Immersive Virtual Reality for Older Adults: Empirically Grounded Design Guidelines

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Despite the proliferation of research on immersive Virtual Reality (IVR) technologies for older adults, comprehensive guidelines on designing immersive and engaging VR for older adults remain sparse. Therefore, we first compounded 67 guidelines based on published literature. Next, to empirically ground these design recommendations, we provided 37 older adults of diverse ages, education levels, and cognitive abilities with a first VR experience. Through interviews on their experiences, analyzed via the Laddering method, we found that older adults generally reported positive experiences. With these deepened insights, we reflect on, nuance and contextualize existing design guidelines, and formulate points to bear in mind when designing accessible and engaging VR experiences for older persons.

CCS CONCEPTS • **Human-centered computing** ~ Human computer interaction (HCI) ~ HCI design and evaluation methods ~ User studies • Human-centered computing ~ Accessibility

Additional Keywords and Phrases: Virtual Reality; VR; Older Adults; Design guidelines; Laddering

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1 INTRODUCTION

In the past decade, we have witnessed the proliferation of immersive virtual reality (IVR) technologies (Cipresso et al., 2018), offering a fully immersive experience by using a head-mounted device with near full field of view, positional tracking and gesture-based controllers. Research has explored the potential of immersive VR in the domain of health (Freeman et al., 2017; García-Betances et al., 2015; Tieri et al., 2018), suggesting that it may improve diagnosis and rehabilitation of physical or cognitive impairments due to age-related neurological disorders (e.g., stroke, dementia). Not surprisingly, numerous IVR interventions are currently being developed targeting older adults (Ku et al., 2009; Lecavalier et al., 2018; Rose et al., 2005), and recent studies demonstrated good acceptability and safety of using IVR in older populations (Huygelier et al., 2019; Roberts et al., 2019).

However, limiting IVR for older adults to the clinical realm may reinforce a deficit-focused perspective on ageing (Gerling et al., 2020), ignoring that IVR holds the potential to enable all kinds of new experiences for older adults. Researchers have already shown that IVR can be used by older adults as a *recreational medium* (Hodge et al., 2018), a *social medium* (Baker, Waycott, Carrasco, et al., 2019), or contribute to healthy ageing and well-being in general (Waycott et al., 2018). Additionally disconcerting, to date only few studies include older adults as active contributors of the design process of VR applications (Sears & Hanson, 2012), with notable exceptions (e.g., Bruun-Pedersen, Serafin, & Kofoed, 2016; Hodge et al., 2018; Liddicoat & Newton, 2019). Finally, although many researchers develop IVR applications for older adults, there remains a lack of empirically grounded, comprehensive guidelines to design IVR for older adults. That is, current guidelines often discuss only few aspects of the design of IVR experiences and are often based on small samples (Bruun-Pedersen, Serafin, Maculewicz, et al., 2016; Eisapour, Cao, Domenicucci, et al., 2018; Flynn et al., 2003) or are based on theoretical reviews of human factors studies on age-related decline (McGlynn & Rogers, 2017; Reis et al., 2013). Moreover, studies presenting guidelines on virtual reality for older adults often derive these guidelines from interacting with other adjacent technologies, such as projections of 3D worlds, gesture-based controllers such as Kinect (de Vries et al., 2018; Siriaraya & Ang, 2014) or games in general (IJsselsteijn et al., 2007). As these systems differ from the newest commercially available IVR systems (i.e., Oculus Rift, Samsung Gear, HTC Vive) in the sensorimotor contingencies they support (Slater, 2009) and the level of immersion they offer, these design guidelines may not apply to the newest generation of IVR systems.

In this study, we explore how to design immersive VR (IVR) so that older adults can access, use and enjoy it, by means of an empirical validation of a broad array of existing guidelines on IVR used with older adults. While the current generation of older adults is healthier and more educated than former generations, they may still experience age-related changes in cognitive and physical abilities that impact the IVR experience (Czaja et al., 2009; Fozard & Wahl, 2012). In particular, it has been argued that specific age-associated physical, cognitive and emotional changes may impact their sense of *presence* (Garcia et al., 2012; Schuemie et al., 2001). *Presence* is the subjective feeling of *being in the virtual environment* and lies at the heart of engaging IVR experiences (Lombard & Ditton, 1997; Slater & Wilbur, 1997). Moreover, older adults also have less experience with new technologies than younger adults, possibly negatively impacting attitudes towards this immersive technology (Hauk et al., 2018). However, while physical and cognitive changes and lower technological proficiency are part of older adults' lives, "this does not represent the entirety of the older adult experience"

(Sarcar et al., 2018). It remains important to recognize the heterogeneity among older adults in needs and preferences, and to explore additional factors that may contribute to the use and enjoyment of IVR.

Thus, in this article we aim to establish design guidelines for IVR and older adults, building on three complementary research activities. Firstly, we reviewed existing literature containing design recommendations for older adults and immersive VR. From this review we compounded a comprehensive set of design recommendations.

Secondly, we provided 37 older adults of diverse ages, education levels, cognitive abilities, and computer proficiency, a first IVR experience, and evaluated their experiences via short interviews. We analyzed these interviews via the Laddering method (Reynolds & Gutman, 1988), comprising both a qualitative and quantitative analysis, to derive an understanding of which product attributes of IVR (e.g., hardware, software, content) produce certain functional and psychosocial benefits for older adults. The Laddering method has its conceptual roots in Means-End (ME) (Cohen & Warlop, 1995; Gutman, 1982). It is used to dissect users' experiences based on the central premise that a specific product only has value because its attributes produce desired consequences. Such a means-end understanding lends itself well to understanding both the pragmatic and broader hedonic aspects of product use, and is well engrained in User Experience research (Cockton, 2008; Hassenzahl, 2003). Ultimately, a Laddering analysis entails a quantitative approach as well, and results in *a hierarchical value map*, that details how lower-level product attributes give way to higher-level benefits. The depiction of and insight into this network of linkages is where the true value of the method lies.
Thirdly, based on the results of the laddering study, we empirically ground and reflect on the design recommendations compounded from the literature and present a framework that may inform designers of future immersive VR experiences.

