope and scale of the concept. The models convey definitions much more effectively and provide a much richer set of UDT components and their details.

3.2.2 UDT model development

To understand UDT models more thoroughly, we conducted a narrative literature review [103] and organised the information according to the six-stage methodology proposed by [85]. This framework involves building a virtual city model to test new

solutions before implementing them in an actual city. The UDT model components and their explanations are organised as follows:

- ***Create – 3D CIM:*** UDT begins with visualisation and 3D modelling of the respective city area.

The creation of 3D CIM involves collecting and organising data about the city using various methods, such as field surveys, aerial imagery, and existing data sources. The data is typically organised and cleaned to ensure accuracy and compatibility with exchange formats, following the CityGML standard [93]. The CIM is then modelled at different levels of detail (LoDs), ranging from a simple two-dimensional terrain map (LoD 00) to highly precise geometry visualisations (LoDs 300 and 400)[104]. The creation of a 3D CIM can be achieved using various software options, such as Esri CityEngine [105], Bentley's openCity [106, p. 14], Autodesk Infraworks [107], and ArchiCAD [94], or through the use of 3D point cloud data obtained through aerial LiDAR scanning and photogrammetry [96], [108]. The choice of method depends on the goals of the CIM and the availability of resources, such as high-end equipment and custom modelling software [101].

- ***Communicate – HCI:*** once the CIM is created, it needs to communicate bidirectionally to its users, which is commonly called human-computer-interaction (HCI).

Milgram and Kishino's display taxonomy identifies several types of HCI, including direct displays, transparent displays, and CAVE (cave automatic virtual environment) displays, which include AR and VR [109].

There are several important factors to consider when selecting a user-friendly HCI for CIM, including the user's immersion (the feeling of being absorbed in a virtual environment), sense of presence (the sense of physically being present within a simulation), the design of the user interface, and the overall

satisfaction [110]. Other important factors like the reliability and performance of the computer system, the availability of technical support, and the ability of the system to adapt to the user's changing needs are also reported in a previous study [96]. Additionally, it is essential to consider issues of accessibility and usability, as well as the personal preferences and ethical implications including, age, gender, (dis)ability, prior knowledge, and skills of human-computer interactions [91], [111].

- ***Aggregate – computation tools:*** Computation tools are needed to aggregate the CIM and HCI for exploration, analysis, and evaluation by users.

Various factors determine the appropriate computational tool for vCIM. A critical factor in this regard is the ability to render in real-time [107]. Real-time rendering is a dynamic 3D model that is rendered instantaneously and can be generated in less than a second [112]. The real-time rendering method differs from static image rendering, such as that used in CAD programmes. When rendering a static image, for example, using 3DMAX, we design the model and then define variables. The software then calculates the results. After the results are calculated, we reiterate if structural deformations or other design flaws are found. However, in a real-time rendering, once the model has been designed, we can specify what we want to be tested and we can see the results in real time after the test has been started. These promises of high-fidelity of real-time rendering can change our ways of how we approach research and development and make these processes more straightforward [113]. Furthermore, their high-end graphics capabilities facilitate extended reality experiences by integrating realistic interaction models and physics with high-end graphics capabilities [89].

Another critical consideration in the selection of a computational tool is its "interoperability," for example, the level of

interoperability between different software packages [107]. The interoperability layer is necessary for data conversion and data integration since UDT collect data from a variety of sources, e.g., GIS, CAD, and social media, each of which has its file format. Consequently, an interoperability layer is needed to convert these formats and let them be integrated into CIM.

In order to establish interoperability in CIM, several computation programs are available, including Blender, CityCAD, CityEngine, Cesium, Unreal Engine, and Unity. These programs provide different levels of interoperability, HCI workflows, real-time rendering, and spatial sensory effects. However, recent studies suggest that game engines such as Unreal Engine and Unity offer a heightened degree of interoperability for CIM and provide CAVE HCI workflows, enabling the creation of interactive and immersive CIM experiences. These engines also offer features such as real-time lighting and shadow effects, a variety of camera angles and perspectives, and the ability to incorporate sound and other sensory elements [91], [97], [101].

- ***Analyse:*** This phase produces insights in UDT to facilitate decision-making through the application of co-creation, co-design, and collaborative knowledge sharing. The analysis stage relies on various what-if design scenario models, which are created on top of the CIM. The models should follow the objectives of the design and/or policy decisions.
- ***Insights – feedback:*** The insights from analytics are visualised in multidimensional views during the insight stage. The insights generated during this phase are intended to inform decision-making and support the development of effective policies and strategies for the city. The models created during this phase should align with the objectives of the design and/or policy decisions being considered and may

be used to simulate and test different scenarios and strategies.

- ***Store— lifecycle management:*** The last phase of the UDT development process involves manageing the lifecycle of the UDT, which includes recording and storing decisions and variations made to the UDT in order to represent a space not just as it currently is, but also as it was designed, tested, and built in the past, and as it may be operated and maintained in the future. This information is kept in the CIM repository along with the original requirements, design decisions, and simulation results. By preserving this data, the UDT can accurately depict not only the current state of the physical city, but also its evolution over time.

3.2.3 UDT applications and their deficiencies in implementing CIM for community design

A number of UDTs have been documented in the literature or are available online, including the Digital Twin of Zurich [90], Digital Twin of Herrenberg [81], and Digital Twin of Rotterdam [114]. These cases illustrate the utility of vCIMs (city information models) in addressing a wide range of socio-technological issues related to the integrative management of complex spatial developmental processes. The increasing prevalence of such references in recent years also suggests that CIMs are gaining recognition and adoption among urban designers and planners.

The *Digital* Twin of Zurich is a spatial, digital representation of a city 3D model, addressing complex spatial themes [90]. It is designed to simplify digitising space and performing further processing through creating a spatial data infrastructure with 3D spatial data and their models. The focus is on 3D spatial data, and it becomes the reference to link spatial and other data. It inter-connects the data and thus the digital space increasingly approaches the real world. Opening the 3D spatial data to public use can

promote dissemination and create new applications. However, the access to the data must be made simple and attractive. Generating more and better inter-connected 3D data and better interconnection of the BIM and GIS world is needed in design of urban 3D models.

The Herrenberg Digital Twin is a vCIM composed of various urban data from various models, analyses, and simulations, and social data gathered from citizens. The platform also allows citizens to explore visualisations in the vCIM to ensure public participation in democratic city governance. According to [81], the use of VR enhances discussion in Herrenberg's vCIM and builds consensus among stakeholders in co-creation and decision-making. Despite these strengths, the vCIM faces a number of challenges, including providing easy-to-understand workflows for citizens to better experience and digest the complexities of the current city systems. This creates uncertainty when making inclusive design, co-creation, or local policy decision strategies with non-specialists, for example, community members, citizens, and other stakeholders. Considering post-human communications in future vCIMs will ensure that inclusive and user-centred policy decision-making strategies can also meet their objectives in the pursuit of urban digital twinning.

The Rotterdam Digital Twin simulates a 3D city in order to illustrate the importance of 3D urban models for the development of digital twin municipalities in the future. The system enables a comprehensive CIM platform to help manage rapid urban development. It also allows to bring together different sources of information which are then displayed and analysed at different levels of space, for example, the inside and outside of buildings as well as above and below ground. According to RotterdamDigital (2023), the Rotterdam Digital Twin system is still in the early stages of adoption and faces common challenges, such as the level of detail, interoperability, and openness of the platform for future development. In addition, the system needs to be usable and useful for all users. While existing vCIMs incorporate multiple

technological features such as multi-channel HCIs, distributed modelling, simulations, and collaboration tools to interpret “City”, they are still too complex to be understood by at least a portion of stakeholders like non-specialist users such as citizens. Therefore, it appears that urban digital twin ambitions need to pay close attention to the user behaviours of vCIMs in future development. The case is particularly pertinent to ambitions that aim to shape inclusive cities of the future.

Although the utilisation of UDTs has the potential to augment city infrastructure resilience, the implementation of UDTs in participatory and community planning is accompanied by several challenges. Specifically, the current UDTs are deficient in the following areas:

- Incomplete data: Most UDTs rely on data from a variety of sources, and it can be difficult to ensure that all relevant data is included. This can lead to incomplete or inaccurate representations of the city.
- Lack of interoperability: Different UDTs may use different data formats and standards, making it difficult to exchange data between them or to integrate them into a larger system.
- Limited flexibility: There may be limitations in the types of data UDTs can handle or the kinds of analyses they can perform. This can limit their usefulness for certain types of planning or decision-making such as participatory and co-creation initiatives.
- Complexity for participatory urban planning and community design: UDTs can be complex systems, and it may be difficult for users (especially non-specialist users like citizens) to understand how they work or to use them effectively in the community design and planning approaches.

In order to address the challenges facing UDTs and realise their full potential as tools for planning and decision-making in the built environment, considering the development of a user-centred CIM is necessary. This may involve improving data management practices, developing standardised data protocols and formats, and investing in training and resources to improve the technical skills and knowledge of users. It may also involve designing and implementing more user-friendly and intuitive interfaces and tools and seeking input and feedback from users to identify and address any usability issues. Ultimately, addressing these challenges will require a concerted effort from a variety of stakeholders, including city planners, data scientists, technologists, and policy-makers, working together to develop and implement effective solutions.

In this research, we aim to develop a vCIM for urban optimal design and policy decision-making and investigate its usability from the perspective of (non-expert) users. Our vCIM offers a novel approach to decision-making, enabling stakeholders to assess and evaluate design scenarios in a simulated environment prior to reaching a final decision. This approach has the potential to enhance the community design process by providing a platform for stakeholders to engage in the early stages of policy development and observe the potential outcomes of their actions in a realistic setting. While it should not be viewed as a replacement for other community planning approaches, such as placemaking, the vCIM may prove to be a useful tool for collecting credible feedback and informing the community design and management processes.

Ultimately, in this vCIM exercise, we seek to highlight the socio-behavioural and user-centred aspects of urban digital twin ambition, recognising that this field is still in its infancy. While we acknowledge that there may be challenges and setbacks, we believe that through a process of trial and error, we can continually improve and advance our understanding in behavioural aspects of vCIMs. Our ultimate goal is to demonstrate that with sufficient practice,

even the most daunting challenges can be overcome. *Figure 8* presents the components of our user-centred vCIM model and their relationships, which will be further explained in detail in 3.3.

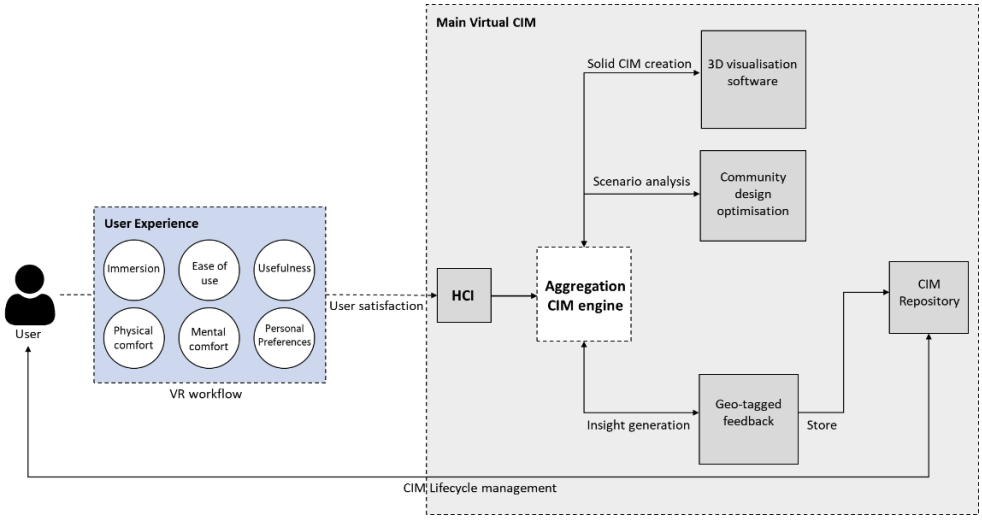


Figure 8. User-centred vCIM model components and their relations. The dashed line signifies that this framework is open to further exploration and integration of additional elements.

3.3 Method

This socio-technical research combines a case study approach and mixed-methods prototyping Tashakkori & Creswell (2007) to create a vCIM and investigate the immersive behaviours of the CIM from the perspective of (non-expert) users in a real-life community design case study, the Blue Zone Malvalaan [115].

3.3.1 Case study context

The placemaking case study is an urban neighbourhood, called Malvalaan, located in the Brabant municipality of Waalre, south of Eindhoven, in the Netherlands. With an area of 19,703 square meters, Malvalaan is situated in the village of Aalst, specifically in the Voldijn district, which is bordered by a highway to the north, an N-road to the east, and agricultural and forest areas to

the west (*Figure 9*). The Voldijn district was primarily developed between 1970 and 1980, and it consists of a variety of housing types, including detached houses, semi-detached houses, terraced houses, and four blocks on the Malvalaan. The district is home to several businesses and shops on Burgemeester Mollaan, a road that leads to the Voldijn district and includes two roundabouts, which may serve as barriers to the neighbourhood due to high traffic speeds. The centre of Aalst, with its amenities and shops, is within cycling distance of the Malvalaan neighbourhood (1.6 km).

Figure 9. Location of Malvalaan in relation to Waalre, Aalst, and Voldijn, source: OpenStreetMap.

The Malvalaan neighbourhood consists of four five-story blocks separated by grass and trees (*Figure 10*). These blocks, which are outdated and primarily used for residential purposes, are owned by Wooninc, a housing association, with the exception of the westernmost block, which formerly served as the home of the Oktober care institution. Despite the presence of greenery, the outdoor spaces in the neighbourhood are primarily used for decorative purposes, rather than as functional areas. From an aerial

view, the neighbourhood appears green, with a large portion of the west side covered in lush shrubbery and fields that are primarily agricultural in nature.

Figure 10. Aerial and street views of Malvalaan, retrieved and taken in January 2022.

3.3.2 Virtual CIM prototype development

Malvalaan's VCIM model is a prototype developed using a mixed-media approach [115] and grounded in a methodological framework outlined in [85] for the creation of urban digital twins. Comprised of six layers of information, the model offers a virtual and interactive representation of Malvalaan that allows stakeholders to examine the various components and systems comprising the neighbourhood, evaluate potential design scenarios, understand the environmental impacts of these scenarios, and provide geo-tagging feedback for further optimisation. *Figure 11* presents the conceptual design of Malvalaan's VCIM, with the following description detailing its construction:

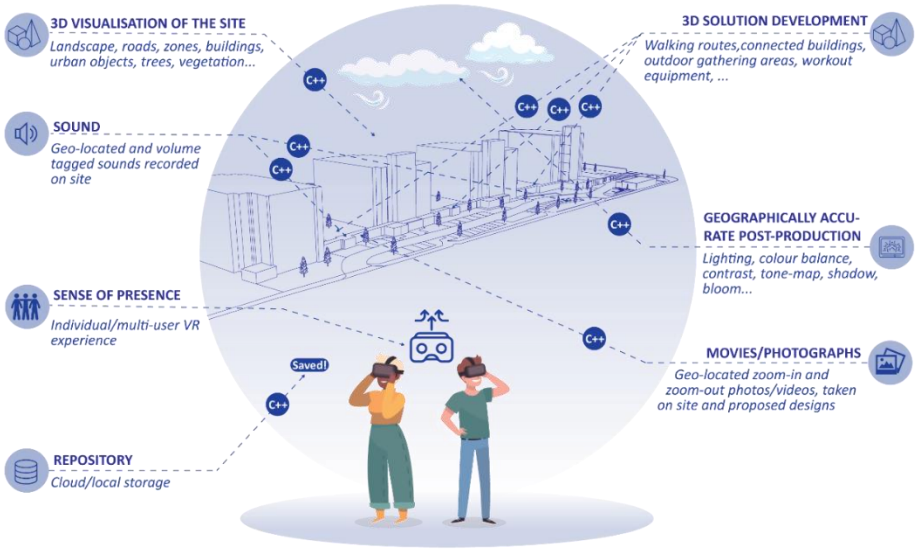


Figure 11. The vCIM conceptual framework for Blue Zone Malvalaan optimisation.

1) **Computation – game engine**: The prototype of Malvalaan's vCIM was implemented using Unreal Engine 5 (UE4.6). The decision to utilise Unreal Engine was due to its comprehensive set of tools for creating 3D environments, including the ability to import and use 3D models from various sources. In addition, the engine boasts advanced rendering and lighting capabilities, enabling the creation of highly realistic and visually appealing urban environments, buildings, roads, and other infrastructure.
2) **Creation – 3D CIM of Malvalaan (LOD 300)**: The 3D geo blueprint of the Malvalaan CIM was generated through aerial LiDAR scanning using the 3DNL dataset, a photorealistic 3D model of Dutch cities. The blueprint includes the neighbourhood's infrastructure, such as roads, waste containers, GSM zones, parking signs, parking lots, public lighting, sofas, pavement, gutters, and green spaces like trees and flower bulbs (Figure 13). Autodesk Revit and

SketchUp were also used to create 3D content, including façades and building corridors, that was of insufficient quality for pedestrian viewing in the 3DNL dataset due to anomalous elevations sometimes occurring during LiDAR scanning.

Since the Malvalaan vCIM utilises various file formats (3D point cloud files in glTF format from 3DNL, 3D models in SKP format from Sketchup, and 3D models in STL format from Revit), data integration required an interoperability pathway. We defined this in Blender, as this software has a wide range of import and export options, allowing us to bring files from other programmes into Blender and then save them in a format that can be used in other applications. This makes it easy to integrate Blender into an open workflow that involves using multiple different software programmes. Additionally, Blender is able to read and write many different file formats, including SKP, STL, FBX, and glTF. This means that it can handle our files from a wide range of sources, making it a versatile tool for integrating different file formats. Our interoperability path in Blender consists of two stages (Figure 12). In the first stage, we used the STL, SKP, and glTF file formats to create our solid models and then imported them into Blender, where we exported them as FBX files for the Unreal engine to read. During the second stage, we should address two significant issues: the UV mapping of the STL model and the STL file format itself. These issues only arise if we do not edit STL models in Blender. Essentially, UV mapping defines how and at what scale the texture of the material should be applied to the model. While it is possible to create a UV map from scratch, this process is time-consuming. To address this, we used the DATASMITH plugin, a python-based plugin developed by Unreal Engine that can eliminate the need for fixing UV maps and can create high-fidelity visuals and lighting from

STL file format models in Unreal Engine. One of the additional benefits of DATASMITH is that it maintains the dimensions in scale, ensuring that, for example, a one-meter cube in Revit is the same size in the virtual environment. This allows the whole experience to be designed to the scale of a real building.

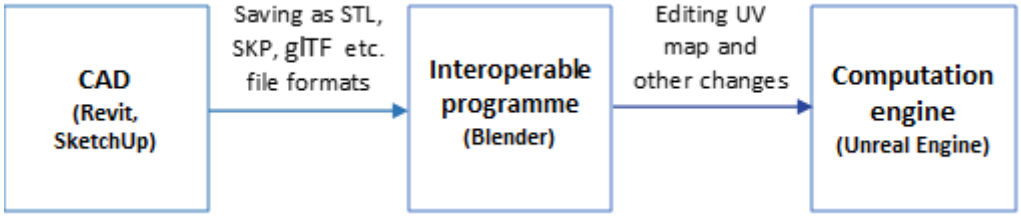


Figure 12. Scheme of software user for CIM creation in particular order.

Figure 13. illustrates the solid CIM of Malvalaan in Unreal Engine.

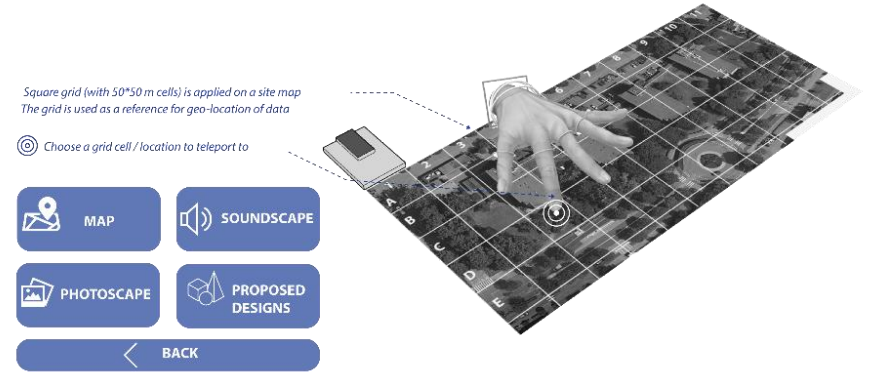
Figure 13. Malvalaan 3D CIM.

3) **Communication-HCI:** we implemented the user communication workflow through the SteamVR software

development kit (SDK) using the Vive Pro head-mounted display (HMD) with 6 degrees of freedom (DOF) system.

Virtual reality (VR) HCI was selected for its potential to elicit emotional responses from users due to the immersive and present nature of VR environments. To enhance this sense of presence, we designed a user interface with two navigation modes: room-scale walking using a teleport-locomotion system (Figure 14a) and standing mode using a square-grid system as the main menu (Figure 14b). The main menu offers five functions, accessible through clickable buttons on a virtual platform that can be activated using the right index finger. These functions include the ability to relocate to different grids, access proposed design scenarios, visualise the location of sounds on the site, view a collection of photographs, and return to the main menu.

(a) Teleport-locomotion Style



(b) Menu Style

Figure 14. UX styles: functionality/logi.

To enhance LOD and the spatial information conveyed in our vCIM model, we incorporated various environmental sounds, visual effects, and accurate geographical conditions (*Figure 15*). To achieve this, we used complex equations to accurately place the Sun in the software engine based on factors including latitude,

longitude, cardinal points, date, and time of day. These equations replicate the mathematical calculations used to determine the real-life position of the Sun in the sky. The vCIM environment is set to match the real-time of the experiment, which took place on August 21, 2021, at a latitude of 51.4012358N and longitude of 5.4711522E and November 15, 2022. This attention to detail helps to create a more realistic and immersive experience for users interacting with the model.