In sum, the main contributions of the study are that it 1) compiles a comprehensive list of existing design guidelines in the field of IVR and older adults, 2) provides empirically grounded guidelines for the design of IVR for older adults, and 3) details guidelines via an analysis of how specific design aspects of IVR content, hardware and context are associated with certain functional and psychosocial benefits. As older adults constitute an increasing proportion of the global population, and as IVR is receiving increased attention from researchers and policy makers, this can inform how to design future applications to cater to the diverse needs, abilities and preferences of older adults, in turn promoting adoption and enhancing quality of life.

2 REVIEW OF LITERATURE ON VR AND OLDER ADULTS

In this first section, we present a review of the literature on VR and older adults, with the aim of deriving a comprehensive set of design guidelines.

2.1 Method

We searched the literature in the ACM Digital library and PubMed, based on the string: `("virtual reality" OR "VR") AND ("older adult" OR "senior" OR "elderly" OR "retired" OR "aged person")` in September 2019. We retained 432 (66 ACM, 366 Pubmed) studies, which were reviewed in three iterations: on title, abstract and full paper. In each iteration, papers were excluded that 1) did not apply *immersive* VR (i.e., systems that offer a combination of near full field of view and gesture-based controlling), 2) reported on clinical interventions only, 3) had an exclusive focus on system engineering (without implications for design), or 4) focused on very specific disorders (e.g., hemispatial neglect). Papers targeting persons with (mild) dementia were retained. Since only four papers were retained (Baker, Waycott, Carrasco, et al., 2019; Bruun-Pedersen, Serafin, Maculewicz, et al., 2016; Eisapour, Cao, & Boger, 2018; Eisapour, Cao, Domenicucci, et al., 2018), we additionally investigated references of and citations to retained papers. When an appropriate paper was found, we continued exploring references of each additional suitable paper. This approach uncovered several papers on a specific research project, by the same group of researchers. In this case, we retained those publications that compiled the findings of earlier studies or presented new information. This resulted in 13 papers. The final set of papers is given in Table 1.

Afterwards, two authors (AUTHOR2 and AUTHOR1) independently extracted, categorized and rephrased recommendations and implications as design guidelines. The set of chosen guidelines and diverse categories were then once more discussed and iterated with a third author (AUTHOR5). Finally, the decision was then made to organize the categories into *Accessibility, Usability* and *User Experience* guidelines, following a similar distinction as in (Rosa & Valentim, 2020), conceptually layered and based upon the theoretical models of (Basri et al., 2016; Hassenzahl, 2008; Nielsen, 2005) as illustrated in Figure 1. The category of *Accessibility* is reserved to those guidelines that address limitations and challenges of old age and aim to ensure that the IVR application can be accessed by older users across a diverse range of abilities. The category of *Usability* is used for those guidelines that focus on how to ensure that IVR tasks can be carried out effectively and efficiently, minimizing error. Finally, *User eXperience* guidelines focus on providing an emotional and engaging, IVR experience.

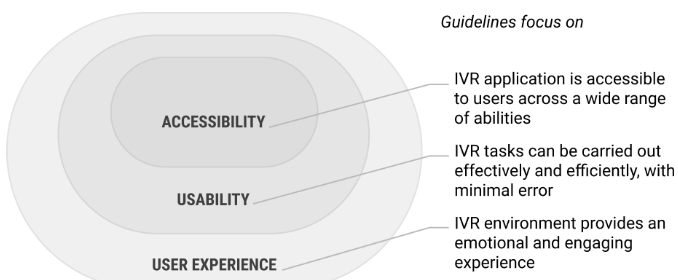

Figure 1. A layered model of Accessibility, Usability and User Experience.

Table 1: Overview of 13 studies on designing IVR for older adults, as included in the literature review.

Authors	Application domain	Type of VR	Virtual environment	Epistemolo gy	Research Method	Type of end-users addressed	Age and nr of end-users included

[1] Baker et al. (2019)	Social VR	Google Cardboard, Kinect, HTC Vive, Oculus Rift	Variety of custom VR scenarios (animated 3D and 360-degree photo environment) and additionally custom created Avatar Probe and SocialVR Probe, both animated 3D	Empirical, qualitative	Action research	Retired or semi-retired, living independently	25 older adults (age >70)
[2] Baker et al. (2019)	Social VR	Variety HMD devices, a.o. Google Card-board, Kinect, HTC Vive, Oculus Rift	Variety of custom VR scenarios; 3 social VR scenarios (social card game, out-door climbing activity, 'high-way of Life'	Empirical, qualitative	Participator y design	Retired or semi-retired, living independently	22 older adults (age 70-81)
[3] Baker et al. (2019)	Recreational VR	Oculus Rift	First Contact (animated 3D), Google Earth VR (360-degree photo environment), Quill (animated 3D), Toy-box (animated 3D), Power Solitaire (animated 3D)	Empirical, qualitative	Observ. + semi-str. interviews	Older adults in long-term care facility	5 older adults (74-88)
[4] Bruun-Pedersen et al. (2016a)	Physical exercise	Oculus Rift DK2	Four animated 3D environments (forest, park, mountain, country)	Empirical, qualitative	Experiment al evaluation	Older adults at care home; 'dementia-affected'	10 residents (age 85.7, SD 9.8)
[5] Bruun-Pedersen et al. (2016b)	Physical exercise	Oculus Rift DK2	Four animated 3D environments (forest, park, mountain, country)	Empirical, quantitativ e & qualitative	Experiment al evaluation	Older adults at care home; 'dementia-affected'	10 residents (age 85.7, SD 9.8)
[6] Eisapour et al. (2018)	Physical exercise	Oculus Rift DK2	Farm (game), animated 3D	Empirical, qualitative	Participator y design	Older adults diagnosed with mild cognitive impairment	4 residents (age /), 6 therapists
[7] Flynn et al. (2003)	Wayfinding	Cave (140° curved)	Urban outdoor environment, animated 3D	Empirical, qualitative	Feasibility study	Persons with dementia, independent and residential	6 persons with dementia (age 52-91)
[8] Hodge et al. (2018)	Recreational VR	Variety HMD devices	Three environments: park, beach and concert hall (3D, not animated)	Empirical, qualitative	Participator y design	Persons with dementia and relatives	4 persons with dementia (82, 83, 53, 54),
[9] Korsgaard et al. (2019)	Social dining	Oculus Rift	Dining room (photo-realistic), overlayed with 3D avatars	Empirical, quantitativ e & qualitative	Observ., logs, interviews	Older adults (general)	27 older adults (over 65)
[10] Mc Glynn &	Presence	/	/	Theoretical	Review study	Older Adults (general)	/

Rogers (2017)							
[11] Reis et al. (2013)	VR Warnings	/	/	Theoretical	Review study	Older adults (general)	/
[12] Roberts et al. (2019)	Generic	Samsung Gear	Jurassic Parc (animated 3D), Cirque de Soleil (360-degree photorealistic environment)	Empirical, qualitative	Focus groups	Older adults in retirement community	41 persons (age 55-99)
[13] Van Schaik et al. (2008)	Wayfinding	Cave (140° curved)	Urban outdoor environment (photo-realistic environment)	Empirical, quantitativ e & qualitative	Experiment al evaluation	Older adults with mild to moderate dementia	30 Persons with dementia (age 71-88)

2.2 Results of literature review

A first set of studies focused on **older adults in general**. McGlynn and Rogers (2017) reviewed literature on presence and ageing and hypothesized that age-related physical, cognitive and emotional decline would limit the experience of presence. Next, they presented a set of theoretical design recommendations to overcome these age-related barriers. A similar approach was taken by Reiss et al. (2013) who enlisted usability issues with a focus on warning signals in virtual environments. Reiss' recommendations were based on literature and resembled common guidelines with regard to general HCI and older adults, focused on ensuring accessibility and avoiding illness (e.g., avoiding cyber sickness) *and usability of VR* and not on optimizing the user experience for older adults.

In contrast, Baker et al. (Baker, Waycott, Vetere, et al., 2019; Baker, Waycott, Carrasco, et al., 2019) focused on *social VR experiences* for older adults and included them as active participants in their studies. First, the authors (Baker, Waycott, Vetere, et al., 2019) explored the use of virtual avatars through an action research approach with 25 older adults, including VR technology ranging from simple technology for viewing 3D environments, such as Google Cardboard, to truly IVR systems such as the Oculus Rift and HTC Vive. Here, they found that older adults were hampered by the limited ability of their avatars to show emotion, and the lack of accurate body tracking and facial expressions. Next, through a series of participatory design workshops, the authors (Baker, Waycott, Carrasco, et al., 2019) designed and evaluated social VR applications with 22 older adults. Through these co-design sessions, Baker et al. identified three global themes: 1) the need for facilitation of social VR interactions (i.e., the need for an expert to be present in the VR environment to moderate and guide), 2) the ageing body (i.e., the benefit of VR as a means to overcome age-related limitations), and 3) the opportunity to reminisce (i.e., to relive the past) in new and interesting ways. Korsgaard et al. (2019) also included end-users in their study and evaluated a prototype with 27 older adults where triads shared a virtual meal together. They found lifelike, high-fidelity avatars were crucial to make older adults feel as if they shared the space with the avatars.

A second set of studies focused on **older adults in residential care settings or care homes.** Roberts et al. (2019) investigated attitudes towards IVR in 41 residents of a retirement community, after they viewed two IVR simulations. Via focus groups and thematic analysis, they identified themes to promote or hinder acceptance of immersive VR. Promoting acceptance were 1) the experience of positive emotions including excitement, immersion, novelty, escapism, and parasocial interaction; 2) content related to travel, educational purposes, or reminiscing; and 3) the perceived usefulness as a replacement for enjoyable activities when limited in mobility, for entertainment in retirement communities and for keeping up with the times. Barriers for acceptance were the lack of age-friendliness and awkwardness of the equipment.

Baker et al. (Baker, Waycott, Robertson, et al., 2019) also evaluated IVR (i.e., Oculus Rift) with older adults living in residential aged care with five residents, but over a period of two weeks. Here, authors found potential in VR to mitigate social isolation, particularly when VR experiences were tailored to personal interests. However, they also reported residents to struggle with the dedicated hand controllers that come with the Oculus Rift.

A final set of studies focused on **older adults with mild cognitive impairment (MCI) or mild dementia.** Flynn et al.(2003) demonstrated the feasibility of their specific *outdoor urban* VR *environment* for six persons with dementia. A follow-up study (Van Schaik et al., 2008) with 30 persons with dementia showed that unattractive street layouts (e.g., too busy) and the use of unclear landmarks or maps for wayfinding acted as barriers to functioning in the outdoor (VR) environment. Familiar landmarks and the use of written messages instead of photographs acted as facilitators. Bruun-Pedersen et al. also evaluated *outdoor natural environments (i.e., restorative environments)*, for and with ten older adults with MCI, with the aim to increase their motivation for exercise (2016; 2016). These authors emphasized the importance of providing nature-based content (forests, parks, etc.) in recreational virtual environments, as these promote intrinsic motivation and enjoyment of older adults (Depledge et al., 2011). Bruun-Pedersen et al. also argued for semantically congruent audiovisual content (birds, water flowing, air dynamics) in order to fit the overall user experience.

Eisapour (2018) similarly focused on a VR program for promoting physical exercise, in which they used a participatory design process with 6 therapists and 4 persons with MCI, leading to a list of specific design guidelines focusing on how to make the exergame accessible to people with MCI, such as keeping targets within the front field of view, avoiding the use of buttons or gestures as control input and prompting verbally before the transition between real and VR world.