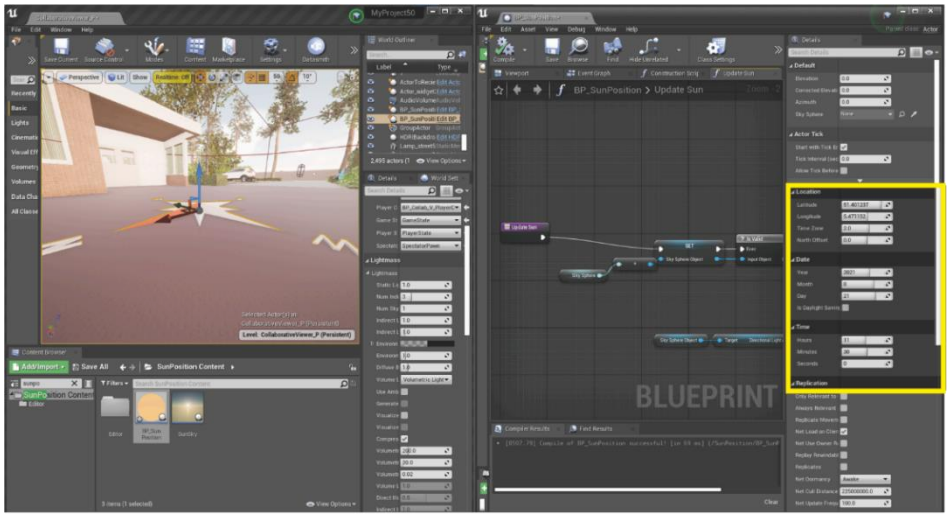


Figure 15. Defining the geographical condition of Malvalaan in UE4.6

4) **Analyse:** The purpose of the analysis in the Malvalaan vCIM is to evaluate the feasibility of the Blue Zone design optimisation framework. Eight scenarios were developed using SketchUp and are based on specific locations (Figure 16). To test their feasibility and allow prospective inhabitants to explore the impact of the design changes, we prototyped the design scenarios as interactive before-and-after content using C++ classes based on the blueprint system in Unreal Engine, as shown in Figure 17. This process allowed us to assess the feasibility of the designs and provide users with an

interactive way to explore the potential effects of these design modifications.

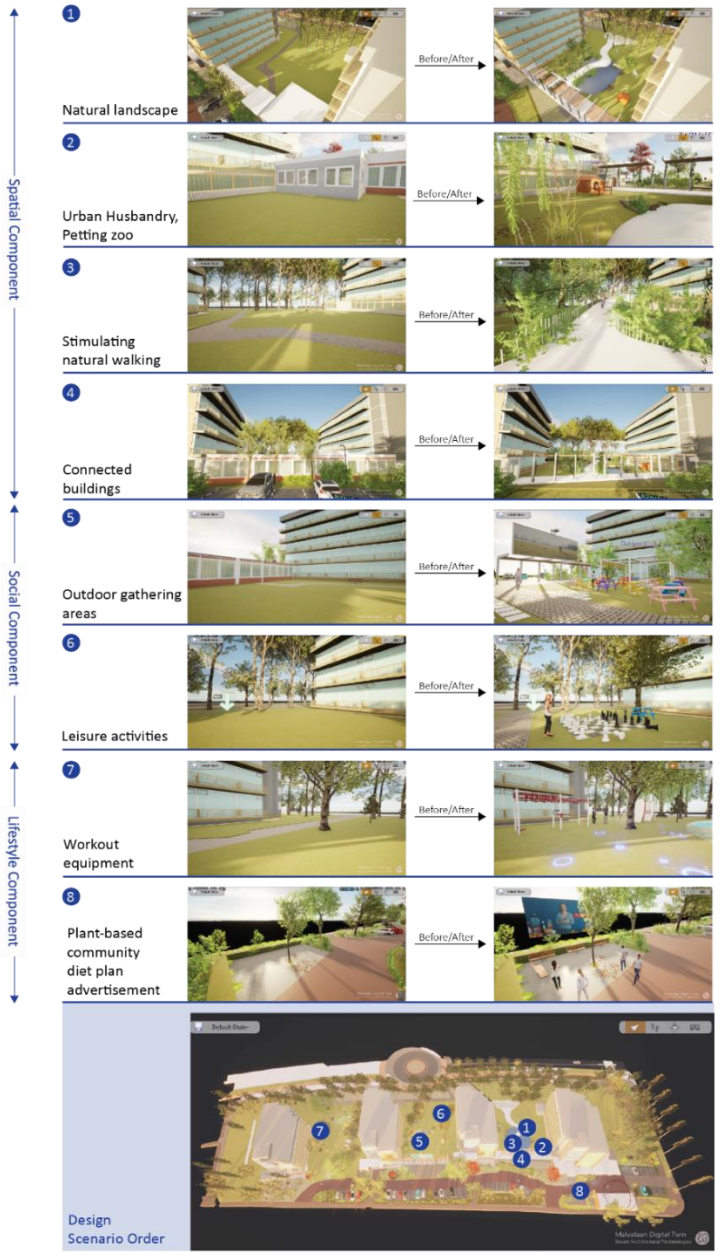


Figure 16. The before/after design concepts for Malvalaan.

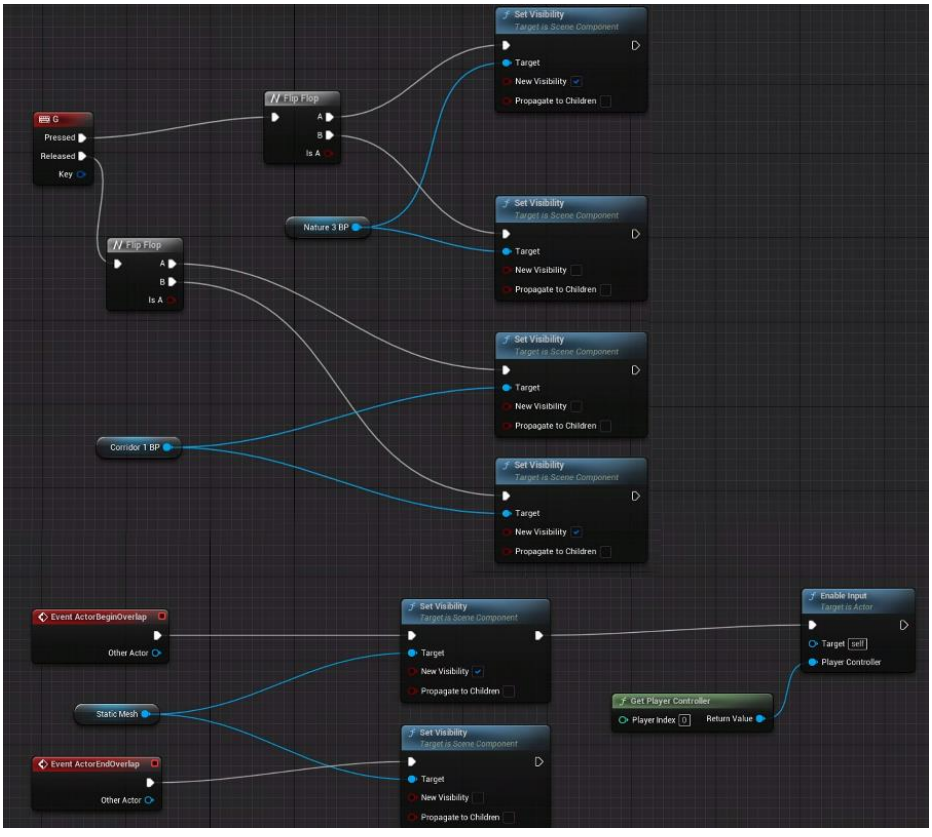


Figure 17. Before/after scenario blueprint prototype in Unreal engine.

5) **Insights:** The analytic insights from the vCIM model of Malvalaan were visualised as geo-tagged user feedback content, which was designed to collect comments from inhabitants regarding the design scenarios. We used a simplified feedback analysis Newell et al., (2018) to create a structured database of the source of the feedback, the actual feedback, and one or more content tags, which are typically the most prominent words mentioned in the feedback [116]. This geo-tagged feedback system was later used to provide a user-centred design guideline for the optimisation process in Malvalaan. The feedbacks were stored in the repository of the vCIM for future reference (Figure 18).

Figure 18. Geo-tagged feedback structure.

6) **Store— lifecycle management:** To support lifecycle management in the vCIM model of Malvalaan, we created a local hosting server to store and clone the design scenarios and geotagged quotes as needed. The storing system creates a lifecycle for Malvalaan. This system can virtually represent how Malvalaan is today, how it has been designed, and may be operated and maintained in the future.
Experimentation and evaluation

Malvalaan's vCIM was designed to be scientifically rigorous and to elicit feedback from the user community on its immersive capabilities. To evaluate these factors, a two-phased user experience (UX) testing process was implemented in the Digital Twin laboratory at TU Eindhoven (Figure 19). The study was supervised by experienced experimenters who provided instructions to participants.

The first phase of the testing process involved administering a questionnaire to assess ease-of-use, usability, immersion, physical and mental comfort, and overall satisfaction among participants with practical experience in immersive technologies (Table 7). The sample included 25 postgraduate students from TU Eindhoven, comprising 13 males and 12 females aged 21 to 33 (mean age = 26.83).

Table 7. User experience (UX) questionnaire

	Extremely disagree 1	2	3	4	Extremely agree 5
Q1 It was easy to use					
Q2 It was useful					
Q3 It was physically challenging					
Q4 It was mentally challenging					
Q5 The prototype content was attractive					
Q6 I was satisfied to experience the VTP model					

Ease-of-use was evaluated based on the ability of users to effectively use the HCI VR and navigate and make decisions within the virtual environment. Usability was assessed through evaluating the ability of users to interact with various elements of the CIM and provide geo-tagged feedback on design scenarios. Immersion was evaluated through testing the sense of presence and level of engagement with the vCIM. Physical comfort was assessed through observing for factors such as visual fatigue, disorientation, dizziness, and headaches. Mental comfort was assessed through observing prolonged use, physical barriers, and ergonomic issues.

The questionnaire included Likert-scale questions to gather a comprehensive understanding of the immersive behaviours of users within the vCIM in the first phase of assessment. Statistical analysis was conducted in SPSS using measures of mean and standard deviation to analyse the variability among users in their understanding and perception of the CIM (Field 2013).

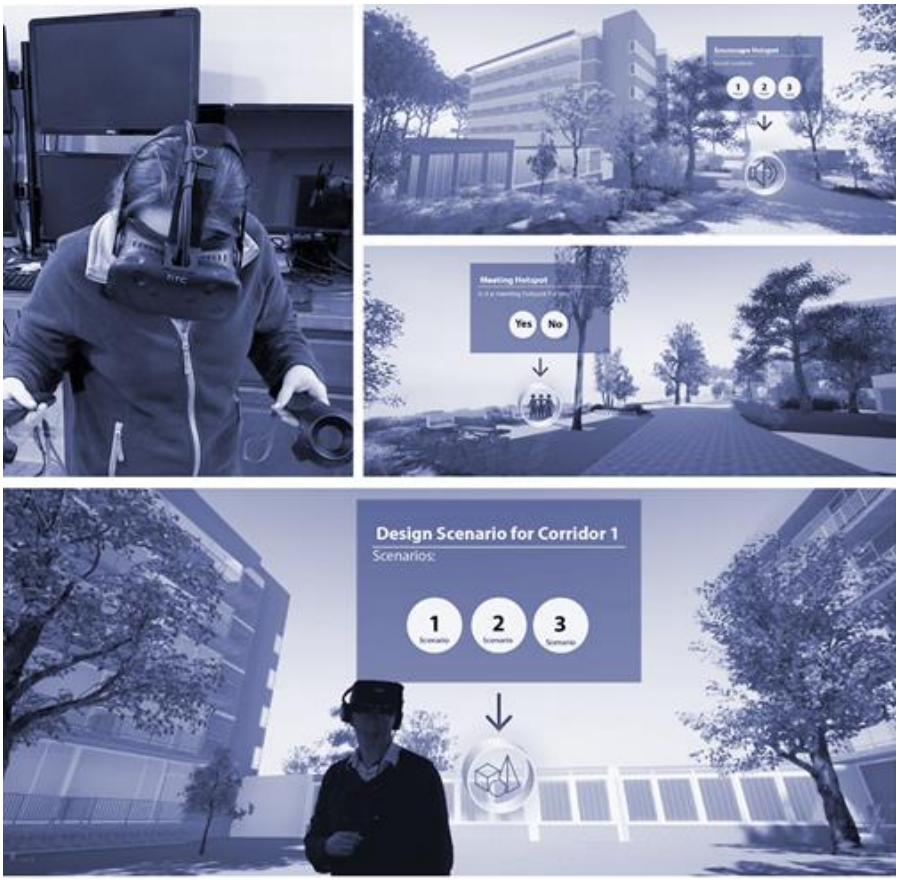


Figure 19. Malvalaan vCIM user experience study: pilot experiment phase I.

The second phase of the testing and evaluation process (November 15 to 18, 2022) involved collecting feedback from a more diverse group of users (Figure 20). A total of 25 senior inhabitants of Malvalaan were recruited for this phase, comprising 13 males and 12 females ranging in age from 42 to 65 (mean age of 55.24). These participants represented a wide range of education levels and had varying levels of experience with immersive technologies. All participants were active senior citizens without prior physical or mental issues, with the exception of one participant who had mobility issues.

Like the first phase, the participants in this phase were asked to test the navigation systems and provide feedback on the prototype using the same set of questions and Likert scale as before. However, in this phase, the tasks were modified to be more challenging and time-consuming, and data was also collected on the feedback and preferences of the inhabitants of the Malvalaan neighbourhood regarding optimal design scenarios. The experiment took approximately 25 minutes for each participant to complete.

It has been noted that previous experience with immersive technology is linked to the usability of the technology [117]. In addition, age and age-related issues, such as changes in vision and hearing, physical limitations, and cognitive impairments, such as memory problems or difficulty processing information, may also influence an individual's ability to adapt to an immersive experience [15], [111], [118], [119]. Further, there is some evidence to suggest that gender may be a factor in the usability of VR workflow [120], and it is important to consider the potential influence of gender (as well as other factors) when evaluating the immersive behaviours of vCIMs.

Figure 20. Malvalaan vCIM user experience study: pilot experiment phase II.

The data collected from both phases of the testing and evaluation process were analysed using a two-way multivariate analysis of variance (two-way MANOVA) in SPSS. This statistical method, which often considered as an extension of the two-way ANOVA is used to determine whether there is a significant difference between the means of two groups, and it involves partitioning the total variance in the data into different components based on the various factors being analysed [121]. In this case, the factors were the phase of testing (Phase I vs. Phase II) and the level of experience with immersive technologies (experienced (postgraduate students)

vs. mixed-experienced (senior citizens)), and gender (male vs female). The results of the MANOVA were used to identify any significant differences between the groups and to guide the refinement of the vCIM based on user feedback. The formula for a two-way MANOVA is

F = (MSB - MSW) / MSW

Where:

F is the F-statistic, which is used to test the null hypothesis that the means of the groups are equal.

MSB is the mean square between groups, which is a measure of the variation between the group means.

MSW is the mean square within groups, which is a measure of the variation within the groups.

The two-way ANOVA tests the null hypothesis that the means of the groups are equal, and the alternative hypothesis is that the means are not equal. If the p-value is less than the significance level (usually 0.05), then the null hypothesis is rejected, and it can be concluded that there are significant differences between the means of the groups.

3.4 User Experience questionnaire test results

A detailed analysis of the questionnaire data shows that, overall, the Malvalaan vCIM succeeded in actualizing a user-friendly community design exercise aimed for; exploring the optimal design scenarios, analysing, and providing geo-tagged feedback. Table 8 includes the mean and standard deviation for six measures of the vCIM user experience test, including ease of use, usefulness, immersion, physical and mental challenge, and overall satisfaction with the experience.

Table 8. A summary of Malvalaan vCIM immersive behaviour questionnaire results.

	Descriptive Statistics					
Dimension	Statement	Experience Level	Gender	Mean	Std. Deviation	N
Ease of use	It was easy to use	Experienced (postgraduate students)	Male	4.23	.599	13
			Female	4.08	.669	12
			Total	4.16	.624	25
		Mixed-experienced (senior citizens)	Male	3.69	.630	13
			Female	3.00	.426	12
			Total	3.36	.638	25
usefulness	It was useful	Experienced (postgraduate students)	Male	4.38	.506	13
			Female	4.50	.522	12
			Total	4.44	.507	25
		Mixed-experienced (senior citizens)	Male	4.46	.519	13
			Female	4.58	.515	12
			Total	4.52	.510	25
immersion	It was immersive	Experienced (postgraduate students)	Male	4.15	.689	13
			Female	3.92	.669	12
			Total	4.04	.676	25
		Mixed-experienced (senior citizens)	Male	3.92	.494	13
			Female	3.67	.651	12
			Total	3.80	.577	25
Physical comfort	It was physically challenging	Experienced (postgraduate students)	Male	1.38	.506	13
			Female	1.67	.492	12
			Total	1.52	.510	25
		Mixed-experienced (senior citizens)	Male	1.69	.480	13
			Female	1.83	.389	12
			Total	1.76	.436	25
Mental comfort	It was mentally challenging	Experienced (postgraduate students)	Male	1.77	.725	13
			Female	1.83	.718	12
			Total	1.80	.707	25
		Mixed-experienced (senior citizens)	Male	3.00	.577	13
			Female	3.00	.603	12
			Total	3.00	.577	25

	Descriptive Statistics					
Dimension	Statement	Experience Level	Gender	Mean	Std. Deviation	N
satisfaction	I was satisfied with my experience of the vCIM	Experienced (postgraduate students)	Male	4.54	.519	13
			Female	4.33	.651	12
			Total	4.44	.583	25
		Mixed-experienced (senior citizens)	Male	4.38	.650	13
			Female	4.00	.853	12
			Total	4.20	.764	25

Note: Users were asked to indicate to what degree (1-5 Likert scale) they agree with the statements. Mean and standard deviation were the mathematical observations used in this assessment. Together, they show the extent of variability among users in perceiving and usability of the underlying components of the vCIM.

1) **Ease of use:** The vCIM was rated as being relatively easy to use by all groups, with mean ratings ranging from 4.08 to 4.23 out of 5. The experienced postgraduate students rated the vCIM as being slightly easier to use than the mixed-experienced senior citizens, with a mean rating of 4.16 compared to 3.36. There were also some differences in the mean ratings between males and females within each group, although these differences were generally small. For example, experienced postgraduate males rated the vCIM as being slightly easier to use than experienced postgraduate females, with a mean rating of 4.23 compared to 4.08.
2) **Usefulness:** The vCIM was rated as being useful by all groups, with mean ratings ranging from 4.44 to 4.50 out of 5. There were no significant differences in the mean ratings between the different groups. This suggests that the vCIM was perceived as being useful by all groups, regardless of experience level or gender.
3) **Immersion:** The vCIM was rated as being relatively immersive by all groups, with mean ratings ranging from 3.92 to 4.15 out of 5. The experienced postgraduate students rated the vCIM as being slightly more immersive than the mixed-experienced senior citizens, with a mean rating of

4.04 compared to 3.80. There were also some differences in the mean ratings between males and females within each group, although these differences were generally small. For example, experienced postgraduate females rated the vCIM as being slightly less immersive than experienced postgraduate males, with a mean rating of 3.92 compared to 4.15.

4) **Physical comfort:** The vCIM was rated as being less physically challenging by all groups, with mean ratings ranging from 1.52 to 1.83 out of 5. The mixed-experienced senior citizens rated the vCIM as being more physically challenging than the experienced postgraduate students, with a mean rating of 1.76 compared to 1.52. This suggests that the mixed-experienced senior citizens may have found the vCIM to be more physically demanding than the experienced postgraduate students. There were also some differences in the mean ratings between males and females within each group, although these differences were generally small. For example, mixed-experienced senior citizen females rated the vCIM as being slightly more physically challenging than mixed-experienced senior citizen males, with a mean rating of 1.83 compared to 1.69.
5) **Mental comfort:** The mixed-experienced senior citizens rated the vCIM as being more mentally challenging than the experienced postgraduate students, with a mean rating of 3.00 compared to 1.80. There were also some differences in the mean ratings between males and females within each group, although these differences were generally small. For example, experienced postgraduate females rated the vCIM as being slightly more mentally challenging than experienced postgraduate males, with a mean rating of 1.83 compared to 1.77.
6) **Overall satisfaction:** The vCIM was generally well-received by all groups, with mean satisfaction ratings ranging

from 4.17 to 4.54 out of 5 for females, and from 4.46 to 4.54 out of 5 for males. The experienced postgraduate students and the mixed-experienced senior citizens had similar mean satisfaction ratings of 4.44 and 4.20, respectively. The overall sample had a mean rating of 4.32 out of 5.

3.4.1 Two-way MANOVA analysis results

The results of the two-way MANOVA tests reveal two statistically significant effects on the ease of use and mental comfort of the vCIM between the experienced and mixed-experienced groups (Table 9).

Table 9. MANOVA tests of Between-Subjects Effects.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	It was easy to use	11.126	3	3.709	10.667	.000
	It was useful	.256	3	.085	.321	.810
	It was immersive	1.481	3	.494	1.248	.303
	It was physically challenging	1.341	3	.447	2.019	.124
	It was mentally challenging	18.026	3	6.009	13.837	.000
	I was satisfied with my experience of the vCIM	1.906	3	.635	1.393	.257

Note: In this table, the sources of variance are the factors included in the analysis, and the dependent variables are the user experience components that were measured in the study. The F-value for each source of variance is calculated by dividing the mean square by the error mean square, and the significance level indicates the probability that the observed difference between the means is due to chance.

The independent variables were found to have a statistically significant effect on the dependent variable "It was easy to use" ($F(3, N) = 10.667$, $p < .001$), with a mean square of 3.709, indicating significant differences in the ease of use among the compared groups. Similarly, the independent variables were found to have a statistically significant effect on the dependent variable "It was mentally challenging" ($F(3, N) = 13.837$, $p < .001$), with a mean square of 6.009, indicating significant differences in the mental challenge experienced by the compared groups.

Contrarily, the independent variables did not exhibit statistically significant effects on the dependent variables "It was useful" ($F(3, N) = .321$, $p = .810$), "It was immersive" ($F(3, N) = 1.248$, $p = .303$), "It was physically challenging" ($F(3, N) = 2.019$, $p = .124$), or "I was satisfied with my experience of the vCIM" ($F(3, N) = 1.393$, $p = .257$). The mean squares for these dependent variables were .085, .494, .447, and .635, respectively, suggesting that there were no significant differences among the compared groups in terms of usefulness, immersion, physical challenge, or satisfaction with the vCIM.

Overall, the results suggest that:

- The vCIM was well-received by both postgraduate students and senior citizens, with both groups reporting high levels of satisfaction with the experience.
- Postgraduate students had slightly higher means and lower standard deviations for all measures compared to senior citizens, indicating that they had a more positive experience, on average, and with less variability in ratings.
- There were slight differences by gender, with males having slightly higher means and standard deviations compared to females.
- The experienced postgraduate students significantly rated the vCIM as being slightly easier to use than the mixed-experienced senior citizens.
- The mixed-experienced senior citizens rated the vCIM as being more physically and mentally challenging than the experienced postgraduate students. However, these differences were relatively small and may not be statistically significant.

3.5 Discussion

3.5.1 A user centred CIM as a base for inclusive UDT ambition

Results of the vCIM user experience test evaluation suggest that a user centred CIM can attract the community design and participatory decision-making initiatives with high potential. This model would allow for a more holistic and comprehensive understanding of the city, taking into account the needs and perspectives of all members of the community. This can help to ensure that the urban models accurately reflects the reality of the city and can be used effectively by city officials, businesses, and citizens.