Finally, the work presented by Hodge et al. (2018) also emphasized the need for *recreational* VR and the importance of soundscapes for persons living with dementia. Working with seven participants (four persons with dementia and three family members/caretakers) from a local dementia care charity, they outlined opportunities and challenges inherent to the design and use of VR experiences with people with dementia. Besides utilizing all senses (and in particular sound) they also highlighted the importance of careful physical design of VR hardware, as older adults may not appreciate their look wearing the headset, to ensure not to render older adults with dementia as passive observers, but rather as the focal point who drives the experience, making room for sharing a VR experience, and finally attempting to personalize environments and blend familiar elements with new.

As aforementioned, first the different guidelines embedded in the aforementioned papers were enlisted and discussed. Next, they were categorized, either according to the category of Accessibility, Usability and User Experience. Additionally, it was added whether guidelines were based on empirical study or based on theories of human factors and ageing. This resulted in Table 2 that lists the 67 different guidelines, derived from the literature above, categorized concerning accessibility (A1-A25), usability (U1-U15) or user experience (X1-X27).

Table 2. Design guidelines based on literature. E = guideline based on empirical study, T = guideline based on theory.

A C C E S S A B I L I T Y			
Physical changes – Musculoskeletal fatigue, discomfort, balance issues			
A1	Consider weight of HMD	[8][9][10][12]	E
A2	Limit unnecessary head movements	[6][10][12]	E
A3	Opt for gesture-based control as grip and force may decline	[10][11]	T
A4	Avoid using buttons or gestures with controllers as control input as they may induce	[6][10]	E
A5	Minimize reaching by putting input devices in ergonomic position	[10][12][7]	E
A6	Use a calibration process to adjust the range of motion for each user	[6][7]	E
A7	Opt for a seated virtual experience	[10] [12]	E
Physical changes – Sensory sensitivities			
A8	Increase contrast ratios and illumination	[10][11]	T
A9	Block out irrelevant physical stimuli, avoid clutter	[10][13]	E
A10	Avoid use of high frequency tones for feedback and 3D localization	[10][11]	T
A11	Opt for tactile feedback where possible but increase vibration intensity compared to	[10]	T
A12	Consider trade-offs: gestures cause less fatigue but lack haptic feedback	[10]	T
Physical changes – General			
A13	Monitor participant and carer for signs of simulator sickness	[12][7]	E
A14	Avoid vertigo by providing an active role to user when navigating	[11]	T
A15	Verify that the IVR system accommodates for glasses and hearing aids	[9][10][12]	E
A16	Use the full spectrum of sensory experiences; as eyesight/hearing deteriorate, sounds and physical touch become more important.	[8][10][11]	E
Cognitive changes			
A17	Remove stimuli that are non-task critical, avoid overstimulation	[10][11][13]	E
A18	Use positively-valenced cues (i.e. rewarding sounds) for items to be attended to	[10]	T
A19	Avoid memory-based tasks	[10][11]	T
A20	Use positive feedback (rewards) for controls to be memorized	[10]	T
General accessibility			
A21	Do not expose participants to the same VE within the same week	[11]	T
A22	Provide assistance if necessary	[7][12]	E
A23	Monitor older adults for symptoms of stress	[10]	T
A24	Bear in mind the heterogeneous, diverse technological understandings	[1]	E
A25	Make use of strengths and abilities remaining within person with dementia.	[7]	E
U S A B I L I T Y			
Navigation and wayfinding			
U1	Avoid unattractive and busy street layouts	[13]	E
U2	Use landmarks obvious in function and association with destination (a mailbox for a	[7][13]	E
U3	Avoid relying on a map for wayfinding	[7][13]	E
U4	Enable 180 degree turns, avoid having to walk backwards without turning to change	[7]	E

U5	Enable exploration of the VR world in a supportive fashion	[6]	E
U6	Provide verbal prompts when transitioning between different VR scenes	[6]	E
Object selection and manipulation			
U7	Consider natural interaction methods, i.e. 'haptic gloves' that track hand movements and provide feedback about virtual objects when pointed at.	[3]	E
U8	Use tasks that implicitly signify how to interact with objects (e.g., salient handles that indicate where to grab and hold)	[6]	E
U9	When moving objects, directly attach objects to the hand, and when target location is reached, directly remove objects from the hand at target locations.	[6]	E
Instructions and task			
U10	Provide verbal prompts before the transition from real world to VR	[6]	E
U11	Provide verbal instructions that bring users into the scene and task, in a gentle, casual, and storytelling fashion	[6]	E
U12	Clearly indicate when a task has been successfully accomplished.	[6]	E
U13	Prevent or avoid users to make errors	[6]	E
U14	Use written messages and texts, instead of photographs	[13]	E
U15	Use sensory feedback to signal task completion.	[10]	T
USER EXPERIENCE			
Presence			
X1	Present ecologically valid items, avoid walking through solid objects	[5][7]	E
X2	Provide nature-oriented elements and details (birds, flowers, water)	[5][7]	E
X3	Provide scenic value (broad views, distant locations, high altitudes…)	[5]	E
X4	Ensure that the diverse objects and details are congruent with the scene, to be perceived as a 'whole'.	[5]	E
X5	Provide congruent soundscapes, fitting role for the overall user experience.	[4][8]	E
X6	Use dynamic and interactive sounds	[4]	E
X7	Use exaggeration in sounds, make them more prominent than in reality	[4]	E
X8	Provide solid body tracking: avatars moving inhumanly disrupt presence.	[1][9]	E
Reminiscence			
X9	Allow to go back in time and recollect personal experiences (e.g. time capsule)	[2][12]	E
X10	Merge aspects of familiar experiences with new settings	[2][8]	E
X11	Avoid major events that are documented already (e.g. moonlanding)	[2]	E
X12	Add music to personalize the experience.	[8]	E
Shared experience			
X13	Aim for a shared experience, allow carers to experience the same environment	[2][3][8][12]	E
X14	Ensure active inclusion of the person with dementia, avoid turning them into passive observers	[1][2][8][12]	E
X15	Involve caretakers for social support, to reduce anxiety and enhance motivation in participants	[7][8]	E
X16	Add an expert facilitator in the VR world to mediate discussions and provide guidance	[2]	E
X17	Support facial expressions of avatars (ability to show emotions).	[1][9]	E
X18	Provide the opportunity to customize avatars	[1]	E
X19	Respect fear of looking silly when wearing the head-mounted display	[8][12]	E
The ageing body			
X20	Exploit VR's ability to overcome limitations of physical body	[2][8][9][12]	E