Thinking beyond the specific field, a user cantered vCIM has the potential to create a UDT that can be used to improve the lives of all citizens and make the city more livable and sustainable. This can involve using the UDT to identify and address socio-behavioural factors that contribute to environmental issues, such as littering and overconsumption, as well as optimising resource allocation and management, such as by predicting and mitigating traffic congestion or predicting and addressing maintenance needs for infrastructure. The adaptability of our vCIM's conceptual and methodological structures allows for its application to a variety of urban development contexts and geographical settings. Through the modification of objectives and design scenarios, as well as the adjustment of constraints to fit the spatial characteristics of the study area, the CIM can be effectively customised to address a range of urban development issues. Furthermore, the CIM's primary goal of promoting inclusivity enables the formulation of strategic measures that prioritise the active engagement of end-users. Overall, the vCIM represents a valuable resource for addressing complex urban optimisation challenges in a user-cantered and inclusive manner.

3.5.2 Further development for a user-centred CIM

The results of the vCIM user experience test identified areas for improvement that can guide further development. We have been grouped them into four categories to support the development of CIMs for community design and inclusive decision-making practices:

1) **Having "the right" HCI workflow:** Our research found that having an effective workflow is essential for a successful vCIM that encourages active user participation. We used VR workflow in our study and both young and senior users reported that it was usable and provided a satisfactory experience for participatory decision-making. However, there were some issues worth mentioning. Young users generally had a more positive experience with less variability in ratings, and the perceived ease of use was a significant issue for senior users. Senior users were less familiar with immersive technology and needed more time to learn how to use VR equipment and navigate VR environments. Additionally, the VR workflow was significantly mentally challenging for senior users compared to younger users, and older participants experienced more motion sickness symptoms such as, dizziness and nausea. It's worth considering that there are other spatial displays such as 3D screens, AR, and MR that could be used for user-cantered vCIM decision-making systems, rather than solely relying on VR workflow.
2) **User's social profile to behave in the right manner:** The characteristics of the end-user, such as their previous experience with technology, gender, and age, can affect the effectiveness of a vCIM for a participatory decision-making. Our research found

that the students with prior expertise in immersive technology had slightly higher scores and lower standard deviations for all measures compared to local inhabitant with mixed-experience level. This finding is consistent with previous studies that have shown that prior experience with technology can impact the overall satisfaction of users in virtual decision-making systems [117], [119], [122]. In contrast to Sanchez-Sepulveda et al. (2019), who found that gender did not have an effect, we observed slight differences by gender, with males tending to report a higher level of immersion in the vCIM compared to females. However, it is important to note that the differences we observed were relatively small and may be due to individual differences rather than gender differences [120]. We acknowledge that age can also influence the vCIM experience [119], [123]. In our experiment, we provided additional training and support to ensure that senior users were comfortable using VR. Despite the extra time needed for this training, the senior users were able to adopt and interact with the vCIM very quickly. This was a pleasant surprise, as it shows that the digital divide may be shrinking in practice.

3) **The LOD of the vCIM matters:** The LOD in a vCIM has an impact on its user-friendliness. We found that our vCIM with LOD 300 was more engaging for expert users, but it was overwhelming or confusing for non-expert users. To the best of our knowledge, this issue has not been studied in previous research. However, our findings suggest that designers of vCIMs should carefully consider the impact of LoD on usability and explore options for

providing adaptable levels of detail or interaction to cater to the diverse needs and preferences of users.

4) **The availability and quality of training and support materials** is also important. Providing clear and concise documentation, tutorials, and other resources can help users to quickly learn how to use the vCIM and make the most of its capabilities. It may also be helpful to offer opportunities for hands-on training or support from experts to assist users in getting started and overcoming any challenges they may encounter.

3.6 Conclusion and perspective

The concept of "community design" has evolved with the advancement of technology. In recent years, the development of CIMs and the proliferation of communication technologies have transformed the way society operates and has led to the modernisation of traditional methods of collaboration. VCIMs demonstrate how a virtually rich city model with an intuitive and user-friendly workflow can address the issue of disjointed design and policy decision-making. However, creating a vCIM that effectively aligns the diverse interests and capabilities of (non-expert) users like local inhabitants for active participation can be challenging.

In this socio-technical study, we sought to create a vCIM and investigate the immersive behaviours of vCIMs from the perspective of (non-expert) users. Our vCIM platform facilitated optimal design and policy decision-making within a virtually replicated environment of a real-life urban neighbourhood environment, enabling local inhabitants to engage with place-based 3D design scenarios while providing geo-tagged feedback cantered on their own experiences. Through this approach, we aimed to gain insights into the outcomes of participatory decision-making and generate

more accurate and feasible design guidelines for future optimisation plans. In addition, by investigating the immersive behaviours of the vCIM, we aimed to gain further insights into the socio-behavioural aspects of CIMs that can be leveraged for user-cantered and co-creation urban digital twin development and integrative decision-making systems.

The process of vCIM development involved conceptualizing design optimisation, formulating a mixed-media methodology that included computation, creating a 3D CIM, establishing HCI communication, analysing what-if design scenarios, gathering geo-tagged insights, and storing data. User experience tests were conducted with both specialist and non-specialist groups, and statistical evaluation was performed. All stages were carried out in cooperation with dedicated, experienced experimenters, and for the testing stage, with local inhabitants of the case study stakeholder group. The vCIM developed in this research represents the first phase of a larger, ongoing research agenda focused on shaping smart and inclusive neighbourhoods for healthy ageing. It is expected that this model will be utilised in training settings and to inform the design and development of CIMs and other urban digital twin systems that are better tailored to the needs and preferences of their users, and that enable more effective and efficient collaboration and decision-making.

Four key findings are found:

- Having "the right" workflow is an important part of the puzzle for the usability of vCIM in the context of participatory optimisation and decision-making.
- Considering the user profile is also crucial for the success of vCIMs. Cultural and demographic factors, such as age, gender, and prior experience with immersive technologies, can impact the user-friendliness of these systems.

- The level of detail and complexity of a vCIM can impact its user-friendliness.
- The availability and quality of training and support materials is also important. Providing clear and concise documentation, tutorials, and other resources can help users quickly learn how to use the vCIM and make the most of its capabilities.

These lessons were learned from direct feedback from both expert and non-expert users of the vCIM comprising senior experimenters, academics, and non-academic users regarding immersive behaviours of model with vCIM developing iteration. These lessons could provide useful information for relevant modelling, and user-centred vCIM decision-making systems for community design and inclusive decision-making.

Future research could try to add to this debate by discussing the psychological and behavioural factors that influence how individuals interact with and use these systems. This could allow for a more holistic and comprehensive understanding of the city, taking into account the needs and perspectives of all members of the community. This can help to ensure that the UDTs accurately reflect the reality of the city and can be used effectively by city officials, businesses, and citizens. Ultimately, a better understanding of the psychological and behavioural aspects of CIMs could inform the development of UDTs that can be used to improve the lives of all citizens and make the city more livable and sustainable.

Chapter 4 Redefining age-friendly neighbourhoods: translating the promises of Blue Zones for contemporary urban environments

Redefining age-friendly neighbourhoods:

translating the promises of Blue Zones for contemporary urban environments

This chapter has been published as follows:

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For consistency of the dissertation some typos are adjusted and phrases are reworded without changing the content

ABSTRACT

The longevity and healthy ageing observed in Blue Zones offer valuable insights for contemporary urban neighbourhood planning and design. This paper reviews the age-friendly features of the built environment in Blue Zones, aiming to translate these insights into actionable strategies for urban neighbourhood development. Employing a systematic literature review and Convolutional Neural Networks (CNNs) analysis of Google Street View imagery, this study assesses the built environments in Blue Zones, including housing, public spaces, and transportation systems. Key findings highlight the presence of adaptable housing, building designs that foster a connection with nature, and semi-public spaces that encourage social interaction and physical activity.

A notable emphasis on walkability and limited public transport access was observed. The CNN analysis corroborated these findings, providing a quantitative view of age-friendly features. This research contributes to the academic discourse in urban planning and design by providing practical insights for developing age-friendly neighbourhoods, inspired by Blue Zones. It concludes by offering policy advice and future research directions for creating sustainable and inclusive urban environments conducive to ageing populations.

4.1 Introduction

The World Health Organisation (WHO) strives to assist and inspire contemporary urban environments to become more 'age-friendly' through the Global Age-Friendly Cities and Neighbourhoods Guide [124]. An age-friendly neighbourhood offers a supportive environment that enables residents to grow older actively within their families and civil society and offers extensive opportunities for their participation in the community [125]. In attempts to make contemporary urban environments more age-friendly, the concept of Blue Zones—regions of the world where people live exceptionally long lives—offers a fascinating lens for urban planners, designers, and neighbourhood policymakers [126], [127]. These zones are renowned for their unique lifestyle and environmental characteristics known to contribute to longevity and healthier ageing. Understanding these characteristics in urban planning and design is critical for shaping sustainable, accessible, and engaging urban environments tailored for ageing populations. As global demographics increasingly shift towards an older age spectrum, the need for adaptable, age-friendly urban environments becomes more pressing [10,11]. Examining Blue Zones allows urban planners and designers to glean valuable lessons on enhancing the quality of life for senior citizens within urban environments. This paper aims to systematically review the age-friendly features of the built environment in Blue Zones, employing a combination of

qualitative and quantitative approaches to provide comprehensive insights and neighbourhood development policy advice.

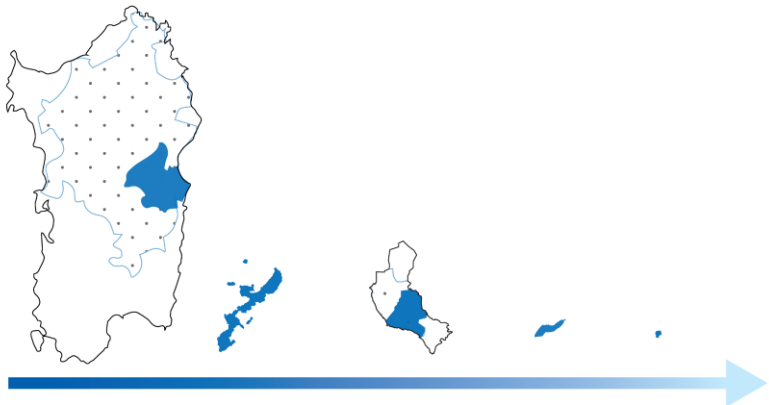
The concept of Blue Zones was introduced to the academic community nearly 20 years ago. Michel Poulain and Giovanni Mario Pes coined the term following their demographic research in the Nuoro province of Sardinia, Italy, where they noted an exceptionally high number of centenarians [28]. This discovery was focused on a cohort of centenarians residing in 14 mountainous villages of Sardinia. Researchers devised the Extreme Longevity Index (ELI), calculated as the centenarian count per 10,000 newborns. Their analysis revealed an average ELI of 508 per 100,000 births, a figure notably two to four times higher than the ELI values observed across the remainder of Sardinia. Expanding on this research, Dan Buettner identified four additional regions with similarly elevated centenarian populations [129]:

- **Okinawa, Japan,** is renowned for having the world's highest life expectancy among women [130], [131], [132]. The Centenarian Rate (CR)—the proportion of those surviving to age 100 per 10,000 individuals alive at 60—for men is markedly higher compared to those observed in other regions, while the rates for women are typically higher than or equal to those found in other regions.
- **The Nicoya Peninsula in Costa Rica** is distinguished by the Vienna Yearbook of Population Research as a longevity hotspot. A survival analysis from 1990 to 2011 of 1630 older adult Costa Ricans revealed a male death rate ratio (DRR) in Nicoya of 0.80 (95% CI: 0.69–0.93). For Nicoyan males aged 60, the probability of reaching centenarian status was sevenfold that of their Japanese counterparts, accompanied by a life expectancy surplus of 2.2 years [133], [134].
- **Ikaria, Greece,** a small island in the Aegean Sea, boasts a significant centenarian population [135], [136], [137].

Cardiologic examinations conducted in Ikaria in 2009 highlighted the anomalously high average age at natural death, which surpasses that of other global regions, including Greece, by nearly a decade, with over 30% of fatalities occurring post-90 years of age.

- Lastly, **Loma Linda in Southern California,** USA, with its large Seventh-Day Adventist community, has a life expectancy nearly a decade longer than the average American [138].

Figure 21 summarises the key demographic and spatial factors of local representatives of Blue Zones.



	Sardinia (Nuoro province)	Okinawa (prefecture)	Nicoya Peninsula	Ikaria/Icaria	Loma Linda
Context	Italy	Japan	Costa Rica (Santa Cruz, Car-rillo, Ni-coya, Nandature, and Ho-jancha)	Greece	United States
Area	Total:24,000km² Extended BZ: 13,053 km² Restricted BZ: 1559 km²	1201 km²	Total: 5696 km² Restricted BZ: 788km²	255 km²	19 km²
Population (year)	36,900 (2017)	1.4 million (2020)	183,184 (2013)	8423 (2011)	25,072 (2021)
Estimating centenarian (prevalence per 100000)	17	50	23	84 in 8423	20

Figure 21. The key demographic and spatial factors of Blue Zone local representatives; source: authors.

While extensive epidemiological research has explored various facets of Blue Zones, such as diet [138], [139], mental health [140], [134], [141], cardiovascular health, longevity, obesity, and physical activity, a notable gap persists in understanding the contribution of urban planning and design to these exceptional health outcomes [126], [127]. This study aims to examine the specific elements of the built environment that potentially underpin the success of Blue Zones. This inquiry holds particular significance for

the field of urban planning and design, especially in the context of neighbourhood planning and policymaking. A primary aim of this research is to develop practical guidelines and policy advice, especially in understanding how the built environment in Blue Zones promotes healthy ageing among its residents.

To achieve this, we will conduct an in-depth review of relevant research and perform a spatial analysis of built environments in Blue Zones to derive comprehensive recommendations and neighbourhood development policy advice.

This review will collate insights from existing research on the built environment characteristics of Blue Zones. Next to this, an in-depth spatial analysis is essential for an empirical examination of the built environment features in Blue Zones. However, the global dispersion of Blue Zones makes traditional methods like field surveys challenging due to the extensive time, cost, and effort involved. Fortunately, recent advancements in AI and deep learning algorithms, particularly Convolutional Neural Networks (CNNs), offer a viable alternative. These technologies allow for the remote, high-level analysis of digital images. In our study, CNN techniques are employed to analyse the built environment features of Blue Zones by using publicly available datasets, such as Google Street View (GSV). This approach provides empirical evidence to supplement our qualitative literature review, enhancing our understanding of the age-friendly built environment features in Blue Zones.

The structure of this paper is as follows: Section 4.2 provides an overview of the variables that contribute to an age-friendly built environment. Understanding these variables is crucial, as it guides our exploration of specific built environment features in the Blue Zone literature review and the CNN analysis. Section 4.3 details our methodology, elaborating on how we structured our systematic literature review and CNN analysis to investigate age-friendly built

environment features in Blue Zones research and the GSV imagery. Section 4.4 presents our findings, culminating in insights for Blue Zone Neighbourhood (BZN) policy advice, aimed at enhancing healthy ageing within contemporary neighbourhood planning and design initiatives. In Section 4.5, we discuss the implications of our findings, reflecting on how they contribute to existing knowledge and suggesting potential implications for future research in urban design and planning. Finally, Section 4.6 concludes the paper, summarising our key findings and the future direction of our research for shaping healthy ageing neighbourhoods within contemporary society.

4.2 Materials: age-friendly built environment variables

The built environment encompasses human-crafted spaces for dwelling, working, and leisure activities. The WHO champions age-friendly built environments as part of its Global Age-Friendly Cities (AFC) initiative [124], [128], [142]. This concept includes three built environment domains: housing and buildings, open/outdoor public spaces, and transport networks.

4.2.1 Age-friendly housing and buildings

Providing adequate housing that enables older adults to age in their home environment while retaining their autonomy and independence is pivotal for promoting an age-friendly built environment [143], [144]. Central to this is the ‘ageing in place’ concept, which allows older individuals to remain in their homes, living independently and comfortably, irrespective of age, income, or abilities [145]. This approach goes beyond staying in the same location; it encompasses adapting to or relocating to more suitable environments as needs evolve. Attachment to place plays a significant role, fostering a sense of identity and independence [146], [147]. Ageing in place might involve staying in the same

home or transitioning to more accessible residences, facilitating independent or assisted living [144].

Housing options for older adults vary depending on their mobility and health needs, ranging from regular houses and apartments to retirement communities for independent living, as well as specialised care homes offering intensive support [148]. This spectrum includes various housing typologies alongside institutional care facilities for highly dependent individuals. Ageing in place can delay or eliminate the need for institutional care [144].

The design of housing with ageing needs in mind is critical to ensure that older adults can comfortably and safely age in place while maintaining their independence and well-being. Such designs enable accessibility and ease of movement for residents of varying abilities, minimising later modifications. Age-friendly homes benefit not only the residents but also the wider community by reducing reliance on institutional care facilities [143]. Alongside the design requirements, the buildings' facilities, particularly public ones, must be accessible and user-friendly for all ages and abilities. Essential features include ramps, elevators, handrails, anti-slip floors, seating, accessible toilets, clear signage, and designated parking areas [124], [126], [147].

4.2.2 Age-friendly open/public spaces

An age-friendly built environment is also associated with neighbourhoods that accommodate older adults, featuring easily accessible public/open spaces, supportive social services, and inviting third places, which can substantially improve life quality and overall well-being for this demographic [148]. Easily accessible spaces mainly refer to those public spaces that promote safety and comfort and encourage outdoor engagement among older adults [149]. As loneliness and depression are prevalent among older adults, particularly those living independently without spousal or partner support, accessible open spaces enable them to socialise and

age within their neighbourhoods [150]. Common areas such as coffee shops, public gardens, retail centres, libraries, marketplaces, and local community hubs are considered as alternative social spaces, separate from homes and workplaces [151]. These spaces, also well known as “third places”, can foster voluntary social interaction and provide opportunities for older individuals to be involved in their communities and build social networks, both casual and close, which are essential in combating solitude and isolation [152], [153].

Open spaces accommodating older adults are also linked to encouraging physical exercise and improving their health 40]. Regular physical activities, especially walking, which is a preferred exercise among older adults, are facilitated by neighbourhoods designed to be pedestrian-friendly. This is mainly characterised by a balanced mix of different land uses, well-connected pathways, and dense residential areas [157], [158]. Mixed-use developments, with their integration of residential, commercial, and communal spaces, attract people outdoors and encourage regular walking. The layout of streets and the size of blocks play a crucial role in how accessible a neighbourhood feels. The number of people in an area contributes to a dynamic and engaging urban life, creating a sense of belonging in the community. Older adults residing in areas with varied land uses, interconnected streets, and dense populations are more inclined to be physically active, owing to the closeness of various destinations [159]. Other factors that affect the walkability of the built environment include pedestrian safety from vehicular traffic with lower speed limits and more road crossings, the connectivity of pedestrian facilities, public safety from crime and violence, trees and vegetation for shading and amenities, adequate lighting for illumination, distinctive signage for wayfinding, user-friendly street furniture, and inclusive urban designs with barrier-free access [160], [161].

4.2.3 Age-friendly transportation systems

Neighbourhoods designed for walking prioritise a secure, interconnected network for pedestrians, blending different modes of transport to support the mobility needs of older adults. Consistent, dependable, and secure public transportation is crucial in facilitating the ease of navigation for seniors in their environment. The quality of services and perceived travel safety significantly influence older adults' perceptions of public transit accessibility [162]. Age-friendly public transportation facilities, such as train stations, tram stops, and bus stops, are equipped with comfortable seating, shelters, and adequate lighting, creating an inviting environment for older travellers. Ramps, elevators, escalators, and low-floor boarding onto buses enhance accessibility for seniors, allowing them to confidently utilise public transport. Priority seating on public transport encourages passengers to offer seats to older adults and others in need, promoting inclusive and considerate travel experiences. Cost-effective public transportation is also a key element in maintaining mobility for the elderly. In many countries, older adults are offered concession fares or even free access to public transportation, such as buses, trains, and trams [163]. Improved mobility through public transport not only enhances the quality of life of older adults but also contributes to their social inclusion and engagement [164].

Beyond the ease of walking, evaluating neighbourhood transportation also involves considering its suitability for cycling, often referred to as its bikeability or the degree to which it is bicycle-friendly [165]. The act of bicycling serves as a green method of transportation, contributing to the reduction in vehicle use and the enhancement of air quality. Moreover, it acts as a physical activity, aligning with the goals of active ageing and boosting public health [166]. The participation of older adults in cycling is influenced by a range of factors, including the separation from motor traffic, safety

concerns, the behaviour of fellow cyclists, and the ease and presence of necessary infrastructure [167].

It is also noted that senior citizens residing in suburban and remote locations, where public transportation is scarce, often find their ability to move around and their overall well-being tightly linked to owning a vehicle. As they age, a gradual reduction in cognitive, sensory, and physical capacities can lead to slower reflexes, diminished vision, impaired hearing, challenges in focusing, and memory issues. These changes can increase the risks associated with driving and raise various safety concerns [168], [169].

In summary, to provide a structured understanding of age-friendly built environment variables and their associated features, we compiled them into Table A1, which is presented in Appendix B. This table serves as a guiding framework throughout this study, particularly in analysing the alignment of Blue Zones with these age-friendly built environment standards. The subsequent sections will refer to this table to assess the built environments in Blue Zones, integrating insights from both the systematic literature review and the CNN analysis.

4.3 Methodology

In this research, we adopt a dual-method approach, integrating both qualitative and quantitative analyses, to thoroughly investigate the age-friendly aspects of the built environment in Blue Zones. Our methodology includes a systematic literature review and a CNN analysis, each providing unique insights into the age-friendliness of these environments. The methodological framework, depicted in Figure 22, illustrates the progression of our study from reviewing the existing literature and conducting a deep learning neural networks analysis to generating new insights and policy advice for contemporary urban neighbourhood initiatives. This

approach can contribute to the existing body of knowledge by leveraging innovative methods to enhance our understanding of built environments within urban studies. The framework acts as a guiding roadmap for our analysis, informing our examination of the Blue Zones and our contributions to urban neighbourhood planning and policy development. We will delve into the details of this framework in the subsequent sections.

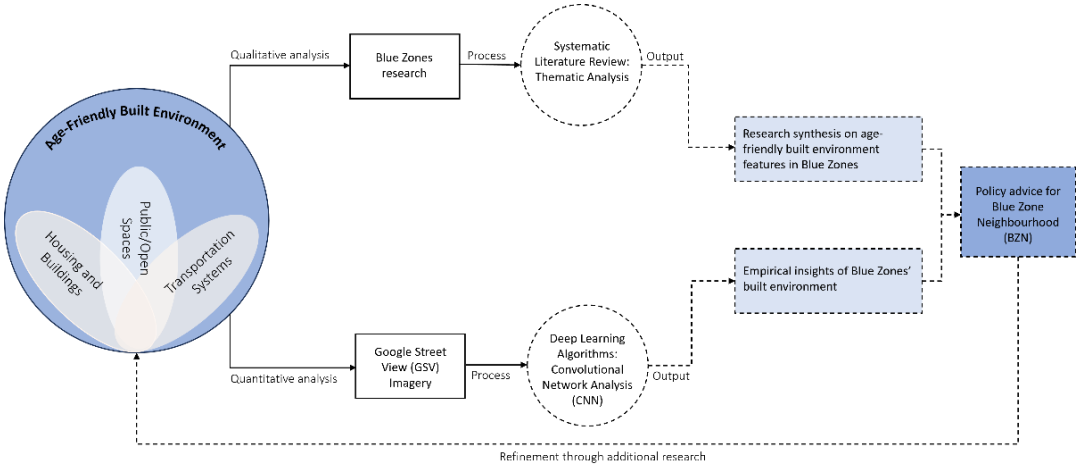


Figure 22. The exploration framework for examining age-friendly built environment features in Blue Zones. Details of the age-friendly built environment variables, along with their contributing descriptions, are provided in Appendix A.