X21	Protect anonymity of the older adult, offer privacy and avoid exposing the ageing body	[2]	E
X22	Avoid competitiveness, emphasize achievement	[8]	E
Purpose and content			
X23	Have older adults tailor VR experiences to their own interest	[2][8][12]	E
X24	Offer outdoor or indoor group exercise/sports	[2][12]	E
X25	Visit places that initiate social interactions (parties, card game…)	[2][12]	E
X26	Travel to new places (city trips, exotic places…)	[2][12]	E
X27	Stimulate self-education (museum tours, guided visits…)	[2][12]	E

Overall, the guidelines are influenced by the different epistemologies of the studies, their underlying diversity in research methods, application domains and typology of older adults. Nevertheless, most of the guidelines are found in more than one study. Moreover, certain guidelines are derived from studies targeting older adults with and without dementia. This suggests that at least some guidelines are generalizable beyond the original group of older adults targeted by the authors, yet this deserves further validation. A total of 11 out of 25 accessibility guidelines are based on theoretical reviews rather than empirical studies. Thus, these guidelines suggest a need for further empirical validation. Moreover, 13 of the 15 usability guidelines are based on a single study. Hence, the extent to which these guidelines apply to other IVR experiences and participant samples is important to empirically investigate. Finally, contradictions remain in the guidelines (e.g., A3 recommends gesture-based control whereas A4 suggests avoiding it).

In sum, in this first section, we reviewed existing literature containing design recommendations for older adults and immersive VR, and compounded a comprehensive set of design recommendations. However, from this review, we also find that guidelines differ in application domains (e.g., accessibility versus entertainment), typology of older adults (e.g., active community dwellers vs older adults in care settings) and their underlying epistemology. Hence, further research is needed to ground, and in particular empirically verify how guidelines apply to a broader sample of older adults. Therefore, in the next section, we turn to an empirical study of older adults' experiences with IVR. In the subsequent section, based on the results of this empirical study, we empirically ground and reflect on the design recommendations from the literature review

3 EMPIRICAL STUDY OF OLDER ADULTS' VR EXPERIENCE

To investigate how the IVR design guidelines generalize to a wider audience of older adults and recreational VR, we conducted a study with 37 older adults across a wide range of ages, cognitive and physical abilities and care settings. We provided them with their first-ever VR experience, and then carried out interviews. Data were analyzed qualitatively and quantitatively according to the Laddering method (Reynolds & Gutman, 1988).

3.1 Method

3.1.1 Participants[1]

We recruited from a diverse population of older adults in care homes first, from age 55 to 95 years, with various levels of education, cognitive status and care settings. Additionally, we recruited independently living older adults matching in age. Participants were recruited through contact lists of previous studies, organizations for older adults and care homes avoiding the use of technology in recruitment. We took VR safety regulations in account for in- and exclusion criteria, excluding candidates with a medical implant or epilepsy. If candidates had impaired vision/hearing that could not be corrected, or if they were unable to provide informed consent, they were not included. No candidates had previous experience with IVR. The study was approved by the Social and Societal Ethics Committee of KU Leuven and executed in accordance with the committee's ethical guidelines.

3.1.2 Instruments

Cognitive assessment was done via the *Montreal Cognitive Assessment* (*MoCA*) (Nasreddine et al., 2005), a widespread tool to measure different cognitive domains (e.g., executive function, memory, language). The official cut-off score to diagnose mild cognitive impairment is 26 on a maximum of 30. The ability to perform purposeful actions with the upper limbs was assessed via the praxis subtask of the *Birmingham Cognitive Screen* (*Praxis*) (Bickerton et al., 2012). Participants had to copy complex line drawing; their score was compared to age-adjusted cut-off scores. *Computer proficiency (CP)* was measured using a 22-item Likert-scale questionnaire (range 1-5) in which participants indicated if they were able to perform certain actions (e.g., I can turn a computer on).

[1] The data used in the current paper were collected as part of a bigger study investigating the acceptance of HMD-VR in 76 older adults with different characteristics (Huygelier et al., 2019). In the current paper, we analyze the qualitative data (open ended interviews) of the experimental group (n = 37).