4.3.1 Systematic literature review: thematic analysis

Among several approaches suitable for conducting a qualitative analysis, we selected a thematic analysis as it allows us to identify, analyse, and interpret patterns of meaning within qualitative datasets [170]. Within our study, a thematic analysis will help us to unravel and interpret patterns in the Blue Zones research relevant to (1) housing and buildings, (2) public/open spaces, and (3) transportation systems. The interpretations can later help us to develop possible policy advice and recommendations by illuminating the interconnectivity of themes and their implications for neighbourhood design and planning.

4.3.2 Summary of search strategy

We carefully selected the relevant academic sources by using defined criteria such as keyword relevance, language, and publication date. Online databases including Scopus, Google Scholar, Web of Science, and PubMed, along with a manual snowball search—identifying related works by consulting the bibliography or references section at the conclusion of a paper—completed on 15 September 2023 provided a comprehensive collection of the international literature. Peer-reviewed papers, book chapters, and grey literature such as reports and conference proceedings were reviewed for inclusivity.

4.3.3 Study selection

In online databases, *"Blue Zones"* is used as the primary keyword in the search within titles, abstracts, and keywords. Additional terms *"Sardinia," "Okinawa," "Ikaria," "Nicoya Peninsula," "Loma Linda," and "Adventist"* are also considered based on their frequency in the retrieved articles. To broaden the search, synonyms of the term Blue Zone such as *"longevity hotspots"* and *"world's longest-lived populations"* are included (Figure 22). The search timeframe spans from 2004 to 2023, coinciding with the emergence of the Blue Zones concept [28]. Non-peer-reviewed papers (e.g., reports, abstracts, book chapters, and conference proceedings) and selected papers were included separately (category "grey literature") and used to hand-select additional relevant resources. An initial inquiry resulted in 357 non-duplicated citations for further investigation (Figure 23).

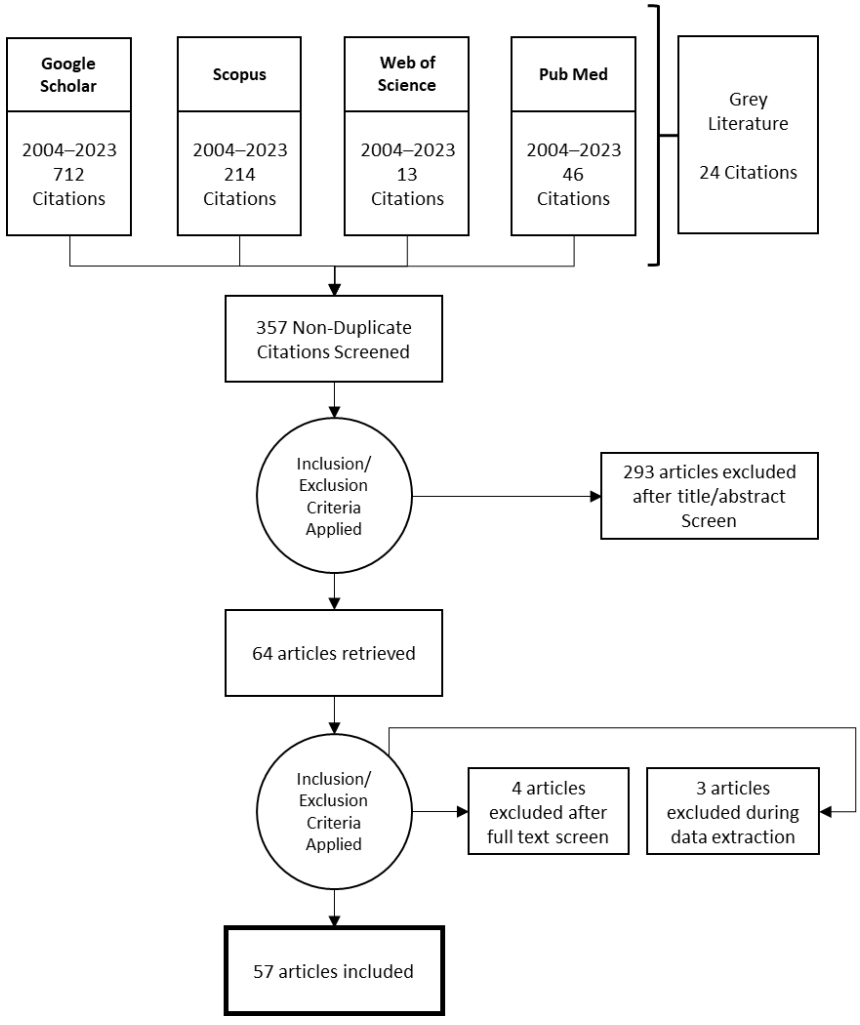


Figure 23. Selected papers for thematic analysis using PRISMA.

4.3.4 Inclusion and exclusion criteria

All 357 non-duplicated citations were screened by using the title and abstract. The selected papers met the following criteria:

- Geographic location of study: the research focused on the five established Blue Zones.

- Exposure of interest: the paper targeted populations of centenarians and older adults aged 75 years and older. Language: published in English between 1 January 2004 and 19 September 2023.
- Peer review: the paper was peer-reviewed.
- Reported outcomes: The outcome of the paper reported the influential factors of the longevity of centenarians in Blue Zones. Selected papers were examined on whether influential factors were reported appropriately and in a consistent manner. Papers/sources using self-reported outcomes rather than objective measures were excluded.
- Prior to final selection, it was deemed necessary to exclude Loma Linda from the study due to its distinct contextual differences compared to other regions. Due to distinct contextual differences, Loma Linda was excluded from this study. This decision was based on its unique demographic and cultural landscape, the quality and availability of healthcare services, and its economic landscape, which differs significantly from the other Blue Zones. Additionally, Loma Linda's level of urbanisation and environmental factors diverge from the more isolated and less urbanised settings of other Blue Zones.

Ultimately, this review encompasses 57 peer-reviewed publications, forming the basis for an in-depth thematic analysis detailed in Appendix C.

While the systematic study selection provides a rich repository for qualitative analysis, we acknowledge some limitations: This research was also restricted to publications available in English, thus potentially excluding valuable content in

other languages from the interpretation. Additionally, by exclusively focusing on online resources and full-text publications, there is a possibility of overlooking the most recent evidence, such as abstracts, which may provide valuable insights. To mitigate this, we included a thorough review of bibliographies to encompass a broader range of perspectives.

Finally, to delve deeper into our qualitative data, we utilised ATLAS.ti 23 for a thorough thematic analysis. This involved meticulously coding and categorising the data, ensuring alignment with the age-friendly built environment variables that we previously identified and listed in Appendix C.

4.3.5 CNN analysis

To complement our qualitative analysis, we deployed a deep learning neural network, specifically a CNN, capable of processing assembled data and extracting key features [171]. In our study, the CNN primarily detects age-friendly built environment variables within the GSVs, providing quantitative support for our qualitative findings (details in Appendix D). Additionally, the CNN analysis employs image segmentation techniques to classify the object types associated with these variables. This method involves segmenting and categorising different areas within the images, allowing for a more precise and detailed analysis and interpretation of each object [172].

4.3.5.1 GSV imagery acquisition

To initiate the CNN analysis, we first needed to collect relevant images of the built environment in Blue Zones from various open datasets known for offering comprehensive urban imagery. Among these, we employed the Google Street View (GSV) platform, which is recognised in urban studies for its extensive and regularly updated street-level imagery. We utilised the GSV API to systematically retrieve images of Blue Zones from Google Services.

We delineated the boundaries of the Blue Zones in accordance with Poulain's demographic study, in which he and his team identified regions inhabited by the longest-lived populations [29] (Figure 24).

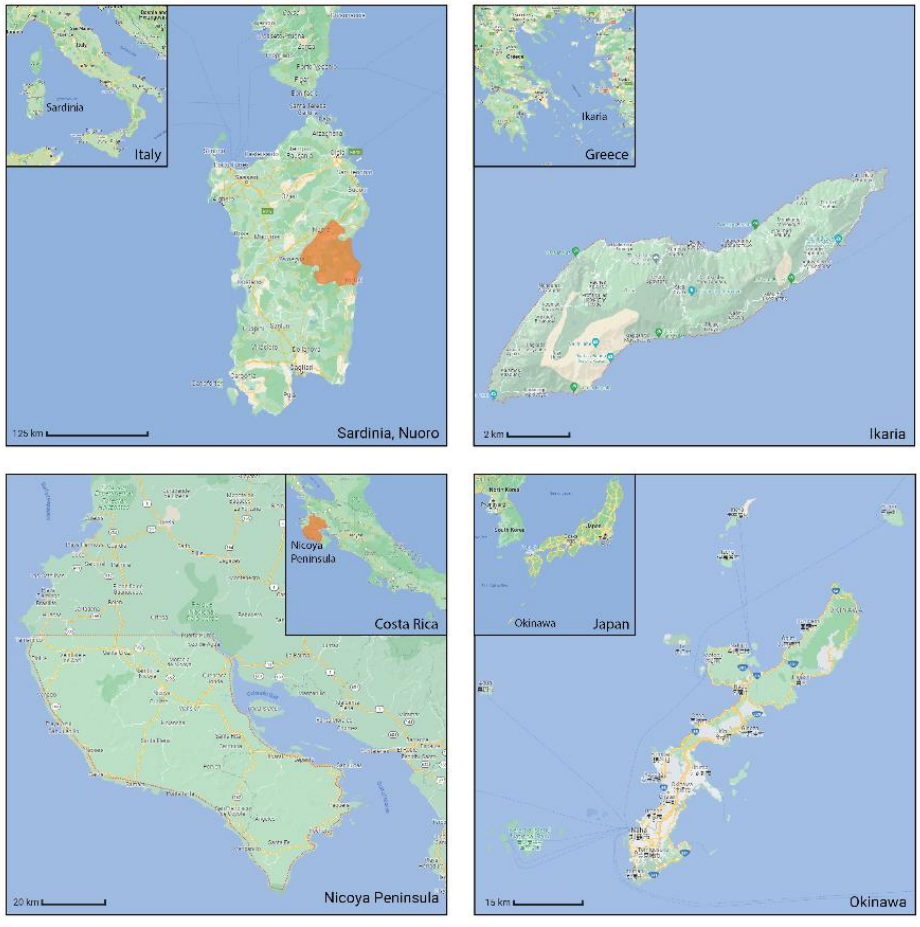


Figure 24. The four Blue Zones located in Sardinia, Ikaria, Costa Rica, and Okinawa are illustrated in accordance with the geographical delineations provided by [173].

In acquiring GSV imagery, several criteria were tailored to effectively facilitate the CNN analysis. These criteria included the density of the GSV imagery, the diversity of the built environment, and the computational capabilities of our model. Adjustments to the GSV API parameters were made to optimise the image-capture

process. Specifically, we set the heading to 180 degrees to standardise the image direction, adjusted the pitch to 0 degrees to align the camera angle horizontally, and set the field of view to 50 degrees to ensure a wide yet detailed view. Each image was obtained at a resolution of 600 × 600 pixels, which is the highest resolution available through the GSV API.

4.3.5.2 Pre-processing

After collecting the Blue Zones GSV imagery, our initial step involved reviewing and curating the images, removing those that were not relevant or of poor quality. Ultimately, a total of 2980 images were selected for the final dataset, which we divided into three parts:

- The training set (70%) is used to train the CNN model, enabling it to recognise patterns within the data.
- The validation set (15%) is used not for training but rather to tune hyperparameters and provide an unbiased evaluation of the model fit during the training phase.
- The testing set (15%) is employed post-training and validation to offer an unbiased evaluation of the final model's performance.

During the collection of the GSV imagery, we encountered significant variations in image availability across the different Blue Zones. The GSV coverage for Okinawa and Sardinia was nearly comprehensive, providing a rich dataset for these regions. Conversely, the availability in Ikaria and the Nicoya Peninsula was more limited, reflecting variations in geographical accessibility and Google's mapping efforts. To address these discrepancies, we made conscientious efforts to maximise the utility of the available data, ensuring our analysis is as representative and comprehensive as possible within the existing constraints. Overall, the final dataset comprised 2086 GSVs for training, 447 GSVs for validation, and 447

GSVs for testing our model. Table 10 details the number of GSVs selected for each class in our dataset.

Table 10. The number of GSVs selected for each Blue Zones in the CNN dataset

Class	GSV imagery count (access: November 2023)
Ikaria	195
Nicoya Peninsula	385
Okinawa	1200
Sardinia	1200

4.3.5.3 CNN model architecture and object extraction

Our CNN model employs the YOLO (You Only Look Once) architecture developed by Redmon et al. (2017) [174]. This architecture is renowned for its efficiency and accuracy in object detection across diverse contexts [175]. We selected YOLOv5 for its proven efficacy in urban design applications, as evidenced by [176], [177], [178]. YOLOv5 was instrumental in identifying and extracting objects from the Blue Zones' GSV imagery.

A crucial aspect of developing and validating object-detection models is image annotation, which entails labelling or classifying objects within images. For this purpose, our study employed the ADE20K dataset [179], a widely acknowledged resource in urban scene parsing. This dataset facilitated the annotation of age-friendly built environment features in the Blue Zones' GSV imagery, and the process is elaborated upon in Appendix D.

4.3.6 Model performance evaluation

We evaluated our CNN model by using four key evaluation metrics, namely Mean Average Precision (mAP), Precision, Recall, and Intersection over Union (IoU):

Mean Average Precision (mAP): This metric measures the accuracy of an object-detection model. A higher mAP value indicates

better performance. Specifically, it is calculated by averaging the Precision scores across all classes at different IoU thresholds. In the case of YOLOv5, the average Precision is calculated at an IoU threshold of 0.5.

Precision: This metric reflects the proportion of correctly predicted positive observations to the total predicted positives. It is defined as the number of true positives (TP, or correctly identified positive instances) divided by the sum of true positives and false positives (FP, or negative instances incorrectly identified as positive).

Recall (Sensitivity): Recall measures the model's ability to correctly identify all actual positives. It is calculated as the number of true positives divided by the sum of true positives and false negatives (FN, or positive instances incorrectly identified as negative).

Intersection over Union (IoU): IoU is a metric used in object detection to evaluate the accuracy of a predicted bounding box. It calculates the area of overlap between the predicted bounding box and the ground truth bounding box, divided by the area of union between these two boxes.

These metrics collectively provide a comprehensive evaluation of our CNN model's performance in detecting and classifying objects within the dataset.

4.4 Results

4.4.1 CNN model performance

The performance of our CNN model demonstrates its effectiveness in accurately identifying and analysing age-friendly built environment features within Blue Zones GSV imagery. The model achieved a mAP score of 78%, which represents a relatively satisfactory level of accuracy in object detection. The Precision of the

model was recorded at 75%, indicating the proportion of true positive detections relative to the total number of predicted positives (true positives and false positives). This highlights the model's reliability in making predictions. The model also exhibited a Recall rate of 72%, illustrating its capability to correctly identify all actual positives. Furthermore, the IoU score was calculated to be approximately 70%, confirming the model's effectiveness in localising objects accurately. Figure 5 illustrates the process by which GSV images are transformed into convolutional layers for CNN image segmentation. This transformation subsequently facilitates the identification of the pertinent built environment criteria within a dataset of 2980 GSVs. A detailed analysis of these outputs within the framework of thematic investigation is presented in the ensuing sections.

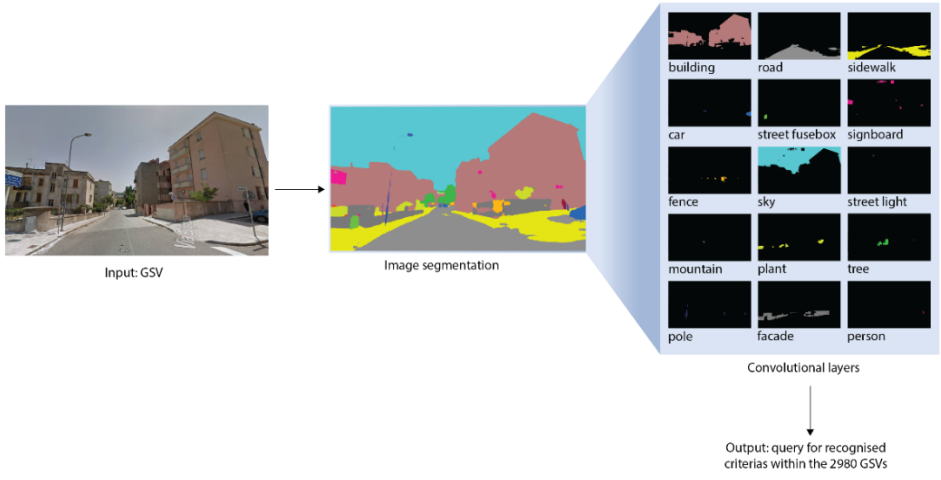


Figure 25. GSV transformation into convolutional layer for CNN image segmentation

4.4.2 Blue Zones' housing and buildings

4.4.2.1 Ageing in place

Our thematic analysis underscores a strong focus on ageing in place within Blue Zones, deeply influenced by solid social support networks. A notable example of this is seen in Okinawa, where

'Moai' groups—social collectives dedicated to providing lifelong support—are prevalent. These groups are instrumental in motivating older centenarians to remain within their communities, helping them to stay actively engaged and connected. In areas such as Sardinia and Nicoya, it is customary for senior individuals to live close to or with their families, ensuring they receive the necessary support]. This practice is mirrored in Okinawa, where the Moai members often reside within walking distance of each other, fostering consistent support that is especially crucial for ageing-in-place [15], [181].

4.4.2.2 Housing options

Our CNN model analysis reveals varied housing options across Blue Zones. In Ikaria, traditional stone houses, villas, and seaside bungalows dominate, with apartment complexes found primarily in central villages. Sardinia displays a wide range, including traditional stone houses (24% of the GSV imagery), modern apartments (62%), luxury villas (9%), and seaside cottages (5%). Okinawa's landscape comprises modern apartments and condominiums (56% of the GSV imagery), with the rest being stand-alone houses, including Minka and ryokans. In Nicoya, single-story buildings predominate (78% of the GSV imagery), with a mixture of apartments and housing complexes (Table 11).

4.4.2.3 Building design

The GSV imagery of the Blue Zones conveys a predominant theme of "simplicity" in housing and building designs. In Ikaria, 95% of the GSV imagery features homes made of stone and natural elements, exemplifying a minimalist approach. This local ethos is also captured in an Ikarian saying [182]: "Home as much as you can fit and place as much as you can afford." Sardinia's historical urban areas also reflect simplicity through traditional stone masonry structures. Conversely, Okinawa prioritises functionality with

buildings primarily made from concrete or cinder blocks, as observed in over 85% of the GSV imagery.

Moreover, the multifunctionality of living spaces seems to be a key feature across the Blue Zones. Homes often serve as both living- and workspaces, as seen in Ikaria's flat roofs and Sardinia's home gardens, which facilitate leisure and family gatherings [183]. In Okinawa, many buildings' ground floors have dual residential and commercial uses.

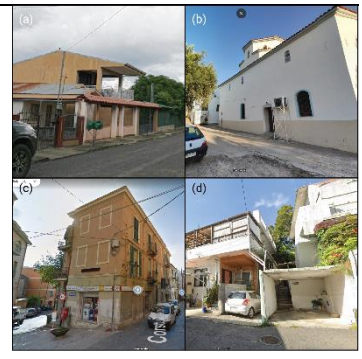
Furthermore, the housing design often mirrors a deep connection with nature. In Nicoya, vernacular architectural styles using local materials are set amidst lush greenery and harmony with nature. Even in Sardinia's more urbanised areas, natural elements are often integrated into Mediterranean-style homes.

Table 11 provides a detailed analysis of age-friendly housing and building features across Blue Zones.

Table 11. Age-friendly housing and buildings features across Ikaria, Sardinia, Okinawa, and Nicoya using CNN evaluation of GSV imagery.

Housing and building features	Sampled GSVs
Housing options	
* (a) Single-story buildings, apartments, housing complexes	-
* (b) Stone houses, villas, seaside bungalows	
* (c) Stone houses, modern apartments, villas, seaside cottages	
* (d) Modern apartments, condos, stand-alone houses (Minka,	

Housing and building features	Sampled GSVs
resort-style villas, ryokans)	
Spatial distribution of buildings (a) Null** (b) Sparse and organic settlement patterns, spread out houses (c) Compact space organisation with narrow pathways, limited pedestrian/vehicular circulation (d) Compact with narrow pathways; spacious buildings along central regions	
Dominant building design characteristics (percentage of GSV imagery) (a) Vernacular buildings (Single-story 78 percent, Others 22 percent) (b) Natural elements, Mediterranean architecture (95 percent) (c) Traditional masonry (24 percent), Apartments (62 percent), Villas (9 percent), Cottages (5 percent) (d) Modern style apartments (56 percent), Stand-alone house (44 percent)	

Housing and building features	Sampled GSVs
Dominant design materials (a) Corrugated metal, bricks, concrete blocks, local materials (b) Stone, natural elements, vegetation incorporated (c) Stone, terracotta, plaster, brickwork, commercial/residential ground floors (d) Concrete, cinder block, minimal ornamentation	-
Dominant building layout (a) Null (b) Layout seems adaptable to sloped terrain (c) Null (d) Null	-
Dominant ground floor functionality (a) Null (b) Null (c) Often used for garages or commercial purposes (d) Partly residential, partly for vehicular storage, or commercial spaces	
Façade colour (a) Null (b) White/bright (c) Varied: plastered to exposed brickwork and stone (d) Null	-

Housing and building features	Sampled GSVs
Roof Style (a) Null (b) Flat/low-pitched (c) Pitched roofs with terracotta tiles (d) Null	-
Integration of Vegetation (a) Null (b) Integrated among buildings as trees and small gardens (c) Null (d) Null	

*: (a): Nicoya Peninsula, (b): Ikaria, (c): Sardinia, (d): Okinawa
**: Insufficient Data

4.4.3 Blue Zones' open/public spaces

4.4.3.1 Outdoor space accessibility

Our research reveals that Blue Zones commonly feature landscapes that seamlessly integrate with nature. Studies support the notion that living in these environments has a positive impact on the health of older adults [28], [137], [139],[184, p. 201]. The CNN analysis shows that 65.1% of Blue Zone areas are characterised by open, natural spaces. Ikaria, Sardinia, and the Nicoya Peninsula in particular showcase extensive accessibility to natural landscapes in about 35% of GSVs. Okinawa differs slightly, with 21% of GSVs depicting more urbanised parks and plazas, whereas Sardinia presents a mixture of both natural settings and designed open spaces.

4.4.3.2 Third places

In Okinawa, our analysis found a prominent presence of third places such as restaurants and markets, making up about 65%

of the GSV imagery. Sardinia also displays a significant number of such places, mainly concentrated in urban centres and residential areas, appearing in 18% of GSVs. Due to limited GSV coverage, the findings in Ikaria and Nicoya are less definitive, but trends in thematic analysis suggest a focus on home-centred social gatherings. These gatherings, often facilitated by family and close-knit groups, are vital in fostering community bonds among older adults [29], [185]. Research emphasises the importance of these local social interactions in enhancing community well-being]. Community events, ranging from shared meals to cultural festivals, are a staple in Blue Zones and are typically accessible and affordable. Semi-public spaces like terraced gardens in Ikaria and residential gardens in Sardinia likely serve as third places for these activities [20,72].

4.4.3.3 Pedestrian infrastructure and accessibility

Our model indicates that Okinawa and Sardinia have robust pedestrian infrastructure, with 39% and 26% of GSVs, respectively, showing pedestrian-friendly features like separated pedestrian routes, crossings, etc. Physical activities such as walking and cycling are less prevalent, noted in a smaller fraction of GSVs. The analysis of Ikaria was limited due to model constraints, leading to an underrepresentation of these activities. In terms of wayfinding, Sardinia and Okinawa show higher instances of signage. Conversely, Ikaria and Nicoya display limited wayfinding aids, mostly around tourist areas. The distribution of street furniture also varies, with a more consistent presence in urbanised areas of Sardinia and Okinawa, indicating a higher integration of urban amenities. This contrasts with the more sporadic distribution in Ikaria and Nicoya [137].

Table 12 overviews our findings on age-friendly features in the open/public spaces of Blue Zones, detailing the prevalence and types of outdoor spaces, social support facilities, and pedestrian infrastructure.

Table 12. Age-friendly built environment instances extracted from the Blue Zones GSV imagery.

Feature		Sampled GSVs
Open/outdoor space instance		
a* (%)	35	
b* (%)	21	
c* (%)	35	
d* (%)	35	
Third place instance		
a (%)	18	
b (%)	65	
c (%)	Null**	
d (%)	Null	
Pedestrian infrastructure		
a (%)	26	
b (%)	39	
c (%)	Limited detection	
d (%)	1	
Physical activities		
a (%)	Walking (7%)	
b (%)	Walking (5%)	-
c (%)	Cycling (3%)	
d (%)	Cycling (3%)	
Wayfinding signage		-

Feature		Sampled GSVs
a (%)	19	
b (%)	17	
c (%)	2	
d (%)	2	
Street furniture		
a (%)	55	
b (%)	68	
c (%)	Limited to touristic areas	-
d (%)	7	

*: a: Nicoya Peninsula, b: Ikaria, c: Sardinia, d: Okinawa.

**: Insufficient Data

Note: The percentages indicate the proportion of GSV images in which the respective urban element was identified by the CNN model. "Insufficient Data" denotes areas where the CNN model's performance was limited due to the sparse availability of GSV images. "Limited Detection" and "Limited to Tourist Areas" refer to observations where the CNN model detected the element in question in a negligible number of images, often confined to specific zones.

4.4.4 Blue Zones' transportation systems

Multiple peer-reviewed publications, including Poulain et al. (2021) and Fastame et al. (2021), highlight the limited accessibility to public transportation and inconsistent transportation infrastructure in Blue Zones [136], [141]. These highlights also align with our CNN model analysis. In Ikaria, the model was unable to distinctly identify features of public transportation infrastructure. Conversely, in Nicoya, bus stations were identified in about 2% of the GSV imagery, primarily near main thoroughfares. Sardinia shows a more consistent presence of public transport amenities like bus stops, visible in approximately 14% of the GSV imagery and widely distributed across residential areas. In Okinawa, the CNN model suggests a more extensive public transportation network, including buses, taxis, and ferries, evident in around 23% of GSV imagery.

Our thematic analysis reveals that the remote and mountainous locations of Blue Zones could pose challenges to transportation access and convenience, especially for older adults. For instance, in the northern areas of Okinawa, where many centenarians reside, the scarcity of personal vehicles complicates access to essential services, leading most seniors to rely on personal transportation [188]. Similarly, in Nicoya, reaching medical centres and social support facilities can take up to 40 min by car, which is particularly challenging for seniors or mobility-impaired residents [133].

Furthermore, our analysis suggests that limited public transport in Blue Zones may be a contributing factor to increased walkability in these regions. Notable themes identified include "increased physical activity", "cardiovascular health", "exercise", and "improved BMI". Despite a scarcity of dedicated pedestrian paths, the CNN model reveals the prevalence of naturally designed walkways. These pathways, often sloped due to the mountainous terrain, are likely to positively influence residents' cardiovascular health.

In terms of cycling, the GSV imagery reveals a notable presence of bike tracks and cycling trails in Okinawa, accounting for nearly 19% of the GSV imagery. Conversely, in Sardinia and Nicoya, cycling is less prominent but still present, with about 2% and 1% of the GSV imagery, respectively, showing individuals cycling. Notably, our model did not identify a distinct cycling infrastructure in Ikaria.

Table 13 elaborates on our findings, providing an overview of the transportation features in Blue Zones.

Table 13. CNN interpretation of Blue Zones' GSVs focusing on age-friendly transportation systems

Feature	a1 (%)	b1 (%)	c1 (%)	d1 (%)
Detected public transport modes	Bus stations in 2% of GSVs	Not indicated	Bus or bus stations in 14% of GSVs	Bus or bus stations in 23% of GSVs
Public transport infrastructure	Bus routes near main thoroughfares	Limited bus routes, year-round ferry service	Extensive public transport network with bus stops in residential areas	Superior coverage, frequency, accessibility, and integration
Design in transport hubs	Not indicated	Not indicated	Functional and modern design in 11% of GSVs	Design considers climate; shading in 15% of GSVs, symbolic signage in 65%
Detected bike tracks	1% of GSVs show cycling	None detected	2% of GSVs show cycling	Bike tracks in 19% of GSVs

1: (a): Nicoya Peninsula, (b): Ikaria, (c): Sardinia, (d): Okinawa

4.4.5 The BZN policy advice

After doing an in-depth qualitative analysis of Blue Zones research and a CNN-based examination of relevant GSV imagery, we formulated the Blue Zone Neighbourhood (BZN) policy advice. This advice aims to translate our findings from Blue Zones into actionable strategies for urban design and planning.

As delineated in Table 14, the BZN policy advice encompasses insights aligned with three core age-friendly built environment variables. Each variable in the table is supported by findings from our thematic and CNN analyses of the Blue Zones studies. These policy recommendations are intended for testing in later research phases, aiming to create man-made, age-friendly environments reminiscent of those found in Blue Zones within contemporary urban neighbourhoods.

Table 14. The Blue Zone Neighbourhood policy advice guideline.

Category	Policy advice
Open/outdoor spaces and neighbourhoods	Maintain scenic outdoor spaces and symbiotic coexistence with nature as part of neighbourhood planning and design policies.\ Encourage community gardens, urban farming initiatives, and policies supporting local food production and distribution networks within common outdoor areas. Promote initiatives encouraging strong social bonds with family members and friends through community programs, events, and shared spaces. Foster social networking among neighbours through neighbourhood events, communal spaces, and initiatives encouraging interaction and connection. Maintain a communal social support system that facilitates social connections and assists residents in need through community programs, support groups, and outreach initiatives. Integrate physical activity-friendly design principles in neighbourhood planning, such as walkable layouts, exercise stations, and bicycle infrastructure. Incorporate policies that prioritise creating and preserving greenery and protected natural areas within the neighbourhood. Promote fair access to parks, recreational facilities, healthcare services, and other community resources, particularly in underserved areas
Transportation systems	Encourage active commuting by integrating and maintaining walking and cycling infrastructure. Raise awareness about the health benefits of active commuting and encourage incorporating physical activity into daily travel routines. Provide clear signage, wayfinding systems, and information displays for easy navigation and active exploration within the neighbourhood. Incorporate accessible pathways with gentle slopes to ensure easy movement. Implement safety measures, including well-lit pathways, crossings, and traffic calming strategies.
Housing and buildings	Implement policies to increase the availability and affordability of housing options for low-income individuals and families.

Category	Policy advice
	Encourage the development of housing options that accommodate multiple generations living together, including shared living spaces and adaptable designs.
	Support policies for allocating housing opportunities near family members and loved ones.
	Support policies enabling individuals to live and work in the same space, such as flexible zoning regulations and integrating home office infrastructure.
	Encourage housing designs that maximise space utilisation, offering versatile layouts and adaptable features to accommodate various needs and activities.
	Promote housing designs that incorporate elements reflecting the local culture and blend harmoniously with the natural surroundings.
	Incorporate accessible and well-designed outdoor spaces within housing developments, providing residents easy access to gardens and supporting home gardening initiatives.

4.5 Discussion

This study embarked on an exploratory journey to reassess the longevity features of Blue Zones through the lens of age-friendly built environment variables. Our primary ambition was to enrich contemporary urban neighbourhood planning and design with actionable policy advice. By drawing from the unique paradigms of Blue Zones, we aim to enhance environments conducive to ageing populations. Employing a dual-method approach, we merged thematic analysis with deep learning image processing. This combination provided a comprehensive understanding of the built environment within Blue Zones. Our findings offer a new perspective on the integration of age-friendly principles in urban planning and the potential for these principles to be applied universally yet adapted locally.

4.5.1 Key findings and their implications

The formulation of the BZN policy advice, detailed in Section 4.5, stands as a testament to this endeavour. Notably, our study's objective was not to quantify the age-friendliness of Blue Zones per se, but rather to glean insights from these environments that are naturally conducive to healthy ageing, thereby informing current age-friendly initiatives.

Our findings reveal both the congruence and disparity with the WHO's standards for an age-friendly built environment. The concept of ageing in place emerged prominently in Blue Zones, exhibiting diversity in its forms—from extended cohabitation to proximity to family and tight-knit communities. These instances underscore the potential influence of ageing in place on longevity in these regions.

The delineation of third places in Blue Zones presented an intriguing divergence from standard age-friendly urban models. Contrary to the anticipated abundance of public spaces like cafes and libraries, our CNN analysis uncovered a scarcity of such conventional third places. Yet, this scarcity did not seem to equate to diminished social interaction. Instead, our qualitative insights suggest a robust social well-being, fostered within natural settings and home-based or semi-private spaces.

Moreover, the encouragement of physical activity in Blue Zones, predominantly nudged by geographical features and lifestyle necessities, offers a fresh perspective compared to structured urban exercise programs. This aspect, alongside the observed deficiencies in transportation infrastructure, represents a notable divergence from established age-friendly norms.

4.5.2 Critique and counterarguments

Recent critiques in the grey literature challenge the validity of longevity claims in Blue Zones, adding a crucial dimension to our

discussion [189], [190], [191]. These critiques highlight potential inaccuracies in data and record-keeping, advocating for a more cautious approach when interpreting studies on longevity in these regions. While our research aligns with the general narrative of Blue Zones as longevity hotspots, we recognise the possibility of such discrepancies. Given these contrasting views, it is essential that our findings are considered with an understanding of the potential data limitations inherent in Blue Zone studies. This perspective is not only academically significant but also has implications for public health policy and lifestyle guidelines. Accurate data collection and analysis are paramount to robustly validate longevity claims. Recognising these challenges is essential for future research, particularly when such studies can significantly influence public health strategies and recommendations based on the lifestyle and environmental factors associated with Blue Zones.

4.5.3 Summary of key implications

From this review study, we distil several implications that warrant further explorations in the future, offering opportunities for scholars to delve into more in-depth discussions:

The importance of adaptability: The diverse forms of ageing in place observed in Blue Zones highlight the significance of adaptable living arrangements. It is crucial to consider how different cultural and geographic contexts influence the preference for living with family, in close-knit communities, or in remote areas. This adaptability is promising to promote longevity and well-being among ageing populations.

Redefining social spaces (third places): The concept of third places in Blue Zones partially deviates from typical urban standards, focusing more on natural spaces and home-based interactions rather than commercial or public venues. This can suggest that urban planners and designers should be more flexible in defining social spaces, recognising the value of both natural environments and

semi-private spaces like home gardens in fostering social interaction.

Physical activity through environment design: The encouragement of physical activity in Blue Zones is often a by-product of geographical features and lifestyle necessities like farming or husbandry rather than structured exercise programs. This reminds us that urban design can organically promote physical activity through the incorporation of natural landscapes and the encouragement of active lifestyles.

Challenging conventional age-friendly standards: The divergence from conventional age-friendly standards in transportation and the unique characteristics of third places in Blue Zones can suggest that conventional standards might not be universally applicable. This underscores the importance of (re)considering context-specific solutions in urban planning and design that respond to the unique cultural, geographical, and social aspects of different communities with greater emphasis.

4.5.4 Limitations of the research

We acknowledge certain limitations during our study:

(1) The scope of the literature review: while thorough, our literature review might not have captured every nuance and complexity present in the diverse environments of Blue Zones.

(2) Our CNN analysis, focusing on visual aspects of Blue Zones, may not have fully grasped non-visual factors that contribute to age-friendliness, such as community dynamics and social support systems.

(3) Inherent biases could exist in our selection and interpretation of literature, influenced by our research focus and preconceptions.

(4) Our analysis, both qualitative and quantitative, might have limitations in depth or breadth, impacting the comprehensiveness of our findings.

4.6 Conclusion

This study's exploration into Blue Zones provides insightful reflections on contemporary age-friendly urban neighbourhood planning and design. We observed that Blue Zones, characterised by their exceptional longevity, offer invaluable lessons in shaping environments conducive to healthy ageing. The fusion of qualitative and quantitative analyses, incorporating a systematic literature review with a CNN analysis of GSV imagery, allowed us to distil the essence of these longevity environments.

The findings of this study led to the formulation of the BZN neighbourhood planning and policy advice. The BZN underlines the promising role of adaptable living arrangements, the importance of redefining social spaces to include natural and semi-private areas, and the necessity for urban designs that organically promote physical activity. These insights challenge conventional age-friendly standards and highlight the importance of context-specific solutions that respect the unique cultural, geographical, and social fabric of communities. As urban planners and designers, these findings compel us to rethink our approaches and adapt our strategies to foster environments that support ageing populations, drawing inspiration from the natural and community-driven paradigms of Blue Zones. Building upon this, our future research will focus on evaluating the feasibility of implementing the proposed policy advice within novel city digital twin models. This will provide a more comprehensive understanding of the challenges and outcomes associated with implementing Blue Zone practices in diverse urban contexts.

In addition to the underlying promises, this study contributes to the broader discourse on urban planning by showcasing innovative methodologies. In particular, by combining deep learning and Convolutional Neural Networking with the qualitative-quantitative review studies, we provide supportive evidence for interpretations and findings, paving the way for further exploration of these techniques in the field.

Chapter 5: Experimenting a healthy ageing neighbourhood in user-centred digital twins with older adults: the case of Blue Zones

Chapter 5 Experimenting a healthy ageing neighbourhood in user-centred digital twins with older adults: the case of Blue Zones

Experimenting a healthy ageing neighbourhood in user-centred digital twins with older adults:
the case of Blue Zones

This chapter has been awarded as best paper in the 17th international conference on Intelligent Environments (IE) (2021) and part of it has been published as follows:

P. Najafi, M. Mohammadi, P. M. Le Blanc and P. Van Wesemael, "Experimenting a Healthy Ageing Community in Immersive Virtual Reality Environment: The Case of World's Longest-lived Populations," 2021 17th International Conference on Intelligent Environments (IE), Dubai, United Arab Emirates, 2021, pp. 1-5, doi: 10.1109/IE51775.2021.9486595.

For consistency of the dissertation some typos are adjusted and phrases are reworded.

ABSTRACT

The ageing of the population in developed countries asks for smart solutions to promote seniors' inclusion in society. Therefore, how to shape a place that is both smart and encourages healthy ageing is a key question in the field of shaping smart and inclusive living environments. Smart placemaking, i.e. the augmentation of physical place with location-specific digital services, offers a range of powerful

opportunities to add value to public spaces in ways which can translate into health promotion in society and improved living environments for all. In order to successfully shape a healthy ageing living environment through smart placemaking, one could learn from the experience of successful practices of existing healthy communities. An example of such communities can be "Blue Zones" which are home for the world's longest-lived populations. This paper aims to integrate the process of smart placemaking with learnings from socio-spatial characteristics of Blue Zones in a neighbourhood-scale environment, i.e. Malvalaan, in The Netherlands. This integration will be presented in the form of proposing urban and architectural design interventions. The process of integration will be experimented in an immersive Virtual Reality (VR) environment. This paper reports on the feedback received from the participants (inhabitants of the Malvalaan) of the experiment which can lead to a better understanding of the proposed design interventions and, consequently, can help to provide better place-based architectural and urban design guidelines.

5.1 Introduction: the question, the opportunity, and the proposed solution

The escalating global trend towards ageing populations necessitates the urgent integration of healthy ageing principles into urban neighbourhood planning and design. In the Netherlands, where individuals aged 65 and older already constitute 20.2% of the population as of January 1, 2023, and are projected to increase to 26% by 2035, this demographic shift underscores the critical need for intentional and comprehensive spatial (re)planning of neighbourhoods to facilitate positive outcomes for healthy ageing [192], [193]. Despite this pressing need, the **question** of how to effectively shape urban neighbourhoods that support healthy ageing remains a key societal issue in the Dutch context [12]. Digital placemaking, an emerging

approach underpinned by computational systems that facilitate expert engagement, data-driven insights, and informed decision-making, has shown promise in promoting healthy ageing [10], [16]. However, the existing body of research on the application of digital placemaking specifically to healthy ageing remains limited. While promising, the potential of digital placemaking to address the complex and multifaceted challenges of creating age-friendly urban environments requires further exploration. There is a clear need for robust empirical studies and practical implementations to bridge the gap between theoretical concepts and real-world outcomes.

In digital placemaking, the proposition of **a virtual City Information Model (CIM)**– as an altered experience of the real-world environment through the imposition of computer-generated elements– provides a new opportunity to conceptualise, visualise, and optimise healthy ageing neighbourhoods before practising in real-life [13]. CIM typically involves creating a digital representation of a city's physical and functional features, such as buildings, roads, utilities, and other infrastructure [97]. The utilisation of immersive VR technology in CIM (vCIM) allows systematic manipulations of built environments that could not effectively be implemented in the real world and provide more immersive experiences of different environments than videos, photographs, and sketches [13], [94]. The advantages of vCIM application in placemaking include: 1) Conceptualisation: visualise and explore urban design concepts in a virtual environment before physical construction begins; 2) Spatial planning: testing different spatial arrangements, outdoor conditions, and material/component choices to optimise the design; 3) Collaboration and communication: sharing the CIM with clients, stakeholders, and the community to facilitate better communication and understanding of the design vision and enable collaborative design efforts by allowing multiple stakeholders to interact with the models simultaneously; 4) Interactive reviews: using VR and/or AR technologies to immerse stakeholders in a realistic

representation and allow them to interactive in design scenarios and feedback sessions; 5) Fast prototyping and testing: testing design scenario in virtual environments before implementation and assessing the compatibility of design with the context and the user acceptance; and 6) Human behaviour studies: simulating how occupants interact with and experience the architectural design to inform user-centred design decisions [194], [195], [196], [197].

Amidst this technological advancement, especially when it comes to executing new projects to promote healthy ageing, there is an **opportunity** for digital placemaking to draw lessons from the experience of successful and existing healthy living environments for future initiatives. An example of such environments are "Blue Zones" — regions known for their high concentrations of centenarians and exemplary health metrics [29]. The concept of Blue Zones was introduced to the academic community nearly 20 years ago by Michel Poulain and Giovanni Mario Pes[28]. They coined the term following demographic research in the Nuoro province of Sardinia, Italy, where they identified an exceptionally high number of centenarians. This discovery was focused on 14 mountainous villages, and the researchers developed the Extreme Longevity Index (ELI), calculated as the number of centenarians per 10,000 newborns. Their analysis revealed an average ELI of 508 per 100,000 births, a figure significantly higher than those observed in other regions of Sardinia [136]. Expanding this research, Dan Buettner identified four additional regions with similarly elevated centenarian populations (Table 15, for more details, please review Chapter 4):

- Okinawa, Japan: Renowned for the world's highest life expectancy among women, Okinawa has a notably high Centenarian Rate (CR) for men and women. Studies indicate that men in Okinawa have higher survival rates to age 100 compared to other regions, while women's rates are among the highest globally[131].

- Nicoya Peninsula, Costa Rica: Recognised as a longevity hotspot by the Vienna Yearbook of Population Research, a survival analysis from 1990 to 2011 revealed a male death rate ratio (DRR) of 0.80 in Nicoya. Males aged 60 in Nicoya have a sevenfold higher probability of reaching centenarian status compared to their Japanese counterparts, with a life expectancy surplus of 2.2 years[133].
- Ikaria, Greece: This small Aegean island boasts a significant centenarian population. Cardiologic examinations in 2009 highlighted the island's high average age at natural death, with over 30% of fatalities occurring post-90 years of age, surpassing other global regions by nearly a decade[136].
- Loma Linda, Southern California, USA: Home to a large Seventh-Day Adventist community, Loma Linda has a life expectancy nearly a decade longer than the average American[138].

Table 15. An overview of socio-spatial and lifestyle characteristics of Blue Zones based on diverse sources.

Blue Zone	Context	Area (Km²)	Scale	Population	Density (inhab/Km²)	Centenarian Prevalence (per 100,000)
Sardinia	Italy	1559	Macro (part of island)	42113	37	17
Okinawa	Japan	1201	Macro (part of island)	138472	1015	50
Nicoya	Costa Rica	788	Macro (part of peninsula)	326953	67	23
Ikaria	Greece	255	Macro (part of island)	8423	31	84 per 8423
Loma Linda	USA	19	Meso (urban district)	23961	3130	20

In Blue Zones, the concept that residents' healthy ageing can be both an outcome of their socio-spatial environment and their lifestyle

characteristics has profound **implications for its measurement**. Extensive epidemiological studies have examined multiple aspects of life in Blue Zones, including diet, mental health, cardiovascular health, longevity, obesity, and physical activity [134], [140], [183]. In 2024, Najafi et al. embarked on an exploratory study to investigate the age-friendly components of the built environment that contribute to the success of Blue Zones [14]. They employed in-depth qualitative analysis and CNN-based image processing to derive actionable strategies and policy advice for neighbourhood redevelopment, urban design, and planning. The culmination of their research led to the formulation of the Blue Zone Neighbourhood (BZN) policy advice guidelines (*Figure 26*).