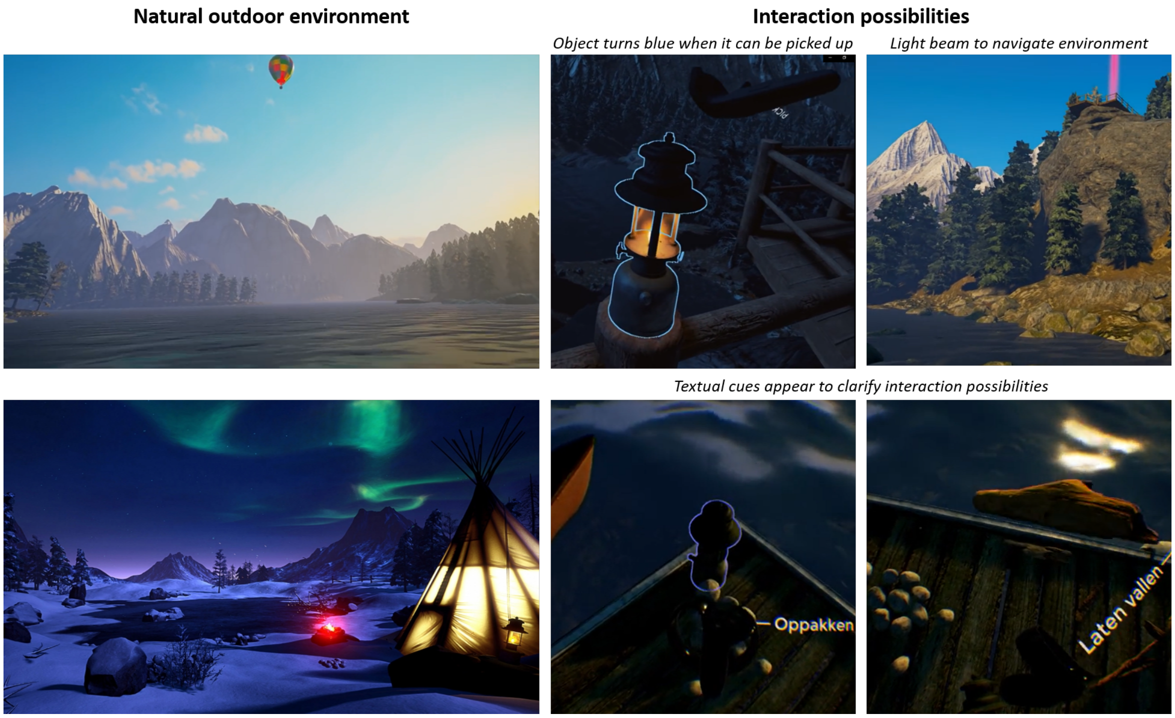

Figure 2. Perfect by nDreams, a compilation video of interactions with IVR application by participants can be found at (Huygelier, 2020).

3.1.3 Immersive VR exposure

Participants experienced the application ‘Perfect’ of nDreams (nDreams, 2016) using the Oculus Rift CV1 and Touch Controllers. Perfect is a commercial VR application that provides an open-ended exploration in three naturalistic locations, a tropical beach, a snowy arctic environment and a mountain wilderness, at different times of day and from different viewing points.

This IVR application was selected in close consultation with two care providers of a local elderly care organization, of which one also acted as reference person on dementia for the local community. The care providers argued for caution when introducing VR to a population of older adults that may encompass frail older adults, possibly with cognitive impairments. The care providers tested two IVR applications (Oculus First Contact and Perfect), and after this review, considered Perfect appropriate for older adults. The choice for a commercial IVR environment was intentional to ensure high quality. To interact with objects and navigate the environment, users needed to tilt the controller to point at objects and simultaneously push a button to carry out an action (e.g., picking up a stick, throwing a ball, traveling to a different world), see Figure 2. In each of the three different locations, aiming and selecting a light beam allowed to navigate to another environment. The environment is rich in both audiovisual details that while not directly needed for interaction and navigation, may still strengthen overall immersion (e.g., a radio playing music, howling wolfs, crackling fire, a butterfly passing by, etc.). In the environment, users can see representations of the touch controllers, but not their own hands.

3.1.4 Procedure

In a first session (ca. 60 min), a demographic interview was performed, after which the MoCA (Nasreddine et al., 2005), BCoS (Bickerton et al., 2012), and CP scale were administered by a clinical psychologist. Special care was taken to ensure that all participants understood each question. In a second session (ca. 90 min), participants first received an explanation about the VR device and how they could interact with the virtual environment. Next, they were exposed to the virtual environment for an average of 26 minutes (SD=5.5 min, range:8-36min) in the different virtual locations. At the start, participants were free to explore the natural environment without specific task instructions or performance measures. After a few minutes of free exploration, the psychologist assisted participants in performing interactions with the virtual objects by providing verbal support and if needed additional manual guidance.

The psychologist stayed with the participants the entire time and participants could ask as much help as desired. Participants remained seated at all times in a swivel or wheelchair. After the VR experience, participants were interviewed, which served as the basis for the Laddering analysis.

3.1.5 Interview and data analysis

The underlying theory guiding the interview and Laddering data analysis is Means-End theory (Gutman, 1982), which posits that people hold different abstractions of product-related knowledge; people prefer products because of certain *Attributes* (product features, either *concrete* (CA) or *abstract* (AA)) that provide certain *consequences* (benefits, either *functional* (FC) or *psychosocial* (PsC)) which in turn align with certain *values* (stable life values, either *instrumental* (IV), i.e., preferable modes of behavior) or *terminal* (TV), goals to achieve through behavior). Relations between these elements are called a *ladder* at an individual level. When ladders are aggregated at the group level, these are called a *chain* (see Figure 3).

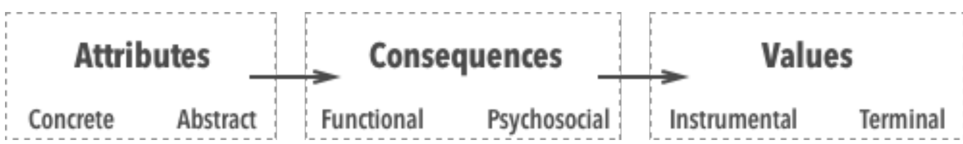

Figure 3: The basic means-end chain.

The final objective of a Laddering analysis is to present an overview of dominant Means-Ends chains (MEC), depicted as a hierarchical value map (see Figure 4), that illustrates the network of linkages, from the attribute to the value level.

In our open-ended interview, the participants were first asked *what they liked*, and next *what they disliked*. This interview served as the basis for the laddering analysis. In line with UX Laddering (Zaman & Abeele, 2010), interviews were short, prompting for salient elements only. Interviews lasted on average 5 minutes 30 seconds (range 54s to 6min25s). First, interviews were transcribed ad verbatim and entered in nVivo. Next, a Laddering analysis was carried out over four iterations by two coders (AUTHOR2 and AUTHOR1). In each of the four iterations both coders performed coding independently at first, next they had a meeting to assess difficulties and differences in interpretation. First, open coding was performed and candidates for core elements (A/C/V) were derived by the two coders independently. These candidates were then discussed and a coding tree of agreed upon core elements was defined and categorized according to the CA-AA- FC-PsC-V level. Next, the interviews were re-analyzed by the two coders independently, on the basis of this unified coding tree. From the interviews, ladders for all participants were coded (see Table 3 for an example) and entered into a score matrix (SM) in the online tool LadderUX (Vanden Abeele et al., 2012).