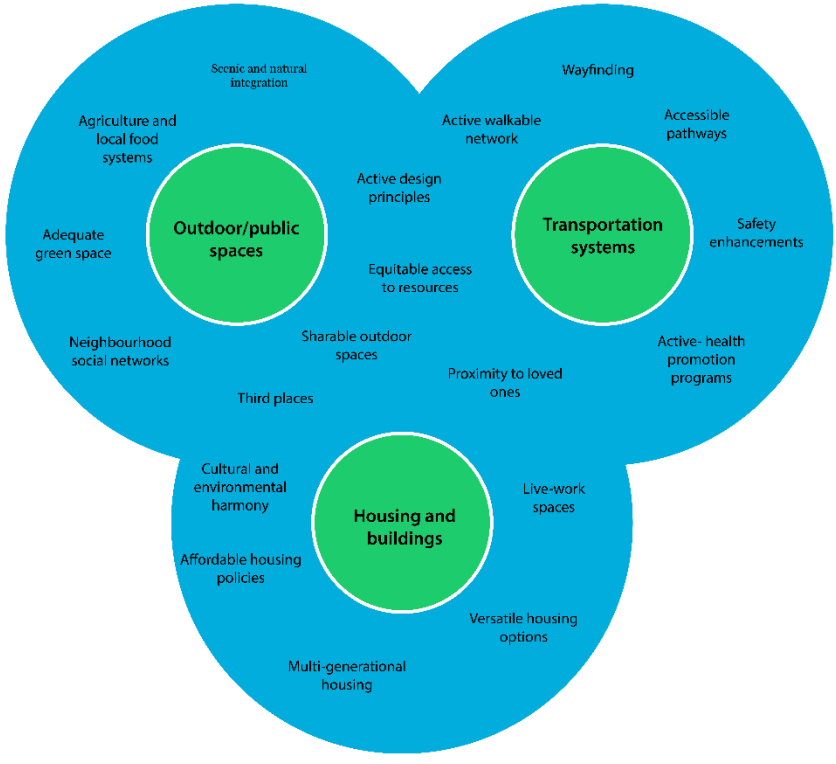


Figure 26. The BZN policy advice, source: adopted from [14].

The potential of **employing vCIM in placemaking, particularly in conjunction with the BZN policy advice guidance**, presents a **compelling opportunity** for urban scholars and practitioners. In vCIM, potential configurations of the neighbourhood in BZN design advice can be assessed on how residents might perceive and value these proposed designs for their future living conditions. This synergistic approach allows for the assessment of potential neighbourhood configurations based on BZN design principles within immersive virtual environments. It offers a unique lens through which to understand how residents might perceive and value these proposed designs, ultimately influencing their future living conditions. However, despite its promise, the application of vCIM in digital participatory urban neighbourhood design and decision-making remains limited due to a range of socio-technical limitations. These include the restricted accessibility and affordability of VR hardware, the complexities of integrating vCIM with existing planning and design workflows, potential technical challenges such as data compatibility and visualisation issues, and user adoption barriers stemming from a lack of familiarity with VR technology and the need for specialised training [13], [85], [92], [97].

This empirical study investigates the innovative application of digital placemaking for designing healthy ageing neighbourhoods. In a pioneering collaboration with older adults (65+ years old), we leverage the Blue Zones Neighbourhood (BZN) policy advice strategies within a vCIM environment. This novel approach enables us to explore potential neighbourhood configurations and, crucially, gather in-depth qualitative insights into how residents perceive and value these proposed designs for their future living conditions. Our research goes beyond theoretical frameworks and aims to produce tangible outcomes. Specifically, we will develop place-based design guidelines and generate design variants tailored for living environments where healthy ageing is central. These outputs have the potential to directly inform and

influence real-world urban planning and design decisions. Moreover, our study is poised to yield significant insights into the benefits and challenges of integrating vCIMs into participatory urban design and decision-making processes, particularly when partnering with older adults. This exploration of the user experience, technological barriers, and the impact on the democratic process will be invaluable for refining future digital participatory planning methodologies.

This paper is structured as follows: Section 5.2 outlines the placemaking process, detailing the steps from defining the study context and stakeholders to evaluating the context and identifying issues, developing a place vision, and conducting a pilot short-term experiment. Section 5.3 presents the study results, including geo-tagged feedback and place-based design guidelines for ongoing re-evaluation and long-term improvements. Section 5.4 explores the broader implications of the findings, focusing on leveraging digital placemaking for age-friendly neighbourhoods, insights from the vCIM experiment with older adults, and the benefits and limitations of vCIM in practice. Finally, Section 5.5 concludes the paper, summarising key findings and suggesting potential areas for further investigation.

5.2 Methodology

5.2.1 The placemaking process

Placemaking encompasses both a philosophical approach to public spaces and a practical process for their transformation. This study adopts the five-step process defined by Project for Public Spaces (PPS) to structure its investigation of placemaking initiatives (Figure 27) [198]:

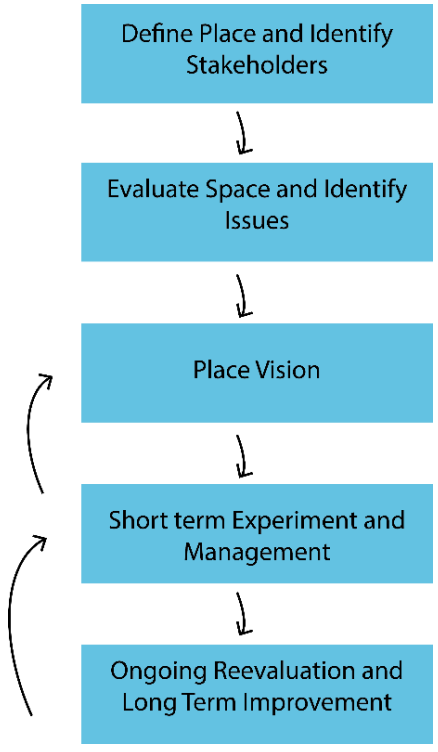


Figure 27. The placemaking five-step functionalities, source:[30]

5.2.2 Step 1: Defining the study context and stakeholders

This research is embedded within a broader investigation of urban neighbourhoods, focusing on the Malvalaan residential compound in Waalre, Netherlands. Situated in the Voldijn district of Aalst, Malvalaan encompasses 19,703 square meters and is characterised by a mix of detached, semi-detached, and terraced houses, along with four apartment blocks at its core (Figure 28). Built predominantly in the 1970s (with one block demolished in 2020), these interconnected buildings share a communal courtyard and corridor system, fostering social interaction among the approximately 140 residents.

Malvalaan's location is significant due to its proximity to essential amenities. Retail zones and local businesses lie within a 400-meter walking distance along major roads like Akeleilaan and Aalst Waalre Apk. Additionally, green spaces such as the park around BP De Voldijn and playgrounds like Speeltuin Bolderiklaan offer recreational opportunities to the inhabitants.

The stakeholders of this experiment are older adult inhabitants of the Malvalaan, who constitute nearly 60% of residents, with a significant portion of the older population remaining healthy and active, with a strong desire to age in place within their community. In addition, the Housing Association Wooninc, the healthcare

organization Oktober, the municipality of Waalre and the Eindhoven University of Technology are the key stakeholders of the initiative.

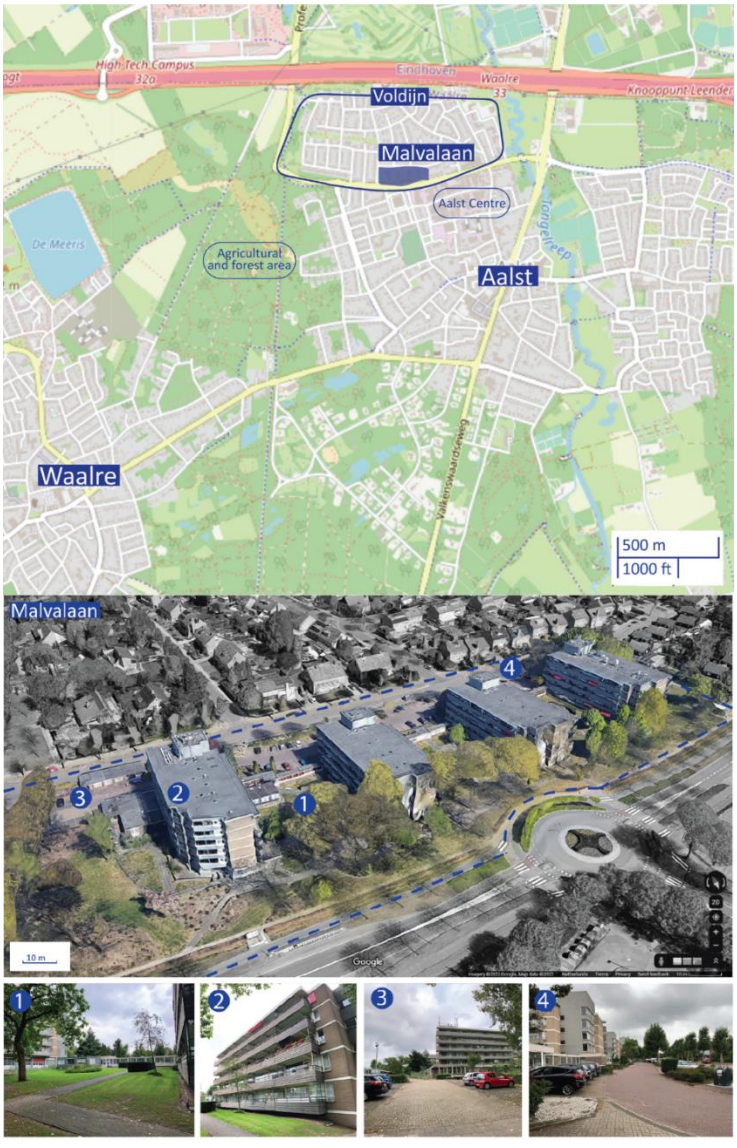


Figure 28. The image above depicts the location of Malvalaan in relation to Waalre, Aalst, and Voldijn, sourced from OpenStreetMap. The image below is an aerial view of the case study area taken from Google Maps in January 2022.

5.2.3 Step 2: Evaluating the Malvalaan neighbourhoods and identifying the issue

The primary challenge facing the neighbourhood is the ageing population; the majority of residents are over 65 and wish to age in place. However, their existing housing stock, predominantly social housing, lacks amenities conducive to healthy ageing, and the surrounding environment presents additional barriers.

To address this, we initiated the Healthy Ageing Malvalaan project in collaboration with stakeholders. This study aims to determine how the neighbourhood environment can be adapted to better support healthy ageing. We utilise the BZN policy advice as a foundation, exploring promising design variants and assessing their applicability within the Malvalaan context.

Employing a participatory research methodology, we conducted two co-creation workshops with 108 stakeholders representing diverse perspectives, including residents, housing agencies, city officials, and academic experts (Figure 29). These workshops facilitated the dissemination of BZN insights and fostered collaborative ideation through brainstorming sessions, focus group discussions, and neighbourhood walks. The input generated from these activities informed the development of a design optimisation framework specifically tailored to Malvalaan. This inclusive approach ensured that the research outcomes are grounded in the lived experiences and aspirations of the community, promoting a sense of ownership and agency in the design process.

Figure 29. Malvalaan co-creation workshop

5.2.4 Step 3: Place vision

The co-creation workshops yielded three fundamental components that will guide the subsequent design optimisation and decision-making phases of this study (Figure 30). These components will be detailed in the following sections, highlighting the specific strategies and recommendations that emerged from the collaborative engagement with stakeholders.

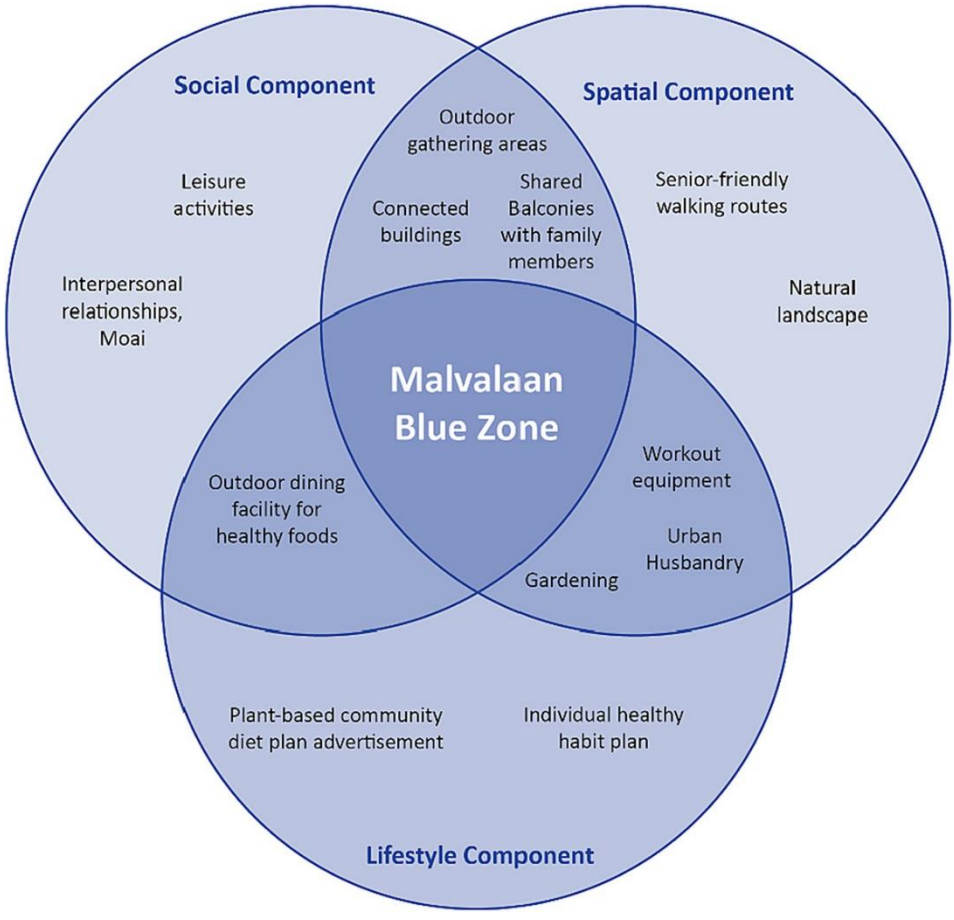


Figure 30. Malvalaan Blue Zone design optimisation plan

5.2.5 Step 4: Short term experiment and management

5.2.5.1 Virtual CIM prototype development

To visualise the place vision, we prototyped the vCIM based on the systems architecture proposed by Najafi et al, (2023) for creating user-centred vCIM for inclusive community design [13]. This approach comprises six interconnected components:

- Data feed: This stage involved incorporating 3D scenarios derived from co-creation workshops with Malvalaan's older

adult residents. These scenarios encapsulate key aspects like preferred outdoor gathering spaces, essential amenities, landscaping preferences, and desired leisure activities (Figure 31). The collected data informs the development of realistic and contextually relevant VR content.

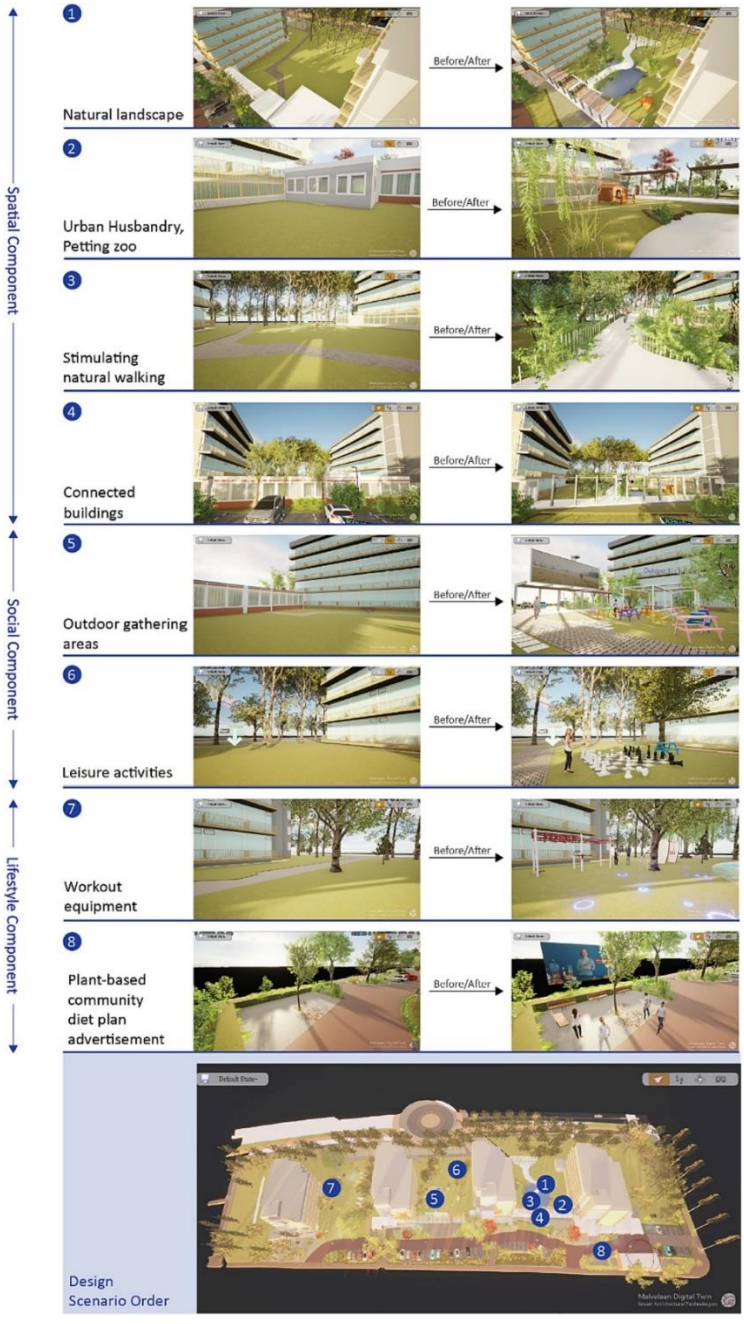


Figure 31. Blue Zones-based design ideas for experimenting in digital placemaking of Malvalaan.

- 3D BIM of the case study: A detailed BIM model of the Malvalaan residential compound is created using a Level of Detail (LoD) 300. This model integrates data from various sources, including urban and architectural drawings, site measurements, and photogrammetry. Developed using SketchUp and Unreal Engine, the model includes intricate representations of the residents' neighbourhoods and homes and is optimised for seamless integration into the VR environment.
- Computational engine: The BIM model is seamlessly integrated into the Unreal Engine, a powerful real-time 3D creation tool. This integration enhances the VR experience with realistic lighting, shadow effects, and interactive elements, enabling users to navigate and interact intuitively within the virtual space.
- HCI workflow: Communication with users is facilitated through the Oculus Quest 2 VR headset, chosen for its user-friendly interface and ergonomic design, making it suitable for older adult users. The VR setup accommodates seated navigation to minimise physical strain during the immersive experience.
- Feedback collection procedure: A robust geo-tagging system is integrated within the vCIM platform, facilitating a comprehensive collection of feedback from both residents and stakeholders. This system enables precise, real-time capture of geographical metadata alongside user feedback, ensuring a nuanced understanding of the relationship between location and sentiment [13]. Participants' interactions, preferences, and satisfaction levels are thus analysed within their spatial context, allowing for a thematic interpretation of data that reveals patterns and trends specific to different areas within the Malvalaan

neighbourhood. The insights gleaned from this geo-tagged feedback serve as the foundation for developing user-centred design guidelines, which guide the optimisation process in Malvalaan to ensure that the proposed renovations align with the expressed needs and preferences of the community.

- **Data store and analysis:** The vCIM platform provides an immersive experience for participants, allowing them to explore virtual models of the Malvalaan neighbourhood before and after proposed renovations. As they navigate these virtual environments, their real-time feedback and interactions are meticulously recorded. This immersive approach also elicits valuable insights into user preferences and spatial experiences, as participants can visualise and assess the potential impact of the proposed changes. All feedback data, along with the associated geographical metadata, are systematically stored within the vCIM repository. This centralised repository serves as a valuable resource for future reference, ensuring that the data remains accessible for ongoing analysis, evaluation, and refinement of the design guidelines throughout the optimisation process.

Figure 32. Geo-tagged Feedback during placemaking in the Malvalaan vCIM.

5.2.6 Pilot short-term experiment

A one-day digital placemaking pilot experiment was conducted at Malvalaan in December 2023 (Figure 33). Two cohorts participated: A) five residents aged 65 and over, and B) five stakeholders, including four architects and a housing association consultant (average age 35.2 years). All participants provided informed consent after being briefed on the research background, aims, and objectives. The experiment, lasting 4.5 hours, commenced with a 30-minute introduction to the eight design scenarios derived from prior discussions on the BZN policy advice. The subsequent 3.5 hours were dedicated to experimentation, communication, and group discussion (Figure 7). Residents spent an average of 18 minutes in the virtual environment, while stakeholders averaged 24 minutes.

The experimentation process lasted for a total time of 4.5 hours, which was about 1.5 hours less than initially estimated. The first 0.5 hours were devoted to introducing nine prototyped (re) design scenarios and a tutorial about using the vCIM. Then, 3.5 hours were devoted to the activity of experimentation, communication, and group discussion (Figure 33). The average time of the resident group

experiencing the vCIM was about 18 minutes, and the group of younger architects and the consultant from the housing association was about 24 minutes.

Figure 33. Digital placemaking pilot study conducted with Malvalaan stakeholders

The immersive experience began at the main entrance of the residential buildings, guiding participants to their virtual homes. After confirming the accuracy of their current home's representation, participants were shown a tailored design scenario for their dwelling. Subsequently, they were teleported to the additional scenarios: 1) scenic natural landscape, 2) community garden, 3) move naturally pathway, 4) building connection corridors, 5) outdoor gathering spaces, 6) leisure activity areas, 7) workout areas, and 8) health promotion stands. Researchers controlled all interactions from the back-end to facilitate ease of use for senior participants.

5.3 Results

5.3.1 Geo-tagged- feedback

Data analysis, encompassing both group discussions and geo-tagged feedback collected through the vCIM during the digital placemaking exercise, identified key requirements and design issues raised by participants (Table 16).

Table 16. The Malvalaan inhabitants' feedback about the optimal design scenarios.

Source	Gender	Feedback	Content tag	Design concept addressed	Feedback translated to English?
Inhabitant Malvalaan complex	F[a]	*The design could use more green areas. Love the idea of taking inspiration from nature. I also like the idea of a bridge over a pond. But I don't think it's right for elderly people. I felt like I was falling, especially when I was on the bridge.*	#green_space #elderly #bridge	1	Yes
Inhabitant Malvalaan complex	F	*In my opinion, points 1 and 5 are still unsafe, especially at night. I see a tiny bit of light along the corridor.*	#safety #corridor	6,7	No
Inhabitant Malvalaan complex	M[b]	*It's a good idea to have a dinner party outside. We Dutch like to get together when it's sunny.*	#outdoor_dining	5,6	No
Inhabitant Malvalaan complex	F	*I think people in neighbouring areas can even use this outdoor gathering design. I would like this space to be more usable for Malvalaan residents.*	#privacy	6	No
Inhabitant Malvalaan complex	M	*I don't think it's a good idea to remove the corridor between buildings 2 and 3. There's a lot of rain here and a lot of people commute between these two blocks.*	#corridor #weather	4	Yes
Inhabitant Malvalaan complex	F	*I like the shared balcony pattern. I'd like to live with my kids, but I don't know if they'd agree [laugh].*	#shared_balcony	4	Yes
Inhabitant Malvalaan complex	F	*I like having a small garden next to my house. It would be great if I could have a few geese too [laughing]. But I don't think the place you've considered is right. Maybe*	#husbandry #gardening	2,3	Yes

Source	Gender	Feedback	Content tag	Design concept addressed	Feedback translated to English?
		behind building 4. There's more open space there.			
Inhabitant Malvalaan complex	F	*It would be better if there were longer walking paths. I walk my dog every day. If we have a route of say 20 minutes in Malvalaan, that will be great for me.*	#walking_route	3,7	Yes
Inhabitant Malvalaan complex	M	*I think the corridors between buildings should be transparent. The Malvalaan is right next to my house, so I can just walk through it to get to the centrum.*	#corridor	4	Yes
Inhabitant Malvalaan complex	M	*I really like the daily health plan. I ride my bike six kilometres a day. I'm retired, so I have plenty of time. So are my friends. If we have a programme for group sports in our neighbourhood, I will definitely join.*	#health_programme	8	No
Inhabitant Malvalaan complex	F	*It doesn't seem like the workout equipment is placed correctly. It's right in front of the building. Personally, I don't mind this, but I don't like feeling patronised.*	#workout #privacy	7	Yes
Inhabitant Malvalaan complex	M	*Leisure activities don't seem to have enough variety and are mostly meant for sunny days. It's nice to be able to go outside during the fall and even winter. Especially at Christmas.*	#leisure_activity #outdoor_dining_activity	6,5	Yes

[a]F: Female; [b]M: Male

5.3.2 Place-based design guidelines for ongoing re-evaluation and long-term improvements

In response to the identified issues, a comprehensive synthesis of key findings from participant feedback culminated in the development of a series of design variants and corresponding urban design guidelines (Table 17) for further optimisation during the placemaking process. These guidelines, designed to inform and refine the ongoing placemaking process, offer context-specific recommendations aimed at promoting healthy ageing within the

unique setting of Dutch urban neighbourhoods. They highlight the importance of considering factors such as accessibility, social connectivity, and the provision of green spaces in creating age-friendly environments.

Table 17. Urban Design Guidelines for Promoting Healthy Ageing in the Malvalaan Neighbourhood

Design variant	Malvalaan Neighbourhood Design Guidelines
Scenic Natural Landscape	Create a variety of microclimates through topography and vegetation to offer diverse sensory experiences and encourage exploration.
	Utilise natural, locally sourced materials (e.g., stone, wood) for pathways, seating areas, and structures to harmonise with the environment.
	Incorporate water features (e.g., ponds, streams) to enhance the aesthetic appeal, provide habitat for wildlife, and create a calming atmosphere.
	Provide interpretive signage to educate visitors about local flora and fauna.
	Integrate seamlessly with the community garden, creating a cohesive and interconnected natural environment.
Community Garden	Ensure privacy for ground-floor residents by strategically positioning garden areas and using appropriate screening elements (e.g., trellises and hedges).
	Maintain an open garden without fences or hedges.
	Create a central, easily accessible area for shared gardening tools, equipment, and resources (e.g., compost bins, rainwater collection).
	Design raised garden beds of varying heights to accommodate diverse mobility needs and encourage participation from all residents.
	Provide a variety of seating options (e.g., benches, picnic tables, moveable chairs) to cater to different group sizes and preferences.
	Incorporate desired elements such as picnic tables, pergolas, fruit trees, berry bushes, insect-friendly plants, flowers, and vegetable garden boxes (especially for herbs).
Move naturally pathways	Encourage a sense of ownership and community by allowing residents to personalise their garden plots and contribute to the overall design.
	Incorporate exercise stations (e.g., pull-up bars and balance beams) along the pathways to promote physical activity and fitness.
	Design looped pathways of varying lengths and difficulty levels to cater to different fitness levels and interests.

	Utilise permeable paving materials to reduce stormwater runoff, mitigate flooding risk, and improve groundwater recharge.
	Create direct and intuitive connections between pathways and key destinations within the neighbourhood (e.g., community garden, main building entrance, bus stops).
Third place and gathering areas	Incorporate wayfinding signage that clearly indicates distances, destinations, and points of interest along the pathways.
	Integrate gathering and play areas into the community garden to encourage intergenerational interaction and create a vibrant social hub.
	Recognise the value of balconies as semi-private outdoor spaces that offer opportunities for relaxation, gardening, and social interaction while respecting individual privacy preferences.
	Acknowledge the existing communal hall as a valuable indoor gathering space and explore ways to enhance its functionality and appeal.
	Provide a diverse range of seating options (e.g., benches, chairs, moveable furniture) to accommodate different group sizes, activities, and preferences.
	Incorporate shade structures (e.g., pergolas, awnings, trees) and windbreaks to provide protection from the elements and extend the usability of outdoor spaces.
	Incorporate natural elements (e.g., trees, water features) to create a pleasant atmosphere.
	Preserve sufficient grass for picnics and events.
Leisure activity areas	Host regular gardening workshops and events to foster community engagement and knowledge sharing.
	Create spaces for collaborative work and hobbies without fixed schedules.
	Offer a wide variety of leisure activities to cater to diverse interests and age groups (e.g., chess tables, bocce ball courts, reading nooks, game areas, art studios).
	Clearly delineate areas for quiet activities (e.g., reading, meditation) and more active pursuits (e.g., games, exercise) to minimise conflicts and ensure a comfortable experience for all users.
	Incorporate public art installations, interactive elements, and natural play structures to stimulate creativity, curiosity, and engagement.
Building connection corridors	Consider covering corridors to protect against rain and inclement weather while ensuring adequate natural light and ventilation.
	Use artwork and murals to add visual interest
	Install handrails and non-slip flooring to enhance safety for elderly residents.
	Provide seating areas for rest and informal interaction.

	Utilise clear and intuitive wayfinding signage, including maps, directional arrows, and floor markings, to help people easily navigate the building complex.
Workout areas	Locate workout areas in proximity to walking and cycling paths, encouraging active transportation and integration into daily routines.
	Consider incorporating natural elements (e.g., hills, rocks) into the design for added challenge and variety.
	Provide a variety of outdoor fitness equipment suitable for different ages, abilities, and interests (e.g., resistance bands, stationary bikes, elliptical machines).
	Create shaded areas with seating to allow for rest and recovery between exercises.
Health promotion stands	Design visually appealing and engaging displays with clear, concise messaging related to healthy ageing and lifestyle choices.
	Strategically locate stands in high-traffic areas with high visibility (e.g., in front of the main entrance, community garden, or along the "Move Naturally" pathways).
	Partner with local health organizations (e.g., Oktober care organisation) to provide relevant and up-to-date information.
	Update content regularly to keep it fresh and relevant.

5.4 Discussion

5.4.1 Leveraging digital placemaking for age-friendly neighbourhoods

The integration of digital placemaking in urban neighbourhood design offers a promising avenue for addressing the evolving needs of an ageing population. Our study, which explored the application of BZN policy advice within a vCIM, underscores the potential of digital tools to enhance participatory urban design and foster healthy ageing environments.

Our findings extend beyond the specific context of a Dutch community, offering insights into the broader field of urban planning and the development of age-friendly cities. Our research highlights the role of digital technologies in meeting this challenge by facilitating inclusive and responsive urban design processes. The principles derived from Blue Zones provide a valuable framework for developing

neighbourhoods that promote longevity and well-being. VCIMs enhance this process by enabling stakeholders to collaboratively explore and optimise design solutions in a virtual space. This approach aligns with contemporary trends in urban digital participatory planning, emphasising community involvement. This aspect is particularly crucial for older adults, who may experience social isolation and a lack of agency in decision-making processes.

Our findings have also significant implications for both policy and practice. Local governments and urban planners can leverage insights from vCIM-enabled participatory design to inform policy decisions and prioritise investments in age-friendly infrastructure. The collaborative nature of the process can also help build consensus among stakeholders, reducing conflicts and facilitating the implementation of design interventions. Particularly, the geo-tagged feedback system within the vCIM can facilitate a nuanced understanding of user interactions, revealing specific design elements that resonate with elderly residents.

5.4.2 Insights from the virtual CIM experiment with older adults

Our digital placemaking with older adults reinforces existing research on the importance of familiarity in promoting technology engagement among this demographic [199], [200], [201], [202]. Notably, we observed that conducting VR-based placemaking sessions within familiar settings, such as communal areas of their residential buildings, significantly mitigated the perceived intimidation often associated with emerging technologies. This familiar and comfortable environment appeared to make the VR experience more approachable and less daunting for older participants.

Further research is essential to fully explore and understand this phenomenon. In-depth studies could identify the specific environmental elements that contribute to reducing apprehension, as

well as examine how these factors interact with the psychological and social dimensions of technology acceptance among older adults.

Additional key insights from our study include:

- **Collective engagement:** Incorporating group dynamics into VR interventions boosted participant engagement and confidence. Enabling older adults to participate in groups with friends or neighbours seems to foster a supportive environment that lessens reluctance towards technological interaction.
- **Communication strategy:** Communicating in the participants' local language ensured clear understanding and maintained engagement. The preference for verbal over written communication among senior participants necessitated provisions for oral interviews and auditory feedback mechanisms within the VR experience.
- **Context-Specific Adaptations:** The critical role of context in practice-to-research endeavours should not be overstated. As Leon (2003) aptly notes, "context provides meaning [203]." Our study, a meticulous examination of a Dutch community's efforts to create a "man-made Blue Zone," exemplified this principle. We found that a direct application of the BZN policy recommendations is insufficient; instead, a nuanced understanding of the local context is essential. For instance, the BZN advocates for active natural movement, such as walking for daily commutes. However, in the context of our Dutch community case study, a majority of inhabitants, including older adults, utilise bicycles as their primary mode of transportation. The bicycle is not merely a vehicle; it is a cultural asset deeply ingrained in Dutch society, contributing

significantly to the high levels of physical activity and overall health observed among residents. This cultural significance was repeatedly emphasised during our workshops, underscoring the need to preserve and promote this value as a contextualised example of increasing physical activity through natural behaviour.

5.4.3 Benefits and limitations of virtual CIM in practice

vCIMs could offer numerous benefits in the realm of urban design. They bridged gaps between diverse stakeholders, facilitating clearer communication of design intentions. The transparency provided by vCIM tools promoted open communication and the documentation of feedback, which is essential for ongoing evaluation and improvement. vCIMs enhanced placemaking processes by 1) Increasing transparency in decision-making. 2) Enabling cost-effective comparisons of design scenarios. 3) Gathering more reliable stakeholder input. And 4) Saving municipal resources through short-term experimentation and streamlined decision-making. Simulating various design scenarios allowed for efficient testing and refinement of ideas before physical implementation, reducing the risk of costly post-construction modifications. Additionally, the interactive features of vCIMs provided a rich dataset for analysing user preferences and behaviour, informing evidence-based design decisions.

However, challenges remain. The development and maintenance of high-fidelity vCIMs require significant resources and technical expertise. Furthermore, the accessibility of VR technology, particularly for older adults, needs to be addressed to ensure equitable participation in the design process. Future research should focus on expanding the scope to include diverse neighbourhoods and demographic groups, investigating the long-term impact of vCIM-enabled design on community health and well-being.

5.5 Conclusion

This research demonstrates the significant potential of digital placemaking and vCIM in designing age-friendly neighbourhoods. Integrating the principles of Blue Zones and leveraging immersive VR technology, we have provided an example for creating inclusive and responsive urban environments that have the potential to support healthy ageing. The active involvement of older adults in the participatory design process provided valuable insights and fostered a sense of ownership and agency.

While challenges such as ensuring equitable accessibility for all demographics and addressing the inherent technical limitations of virtual environments persist, the transformative potential of vCIMs in democratising urban neighbourhood planning and fostering informed decision-making is undeniable. The findings of this study underscore the critical need for a paradigm shift in urban planning practice and policy, moving towards a more user-centred and technology-enabled approach that prioritises the needs, preferences, and aspirations of the community, particularly in the context of designing age-friendly environments. The successful integration of vCIMs into the planning process necessitates a collaborative effort amongst urban planners, technologists, policymakers, and community members to overcome existing challenges and leverage the full potential of this innovative tool for shaping healthier, more inclusive, and sustainable communities for all ages.

Future research should aim to broaden the scope and scale of these initiatives, delving deeper into the longitudinal impact of design interventions on the well-being and quality of life of older adults. An essential departure point for further investigation lies in examining the potential for integrating diverse data sources, such as health records or social media sentiment analysis, to gain a more comprehensive understanding of the complex interplay between the built environment

and individual well-being. As the field continues to evolve, ongoing innovation and the sustained engagement of diverse communities in the design process will be paramount to creating urban environments that not only promote healthy ageing but also enhance the overall liveability and inclusivity of neighbourhoods for individuals of all ages and abilities.

Chapter 6 Conclusions

Conclusions

6.1 Overview of research questions

This chapter provides a comprehensive reflection on the research undertaken in this thesis, addressing each research question before delving into the primary research inquiry. An empathic design living lab methodology was employed to investigate four key research questions, the findings of which collectively contribute to answering the main research question: **"To what extent and how can digital technology and placemaking be combined to shape a healthy ageing neighbourhood with senior citizens?"** The following section summarises the findings from each chapter, addressing each research question before addressing the central one.

Research question 1: What is the state of the art on digital placemaking with respect to exploring the active involvement of senior citizens?

Chapter 2 sought to answer the research question by conducting a comprehensive systematic literature review, exploring the convergence of placemaking, digital technology, and the involvement of senior citizens within placemaking processes. The investigation found that between 2011 and 2022, the participation of senior citizens was notably insufficient and underrepresented, leading to significant concerns about the inclusivity and equitable distribution of benefits arising from advancements in digital and data-driven technologies within urban participatory design studies. The research identified several key barriers to active engagement among senior citizens, including: The digital divide: Limited access to and

familiarity with digital technologies. Cognitive and physical disabilities: Challenges in utilising digital tools and platforms. Psychological factors: Feelings of intimidation, lack of confidence, or discomfort with technology.

Moreover, the study's analysis indicated a significant bias within the existing literature on digital placemaking towards the use of technology as a tool for crafting visually appealing digital experiences. This emphasis on the creation of digital artefacts, such as interactive installations and immersive light displays, often overshadowed a deeper consideration of the role that digital tools and platforms could play in fostering meaningful participation and co-creation among diverse stakeholders. Notably, this lack of attention to digital participatory planning was particularly evident in the underrepresentation of vulnerable populations, including senior citizens, who may face unique challenges and barriers to engagement in digital decision-making.

The study further mapped a scattergram of advanced digital instruments and approaches implemented or cited in current placemaking initiatives. This analysis revealed a notable trend towards human-computer interaction and data-driven approaches, with virtual, augmented, and mixed realities, 3D point cloud simulations, and digital twinning playing a transformative role in recent projects. However, the engagement of less-technical stakeholders, such as senior citizens, in the development and utilisation of these technologies remained under-explored. This knowledge gap underscored the imperative of bridging the digital divide, designing intuitive user interfaces, and adopting inclusive methodologies that enable all parties – both technical and non-technical, including senior citizens – to participate fully in advanced digital placemaking initiatives.

Research question 2: *How do we create a digital placemaking system that supports the involvement of senior citizens during the neighbourhood (re)design process?*

To address the significant underrepresentation of senior citizens in digital placemaking initiatives identified in the previous chapter, Chapter 3 detailed the development of a user-friendly vCIM. Grounded in digital twin system architecture, this vCIM integrates highly detailed 3D visualisations of city models (LOD 300) with an intuitive geo-tagging system and an immersive VR environment. This digital placemaking aims for expert and non-expert(notably senior citizens) engagement, data-driven insights, and informed decision-making. The system efficiently captures and processes geo-tagged urban data, facilitating direct engagement between designers and user-generated content, thereby enhancing participatory planning and decision-making processes in neighbourhood placemaking.

To assess users' perceptions of both the pragmatic and hedonic aspects of the proposed vCIM placemaking system, a user study was conducted with both expert and non-expert users (older adults aged 65+). The study evaluated the understandability, usability, and perceived ease of use of the vCIM through qualitative and statistical analysis. Results demonstrated that the vCIM effectively provides a user-friendly and valuable placemaking experience, fostering a holistic understanding of the neighbourhood that considers the needs and perspectives of all community members, including senior citizens. Furthermore, it was confirmed that the proposed CIM semi-accurately reflects the neighbourhood's reality and is effectively usable by stakeholders in planning and decision-making processes. Finally, potential areas for improvement were identified, highlighting opportunities for further advancement in the digital participatory urban studies.

Research question 3: *Realisation of a healthy ageing neighbourhood; What specific neighbourhood policies and design*

principles, derived from successful existing models of healthy ageing communities, can be effectively translated into placemaking strategies for contemporary ageing neighbourhoods?

In preceding chapters, I explored the potential and barriers to senior citizen involvement in digital placemaking and developed a virtual City Information Model (vCIM) grounded in digital twin principles to enhance their active participation in neighbourhood (re)design initiatives. Chapter 4 shifted focus to the practical realisation of these findings within the broader context of shaping age-friendly urban environments. Specifically, it critically examined the translation of insights gleaned from the Blue Zones, renowned for their exceptional longevity and well-being outcomes, into actionable strategies and policy recommendations for promoting healthy ageing within Dutch urban neighbourhoods.

The selection of Blue Zones as a model was motivated by their status as home to the world's longest-living populations, epitomising natural environments that have successfully fostered healthy living conditions for residents throughout their lives. Investigating the age-friendly attributes of the Blue Zones' built environment was deemed crucial for influencing comprehensive neighbourhood planning and design, particularly in relation to the vCIM placemaking system, where these learnings could be utilised for feasibility testing and realisation.

A comprehensive review of peer-reviewed research on the built environment characteristics of Blue Zones revealed a relative dearth of information, as the majority of studies have concentrated on epidemiological aspects such as cardiovascular health, longevity, and diet, with limited attention given to urban planning and design. To address this gap, an empirical examination of the Blue Zones' built environment was undertaken. Traditional methods, such as field surveys, were deemed impractical due to the geographical dispersion of Blue Zones and constraints related to time, cost, and logistical

efforts. However, advancements in AI and deep learning algorithms, particularly convolutional neural networks, facilitated a remote analysis of the built environment features of Blue Zones using publicly accessible imagery datasets, such as Google Street View imagery.

This analysis culminated in the formulation of the Blue Zone neighbourhood (BZN) planning and design policy advice. Several key implications were identified, including the criticality of adaptability in urban neighbourhood management, the transformation of third places into more versatile semi-private and natural social spaces conducive to healthy ageing, the enhancement of vascular health through environmental design, and the reinforcement of the importance of tailoring solutions to the specific contexts of urban neighbourhood planning and design. The BZN policy advice, formulated in the later stages of this research, equipped the vCIM placemaking with a tested design and planning blueprint for realising and evaluating the feasibility of Blue Zone promises in real-life, user-centric urban neighbourhood experiments with senior citizens.

Research question 4: *How do we co-create a healthy ageing neighbourhood in digital placemaking with older adults within the Dutch context?*

Chapter 5 delved into the practicalities of co-creating healthy ageing neighbourhoods in the Dutch context, employing digital placemaking tools with a focus on older adult participation. The primary goal of this study was to bridge the theoretical framework and system development of previous chapters with real-world implementation, addressing the complex question of how to translate ideals into action.

The findings from the experiment involving real senior citizens proved valuable in several ways. A key finding was the importance of fostering trust and rapport between older adults and

researchers/facilitators. This echoes existing literature on community-based participatory research, but the chapter goes further by suggesting specific strategies tailored to address the encountered barriers to participation in technologically mediated environments. The chapter culminates in a set of design principles for co-creation in digital placemaking, providing practitioners with a roadmap for implementing similar initiatives.

The experiment yielded insights that significantly impacted the vCIM placemaking system. It facilitated a transparent, data-driven workflow between designers and senior citizens, promoting active collaboration during the placemaking process. As urban designers, we were able to shift our role from active enablers of the placemaking process to providers of backend support for seniors' active involvement, managing the system architecture to ensure a seamless experience for them within the virtual environment. Conversely, senior citizens transitioned from occasional passive participants of placemaking to key enablers within the vCIM system, providing input to designers while comfortably exploring scenarios. This workflow also proved valuable in creating a repository of geo-tagged input from senior citizens, informing future optimisation plans.

Furthermore, this represented a valuable advancement in data-driven placemaking and urban co-creation initiatives. It allowed for the collection of more reliable and accurate data directly from the users of urban environments. Importantly, this approach reinforced the digital agency of senior citizens in current digital-based urban initiatives, thereby empowering their involvement. Empowering healthy ageing involves not only creating a conducive environment for senior citizens but also establishing meaningful ways to enhance their potential to continue contributing to their living environment, amidst the rapid advancements in technology.

6.2 Academic contribution

The four studies reported in this dissertation make academic contributions to multiple interdisciplinary domains, including urban design, community health, social inclusion and ICT, particularly focusing on the involvement and empowerment of senior citizens in urban neighbourhood planning. I discuss the academic contributions of these four studies in more detail here.

In Chapter 2, I address a critical gap in existing research by systematically exploring the state of the art in digital placemaking with a specific focus on the active involvement of senior citizens. This chapter contributes to the broader discourse on digital placemaking by highlighting the underrepresentation of agency of senior citizens in digital participatory urban initiatives (e.g., [204], [205]). This finding is crucial as it raises important questions about inclusivity and equity in the advancement of digital technology within urban design studies. The identification of barriers to engagement for senior citizens, such as the digital divide, cognitive and physical disabilities, and psychological restrictions, provides a nuanced understanding of the challenges faced by this demographic in the digital realm.

Moreover, this chapter offered a critical examination of current digital placemaking initiatives, uncovering a prevailing tendency to view digital technology primarily as a means of creating aesthetically pleasing spaces rather than as a tool for enhancing stakeholder participation. This analysis encourages revisiting the role of digital technology in community engagement, particularly stressing the need for more inclusive approaches that cater to the perspectives and requirements of vulnerable and non-expert groups such as senior citizens.

Additionally, the chapter's scrutiny of various digital tools and methodologies in placemaking, including virtual, augmented, and mixed realities, digital twinning, and 3D point cloud simulations,

shed light on the dynamic nature of digital placemaking. While acknowledging the transformative potential of these technologies, this chapter also critically examines their application and development, paying particular attention to the agency and empowerment of non-expert stakeholders. This research underscored the critical importance of bridging the digital divide and developing user-centred interfaces that enable meaningful engagement for all stakeholders, regardless of their technical backgrounds. This emphasis on inclusivity and accessibility aligns with recent studies (e.g., [10], [13], [206]) that highlight the need for equitable participation in digital placemaking processes.