Table 3: Excerpt from an interview alongside two ladders derived from the interview.

Interview	Ladder
I: What did you like about it? P: It was beautiful, the scenery I saw, all of it... really appealing	01 Positive -> 07 Scenery -> 22 Aesthetic appeal
I: And what did you dislike about it? P: Well, because I sat by the water, I was afraid that I would fall in the water. There was water…	02 Negative -> 06 Props-Objects-Details -> 27 Negative immersion – fear

Inter-reliability of the ladders created by coders was assessed, Cohen’s Kappa was 0.80. Upon achieving this acceptable intercoder reliability, analysis continued with the dataset of the coder who performed the interviews (AUTHOR2). Then, the *Implication Matrix* (IM) was created, which sums the amount of direct and indirect links between two elements in the ladders (see A.1 Implication Matrix). A direct link occurs when two elements follow one another directly within one ladder. An indirect link refers to two elements that are positioned in the same ladder, but not positioned adjacently. The IM allows to inspect total linkage strength across participants and establish *Means-End Chains* (MECs) at the group level. Upon inspecting the overall data, cut-off values were defined (the number of times one element needs to be followed by another element in order to be retained for analysis). In line with (Vanden Abeele & Zaman, 2009), they were set at 3 for the CA-AA and FV, at 2 for PsC and 1 for IV. This led to the final hierarchical value map (see Figure 4).

3.2 Results

3.2.1 Participants

We recruited a diverse sample of 38 older adults (18 care home residents (NH), 20 community dwellers (CD)). One of the NH residents (male, 90 years of age) dropped out after the first session, a reason was not given. Twenty out of 37 participants had a *MoCA* score below 26 (5 CD, 15 NH) (Nasreddine et al., 2005), suggesting mild cognitive decline. Four participants failed the *BCoS Praxis* figure copy task. Sample characteristics are described in Table 4.

Table 4: Overview of participants characteristics (n = 37).

Descriptive variables	
Age M (SD, Min – Max)	74.4 (10.2, 60 – 92)
Sex (Male/Female)	18/19
Education (Low/Mid/High)	11/12/14
Community dwellers (CD)/Care home residents (NH)	20/17
MoCA score M (SD, Min – Max), failed/passed	24.1 (4.8, 10–30), 20/17
BCoS praxis figure copy score M (SD, Min – Max)	42.1 (7.8, 0 – 47)
Computer use in hours (CU) M (SD, Min – Max)	2.1 (2.1, 0 – 7)
Computer Proficiency (CP) M (SD, Min – Max)	3.4 (1.5, 1 – 5)
Frequency of playing digital games (never/at least once)	16/21
Ever used a game console (never/at least once)	32/5
Heard of VR before study (never/at least once)	17/20

3.2.2 Laddering data

In total, 127 ladders were generated, with an average of 3.53 elements per participant (SD = 1.00), amounting to 450 datapoints, adequate for quantitative Laddering analysis (Reynolds & Gutman, 1988). Besides the two start conditions (Pos, Neg), 32 different elements were identified (see A.1 Implication , column ‘Core Elements’). Six different means-end chains among participants were identified (Figure 4) and discussed below.