Chapter 3 enriches our understanding of the social and human aspects, or user dimensions, of urban digital twin opportunities for inclusive planning and design. A key feature of this system is its innovative geo-tagging architecture, which incorporates voice recognition to facilitate seamless user feedback input. This approach, increasingly employed by scholars (e.g., [86], [207], [208], [209], [210]), lowers the barrier to participation for individuals with varying levels of technological literacy, ensuring a more inclusive and representative data collection process. Such a feature substantially improves the inclusivity and depth of the data gathered, rendering it an indispensable tool for urban participatory planners and designers.

Chapter 4 of the dissertation presents its scientific contribution to the field of urban environmental research and community health, particularly, in the context of creating policies for healthy ageing communities. The chapter's primary contribution lies in its exploration of how insights from the world's most successful healthy ageing communities, known as the Blue Zones, can be translated into contemporary ageing neighbourhoods. This exploration is particularly valuable as it bridges the gap between theoretical understanding and practical application in the realm of urban neighbourhood design focused on senior citizens. A key

scientific advancement in this chapter is the empirical examination of the Blue Zones' built environment. I addressed the limited focus of existing research, which predominantly centres on epidemiological aspects, and broadened the scope of study to include urban planning and design considerations. My study's contribution to the advancement of knowledge in the field lies in providing actionable strategies and policy recommendations that are grounded in empirical research and tailored to the needs and preferences of ageing populations. This work sets a precedent for future research and practice in designing age-friendly urban neighbourhoods, emphasising the critical importance of integrating the perspectives, experiences, and aspirations of senior citizens into all stages of urban planning and design.

In the study reported in Chapter 5, I investigated the innovative application of digital placemaking for designing healthy ageing neighbourhoods, drawing inspiration from the BZN action policy. provided a unique lens through which to understand how residents might perceive and value these proposed designs, ultimately influencing their future living conditions. A major contribution of this chapter is the empirical evaluation of the vCIM system's usability by senior citizens. This evaluation addresses a critical gap in the current understanding of how senior citizens interact with advanced digital placemaking technologies. This addressee adds substantial knowledge to the field of digital participatory planning. Moreover, the findings from experiments involving real senior citizens are a testament to the chapter's scientific value. The establishment of a transparent, data-driven workflow between designers and senior citizens exemplifies a novel approach to collaborative urban design.

6.3 Societal implication

The four studies in this dissertation can support urban stakeholders, including decision-makers, planners, designers, community group, health organisation, especially those focusing on

vulnerable community group such as senior citizens, at various stages of placemaking and implementation. The following paragraph explains the societal implications of these studies (*Figure 34*).

The societal impact of the study presented in Chapter 2 reveals the underrepresentation of senior citizens in digital placemaking initiatives. The societal implication is a heightened awareness of the digital divide and the need for inclusive urban digital planning strategies that take into account the challenges faced by older populations. This research identifies barriers such as cognitive and physical disabilities and psychological restrictions and encourages urban designers and planners to develop more accessible digital initiatives, which can lead to achieving more inclusivity in urban initiatives and thereby promoting social equity.

The development of a user-friendly vCIM placemaking system, highlighted in the Chapter 3, has implications for how urban planning and design are approached in society. It demonstrates the potential of data-driven technology to create more inclusive and participatory urban planning processes, where senior citizens are not only considered but actively involved. This approach can lead to shaping inclusive environments that better cater to the needs of an ageing population, enhancing the quality of life for senior citizens and fostering a sense of community involvement and belonging.

Chapter 4 sets the potential of the study to support urban planners and designers in creating neighbourhoods that enable healthy ageing. It focuses on supporting the well-being of the senior population within the current ageing society, with promising insights drawn from the age-friendly features of Blue Zones. These insights can provide valuable content for stimulating healthy ageing communities within the Dutch context. Furthermore, the findings can influence future urban planning policies, highlighting the importance of subjects such as walkability, connection with nature, and the development of home-based and semi-private social third spaces.

This approach is aimed at fostering healthier, more sustainable, and conclusive urban neighbourhoods, responding to the needs of a globally growing ageing demographic.

The societal impact of the empirical study on digital placemaking initiative involving senior citizens, presented in Chapter 5, is multifaceted. Primarily, it showcases a successful model of how data-driven technology can be used to engage senior citizens in the decision-making process of their living environments. This participatory approach empowers senior citizens, giving them a voice and agency in the planning process. This can also lead to more tailored and effective urban digital participatory designs that meet the specific needs of the ageing population, potentially transforming how social housing is approached in urban planning. Furthermore, it sets a precedent for promoting a more democratic and responsive urban design process.

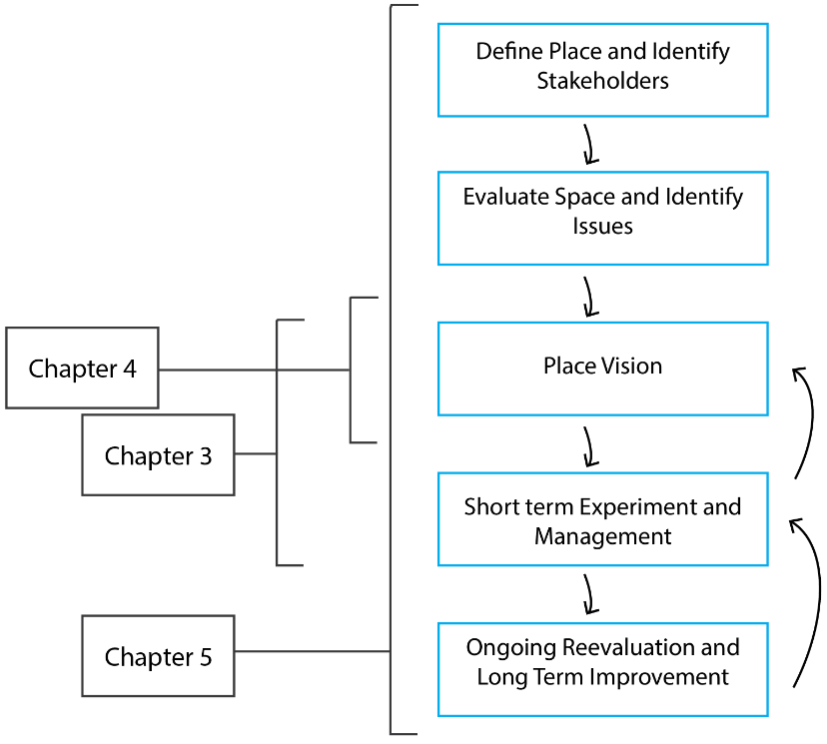


Figure 34. Contribution of each study to the placemaking planning process

6.3.1 General conclusion

This dissertation has endeavoured to unravel the complexities of integrating older people into digital placemaking. The findings and contributions of this research pave the way for a more inclusive and participatory approach to urban planning, particularly considering the rapid advancements in digital technologies. I draw the following conclusions to elaborate on these findings:

Firstly, the involvement of people in digital placemaking is an intricate endeavour, influenced by a multitude of factors that span across different societal, technological, and spatial dimensions. Adopting a holistic approach is crucial in understanding and

facilitating their participation. This involves continuously refining planning and design strategies based on the evolving experiences and needs of senior citizens, thereby enhancing the effectiveness and relevance of urban spaces.

Secondly, viewing urban neighbourhood planning through the lens of vulerable users like older people engagement broadens our comprehension of the various elements that influence their active participation in digital placemaking. It is imperative to consider the broader societal context rather than isolating projects to individual initiatives. This broader perspective can lead to more sustainable and impactful solutions that resonate with the needs and aspirations of older populations.

Thirdly, the dissemination and scaling up of knowledge regarding user-centred design approaches among all stakeholders are vital. The vCIM placemaking systems that are tailored to the needs of senior citizens can facilitate better communication, collaboration, and mutual understanding. Such systems, if designed thoughtfully, can harmonise actions across different scales, ensuring that the planning and design processes are inclusive and responsive to the diverse needs of senior citizens.

Fourthly, learning from the experiences and feedback of senior citizens provides a pragmatic approach to addressing the complexities inherent in urban planning and design research for ageing populations. This 'learning-by-doing' method allows for the adaptation of planning strategies to the specific context of each neighbourhood, ensuring that solutions are not only theoretically sound but also practically viable and relevant to the actual users of these urban spaces.

In summary, the integration of senior citizens into digital placemaking and urban neighbourhood design necessitates cities and planners to adopt a systemic and user-centric approach. This

dissertation contributes to this endeavour by providing insights into the structural conditions that affect senior citizen participation in urban planning and proposes solutions for enhancing their engagement. The research underscores the importance of a comprehensive understanding of these conditions and the development of systems and strategies that facilitate the active involvement of senior citizens, thereby shaping more inclusive urban environments.

6.4 Research limitations and recommendations for future research

The methodologies and approaches employed within this dissertation to investigate the integration of senior citizens in digital placemaking and urban neighbourhood design represent a pioneering endeavour in a nascent field. However, inherent limitations and avenues for further research are evident, particularly given the limited existing knowledge base at this interdisciplinary nexus.

A primary limitation lies in the broad generalisation of the "senior citizen" demographic. While the research provides valuable insights, a more nuanced understanding of this heterogeneous group, recognising their diverse needs, preferences, and levels of digital literacy is crucial. Future studies should disaggregate this demographic, tailoring urban design interventions to specific subgroups within the senior population. This could be achieved through a more robust mixed-methods approach, incorporating qualitative data collection (e.g., focus groups, interviews) to better understand individual experiences and perspectives alongside quantitative analysis.

The application of insights derived from the Blue Zones model to disparate urban contexts presents challenges due to sociocultural, economic, and environmental variations. This necessitates the

development of more context-sensitive methodologies that adapt these principles to the unique fabric of different urban environments. Rather than a one-size-fits-all approach, future research should focus on place-based, bespoke solutions that take into account the specific needs and characteristics of each community.

Furthermore, the efficacy and inclusivity of the vCIM system across users with varying levels of digital literacy requires further scrutiny. Insufficient comprehensive data on the full spectrum of senior citizens' interactions with digital technologies in diverse urban settings limited a full assessment of the strategies' universality and contextual applicability. Additionally, the lack of detailed knowledge about the varying technological adeptness and preferences of senior citizens across different contexts constrained a full evaluation of the vCIM system's adaptability and usability. Future research should prioritise participatory design approaches, actively involving senior citizens in the co-creation of digital tools and platforms, ensuring that these technologies are truly user-centred and accessible to all.

The scalability and broader applicability of the vCIM system, particularly beyond the specific case studies presented, also warrant investigation. Future research should test and refine these systems across a wider range of urban environments and larger population cohorts to ensure their robustness and adaptability. This includes exploring the potential for these systems to be integrated into existing urban planning and design frameworks, rather than existing as standalone solutions.

Beyond these technical considerations, this dissertation underscores a fundamental need for a more critical engagement with the concept of "participatory planning." While the text mentions the term, it lacks a detailed examination of how participatory approaches were (or could be) integrated into the research process. Future research should explicitly address the power dynamics inherent in planning processes, ensuring that the voices of senior citizens are not

only heard but actively shape the design and implementation of urban interventions.

Finally, this dissertation highlights the need for a more interdisciplinary approach in urban planning, incorporating insights from gerontology, public health, and social sciences. However, this should not merely be a tokenistic gesture; future research should actively seek to break down disciplinary silos and foster genuine collaboration between researchers, practitioners, and community stakeholders. This will require a shift in mindset, moving away from top-down, expert-driven approaches towards a more inclusive, co-productive model of urban development.

Appendices

Appendix A

Realm	Year	Reference	Journal Title	Approach	Orientation	Method	Status in Review
SPI[a]	2011	(Cornelio & Ardévol, 2011)	Communications	Standard Placemaking	PB[c]	Case Study	Selected
	2012	(Brunnberg & Frigo, 2012)	Digital Creativity	Standard Placemaking	PB	Online Mapping Platform	Selected
	2013	(M. Bilandzic & Johnson, 2013)	Australian Library	Strategic Placemaking	PB	Online Mapping Platform	Selected
	2014	(M.J. Kim et al., 2014)	Asian Architecture and Building Engineering	Strategic Placemaking	PB	Survey	Selected
	2015	(J. Fredericks et al., 2015)	Conference Proceedings	Standard Placemaking	PB	-	Not Selected
		(Houghton et al., 2015)	Australian Planner	Tactical Placemaking	PB	Survey	Selected
		(Sepe, 2015)	Book	Creative Placemaking	PB	-	Not Selected
		(Tomitsch et al., 2015)	Book Chapter	Creative Placemaking	AB[d]	-	Not Selected
	2016	(Caneparo & Bonavero, 2016)	International Journal of Architectural Research	Strategic Placemaking	AB	Online Mapping Platform	Selected
		(Johnstone et al., 2016)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
		(Mansilla & Perkis, 2016)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
		(Fortin, 2016)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
		(J. Fredericks et al., 2016)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
	2017	(Foth, 2017)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
	2018	(J. Fredericks et al., 2018)	City, Culture and Society	Strategic Placemaking	AB	Survey	Selected
		(Yan Chen, 2018)	Book Chapter	Standard Placemaking	PB	-	Not Selected

	(Stokes et al., 2018)	Conference Proceedings	Creative Placemaking	PB	-	Not Selected
	(Nenko & Petrova, 2018)	Communications in Computer and Information Science	Standard Placemaking	PB	Online Mapping Platform	Selected
	(Mushiba & Heissmeyer, 2018)	Conference Proceedings	Creative Placemaking	PB	-	Not Selected
	(Innocent, 2018)	Conference Proceedings	Creative Placemaking	PB	-	Not Selected
	(Berrett, 2018)	Conference Proceedings	Creative Placemaking	AB	-	Not Selected
2019	(Yu & Blain, 2019)	Media International Australia	Strategic Placemaking	PB	Online Mapping Platform	Selected
	(Glover, 2019)	World Leisure Journal	Creative Placemaking	AB	Media Architecture	Selected
	(Pang et al., 2019)	Behaviour and Information Technology	Creative Placemaking	PB	Online Mapping Platform	Selected
	(Freeman et al., 2019)	Conference Proceedings	Standard Placemaking	PB	-	Not Selected
	(Tarr & Alvarez León, 2019)	Feminist Review	Standard Placemaking	PB	Online Mapping Platform	Selected
	(Hollander et al., 2019)	Urbanism	Standard Placemaking	PB	Survey	Selected
	(Globa et al., 2019)	Conference Proceedings	Standard Placemaking	PB	-	Not Selected
	(W. Wang, 2019)	Space and Culture	Standard Placemaking	PB	Participant Observation	Selected
	(Meenar, 2019)	Journal of Environmental Practice	Standard Placemaking	PB	Survey	Selected
	(Ni & Cattaneo, 2019)	Conference Proceedings	Standard Placemaking	PB	-	Not Selected
	(Stupar et al., 2019)	Sustainability	Strategic Placemaking	PB	Online Mapping Platform	Selected
	(Han et al., 2019)	Energies	Creative Placemaking	AB	Media Architecture	Selected
2020	(Breek et al., 2020)	Urbanism	Standard Placemaking	PB	Online Mapping Platform	Selected
	(Najafi et al., 2020)	Conference Proceedings	Standard Placemaking	PB	VR	Not Selected
	(Garay Tamajón & Morales Pérez, 2020)	Hospitality and Tourism Research	Creative Placemaking	AB	Online Mapping Platform	Selected

		(Hoggenmueller & Hespanhol, 2020)	Conference Proceedings	Standard Placemaking	AB -	Not Selected
		(Budge, 2020)	Urban Technology	Standard Placemaking	AB Online Mapping Platform	Selected
		(Y. Chen et al., 2020)	Sustainable Cities and Society	Standard Placemaking	PB Online Mapping Platform	Selected
		(Chew, 2020)	Conference Proceedings	Standard Placemaking	PB -	Not Selected
		(Kotus & Rzeszewski, 2020)	Planning Education and Research	Standard Placemaking	PB Online Mapping Platform	Selected
		(Prawata, 2020)	Conference Proceedings	Creative Placemaking	AB -	Not Selected
SPE[b]	2012	(Van Hoven & Douma, 2012)	European Spatial Research and Policy	Standard Placemaking	PB Survey	Selected
	2014	(Hanlon et al., 2014)	Health and Place	Strategic Placemaking	AB Participant Observation	Selected
	2017	(Sixsmith et al., 2017)	Working with Older People	Standard Placemaking	PB Survey	Selected
	2018	(Yuen & Cheong, 2018)	Book	Standard Placemaking	PB -	Not Selected
	2020	(Qi & Gu, 2020)	Action Research	Tactical Placemaking	PB Survey	Selected

[a]SPI: Senior People Inclusively, [b]SPE: Senior People Exclusively, [c]PB: Project Based, [d]AB: Activity Based.

Appendix B

Age-friendly built environment variables: description and examples.

Variable	Description	Examples/Specific Types		
Housing and buildings	Age in place	Attachment to place		
	Variety of housing options	Standard family homes		
		Apartments		
		Retirement institutes		
	Design features facilitating age in place	Ramp		
		Elevator		
		Handrail		
		Anti-slip floor		
		Seating		
		Accessible toilet		
		Wayfinding signage		
		Parking area		
Public/open space	Third places	Café, park, shipping mall, library, market, community centre		
	Features encouraging physical activity	Walking	Land use mix	
			Street connectivity	Street pattern
				Block size
			Residential density	Dense of concentration of people
		Pedestrian-friendly facility	Tree/ vegetation for shading	
			Adequate lighting	
			Pedestrian road	
			Wayfinding signage	
			Street furniture	Seating bench, shelter,
Transportation system	Walkability	Accessibility and convenience	Modes	Walking, bike, bus, tram, train
			Service quality	
			Travel safety perception	
			Design of station	Ramp
				Elevator/escalator
				Low-floor boarding
			Priority seat	
			Affordability	
	Bikeability	Cycling-friendly	Segregation from	

	infrastructure	vehicular traffic	
		Safety	
		Cyclist behaviour	
		Convenience	
		Availability of cycling infrastructure	

Appendix C

Final dataset selected for the systematic literature review pertaining to Blue Zones.

Topic area	Authorship	Journal title	Citation	Publication year
Sardinia	[28]	Experimental Gerontology	182	2004
	[211]	Journal of Ageing Research	33	2011
	[212]	Biodemography and Social Biology	28	2012
	[213]	Vienna Yearbook of Population Research	2	2013
	[212]	Vienna Yearbook of Population Research	11	2013
	[214]	Journal of Biosocial Science	2	2015
	[215]	European Geriatric Medicine	1	2015
	[216]	Journal of Clinical Gerontology and Geriatrics	5	2016
	[217]	Europe's Journal of Psychology	15	2017
	[140]	Ageing Clinical and Experimental Research	30	2018
	[218]	Journal of Ageing and Physical Activity	16	2018
	[219]	PloS One	12	2018
	[187]	Behavioral Sciences	14	2018
	[220]	Annals of Medicine	6	2018
	[221]	Ageing clinical and experimental research	8	2020
	[141]	International Psychogeriatrics	11	2021
	[222]	Journal of Religion and Health	5	2021
	[223]	Journal of Ethnic Foods	1	2022
	[224]	International Journal of Psychology	1	2022
	[225]	Journal of Happiness Studies	3	2022
	[183]	Psychology, Health and Medicine	2	2022
Okinawa	[130]	Age (Dordrecht, Netherlands)	63	2006
	[226]	The Journals of Gerontology. Series A, Biological	136	2006
	[227]	Annals of the New York Academy of Sciences	228	2007
	[228]	Journal of Cross-Cultural Gerontology	40	2007
	[188]	The Journals of Gerontology: Series A	59	2008
	[131]	The Journals of Gerontology. Series A, Biological	53	2008
	[184]	Experimental Gerontology	31	2012

Topic area	Authorship	Journal title	Citation	Publication year
	[229]	Experimental Gerontology	7	2013
	[132]	The Journals of Gerontology. Series A, Biological	17	2014
	[230]	Mechanisms of Ageing and Development	19	2017
	[231]	Mechanisms of Ageing and Development	24	2017
Ikaria	[232]	Cardiology Research and Practice	30	2010
	[135]	Cardiology Research and Practice	65	2011
	[233]	Maturitas	49	2011
	[234]	QJM: An International Journal of Medicine	12	2011
	[235]	Maturitas	6	2013
	[236]	International Journal of Cardiology	4	2013
	[237]	Heart and Vessels	13	2013
	[238]	Hellenic Journal of Cardiology	5	2013
	[239]	Angiology	16	2016
	[240]	Hellenic Journal of Cardiology	11	2016
	[137]	International Journal of Environmental Research an	7	2021
	[241]	Hellenic Journal of Cardiology	0	2022
Nicoya Peninsula	[133]	Vienna Yearbook of Population Research	33	2013
	[242]	Experimental Gerontology	45	2013
	[134]	Ageing Clinical and Experimental Research	9	2020
	[243]	Journal of Population Ageing	0	2022
Uncategorised Blue Zone	[185]	American Journal of Lifestyle Medicine	103	2016
	[244]	Mediterranean Journal of Nutrition and Metabolism	11	2018
	[245]	Nutrients	21	2020
	[246]	American Journal of Medicine	1	2020
	[136]	Mechanisms of Ageing and Development	9	2021
	[126]	International Journal of Environmental Research an	8	2021
	[139]	Maturitas	3	2022
	[247]	Journal of Population Ageing	0	2022
	[248].	American Journal of Lifestyle Medicine	0	2022
Total N	57	57	57	57

Appendix D

Integration of ADE20K annotation format in age-friendly built environment feature for image segmentation.

Category	Annotation Label	Description/Examples	ADE20K
Housing and buildings	Building design: entrance, ground floor, door ways	Entrances without stairs, possibly with ramps or level with the ground, allowing easy access for mobility-impaired individuals. Doorways wide enough to accommodate wheelchairs and walkers. Housing units with ground floor access, minimising the need for stair navigation.	#Door, #door frame, #double door, #stair, #steps, #stairway, #staircase, #window, #window pane, #ceiling
	Housing options		#house, #apartment
Public / open spaces	Third places	Parks, gardens, open spaces that are easily accessible and safe for older adults.	#tree, #flower, #plant, #flora, # plant life, #pot, #flowerpot, #vase, #mountain, #field, #rock, #bush #river, #sea, #water,
	Street furniture		#toilet, #commode, #crapper,
	Pedestrian infrastructure	Pathways with pedestrian friendly amenities, with adequate lighting, benches, and clear signage.	#light, #light source, #lamp, # street light, #street lamp #chair, #table, #bench #pillar, #edifice, #seat, #sidewalk, #signboard, #sign
	Physical activity	Walking or cycling	#person, #individual, #someone, #somebody, #bike, #cycling, #route
Transportation systems			
	Public Transport Access	Available public transport modes like bus, taxi, or train	#car, #bus, #machine, #autobus, #coach, #truck, van, coach, #charabanc

Well-Designed Stations	Bus stops and train stations with features like easy navigation, ramps, elevators, and clear, informational displays.	#busstop, #traffic light, #traffic signal, #stoplight,
Bike Paths	Designated bike paths, possibly including electric bicycle charging stations.	#minibike, #bicycle, #bike, #wheel, #cycle, #road, #route, #sidewalk, #pavement, path

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Curriculum Vitae

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