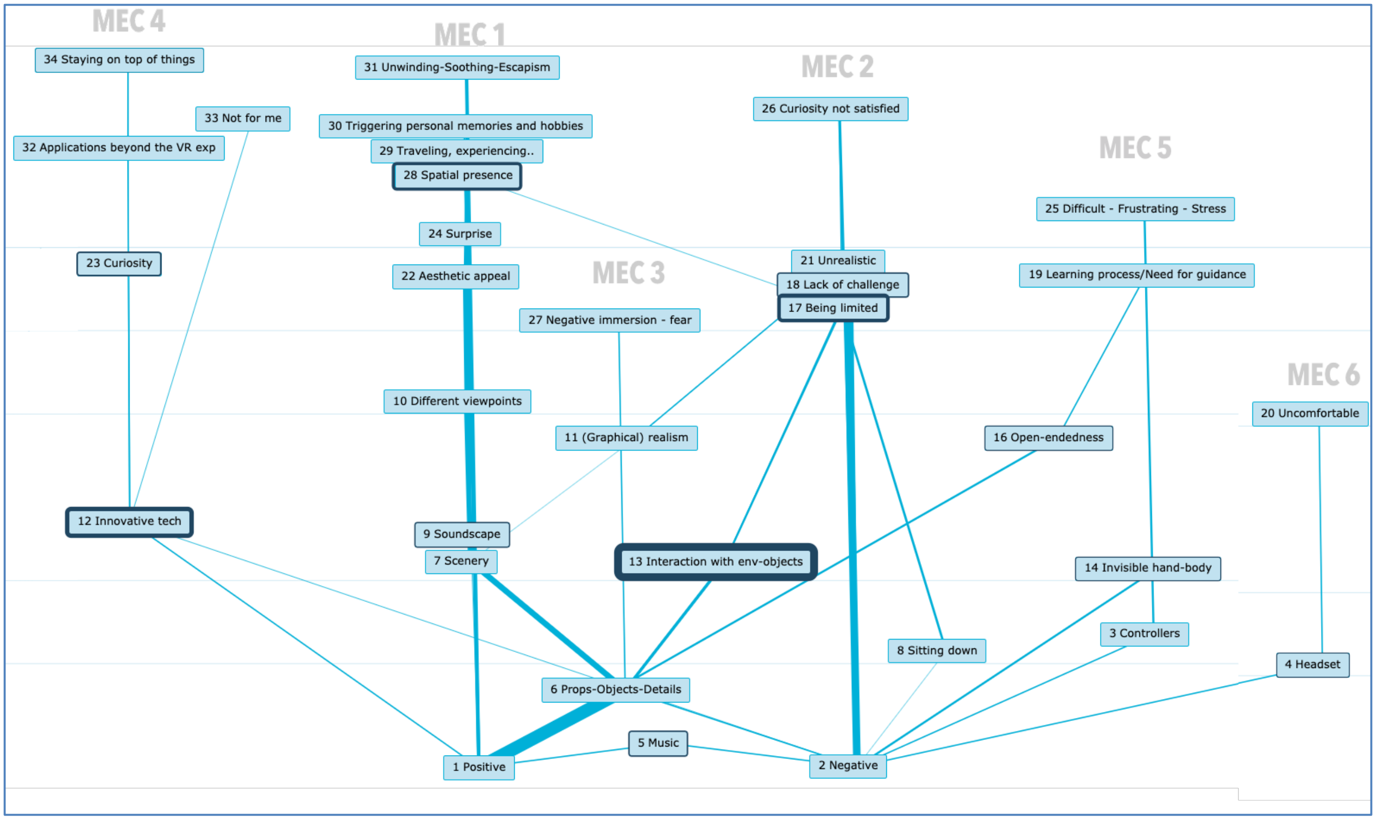

Figure 4: An overview of the Hierarchical Value Map, showing six different MEC's, numbered according to percentages of links they represent. Line thickness represents link strength, border thickness represents centrality of the element. A larger variant of the figure can be found in the Appendix A.2.

3.2.3 MEC1: Transcending reality

The most dominant MEC points to positive VR user experiences, and can be found in the high associations between 'Positive', 'Props-Objects-Details', 'Scenery', 'Soundscape', 'Different viewpoints', '(Graphical) realism', 'Interaction with env-objects', 'Aesthetic appeal', 'Surprise', 'Spatial presence', 'Traveling, experiencing', 'Triggering personal memories/hobbies' and 'Unwinding-Soothing-Escapism'. MEC1 represents 146 direct (45%) and 155 indirect links (50%).

Older adults were highly perceptive of the different audiovisual elements and the scenery. Participants mentioned a variety of detailed elements they liked such as water, butterflies, snow, fire. Equally they mentioned the soundscape (e.g., the crackling of the fire). But often, they simply referred to the scenery in general, and how they enjoyed the aesthetics or "beauty", and how this brought about a feeling of really being there. They also often mentioned how certain scenes triggered sensory immersion, feeling truly cold or warm.

> *Participant (P): Well, I actually thought it was a pleasant experience, I ended up in another world, yes … and that actually made me very calm, yes, also so peaceful, I was*

really able to admire the nature, beautiful! Yes, it really impressed me. [...] And I was kind of part of it, right... part of the environment, that is what it felt like.

Interviewer (I): What was it that made you feel like you were part of it?

P: The fact that I could touch a number of things. And that I could turn on the music, change the channel.

P32: male, 71y, ED high, CD, MoCA 24, Praxis 45, CP 4.3

P: Uhm, maybe something very crazy, but I had the feeling of coolness, it was so warm in the [physical] room here… And still I had the feeling that it was cool, the snowball fell on my feet, I am sitting on ice. […]. Really the feeling that it... with the first scene, where I was high in the mountains and there was wind... I thought "it is too cold here, I should go". […]. The feeling as if "Here is a fire that crackles and the fire is going to give me warmth". This feeling I had was very strong, the cold and the heat and the wind."

P16: female, 64y, ED high, CD, MoCA 30, Praxis 46, CP 4.2

Additionally, certain sceneries, particularly the mountains, triggered older memories, often at the same time warm and nostalgic. Older adults would reminisce during interviews. With some participants it became hard to establish when the discussion of the VR experience ended, and the elicitation of the memory began.

P: The environment was pleasant. …You were catapulted back a bit ... me anyway, in the beautiful things that I also saw in the past. […]

I: Yes, you uttered that it made you long for your travels. And did you like to think back on that or?

P: Well, yes, I'm going to tell you, it was a very, maybe something completely different, we were on the Puy-de-Dôme in France once. And so, we stood up there on the mountain and there was that hang glider, it was the first time I saw that […] Yes, it came back to me by seeing it here. And then I saw, we saw what I thought were stones, white stones. But they were sheep (laughs). And my husband is laughing […] And I tell him "Look at this, what kind of stones"! And he says: "If these really are stones then" (laughs). Yes, these are the kind of memories that…
I: Something you did not like or something you would have wanted differently?
P: No, I didn't think about it either, I liked it and that made me think back to the past. I enjoyed it.

P41: female, 85y, ED high, NH, MoCA 25, Praxis 45, CP 1.9

A few participants also mentioned that they appreciated that the VR allowed them to see places they otherwise would not be able to see anymore. This was in particular true for the northern light, that could be seen in the polar scenery.

P: Seeing everything, seeing the surroundings, … That I could look around in it and really get the feeling of… yes… being right there in it. Yes, I actually found it very…it is uhm… lifelike. […] and I always wanted to see the northern light (laughs), and now I have the feeling that I don't have to go there anymore."

P15: male, 65y, ED high, CD, MoCA 27, Praxis 46, CP 4.9

3.2.4 MEC2: Curiosity not satisfied

The second most dominant MEC starts from ‘Negative’ and leads up to ‘Curiosity Not Satisfied’, containing ‘Props-Objects-Details’, ‘Sitting down’, ‘Soundscape’, ‘Interaction with env-objects’, ‘Being limited’, ‘Lack of challenge’ and ‘Unrealistic’. MEC2 accounts for 81 direct links (25%) and 73 indirect links (23%).

While the VR experience provided a sense of spatial presence, for some participants it felt somewhat unsatisfying. It seemed that the interaction was too limited to provide a meaningful experience, and that after some exploration, suspense of disbelief was interrupted.

> *I: Are there things you missed or would want differently?*
> *P: Yes, maybe to be able to go in the boat, and then maybe get seasick. To test whether you could get the feeling of being seasick would be quite an experience. And a fishing rod to fish, because there were fish. And there was a fire too, so I could have cooked them. [...] There is a fire, but there is no pot to make coffee or tea, so if you are thirsty, you can't grab something to eat or drink.*
>
> *P29: female, 70y, ED mid, CD, MoCA 26, Praxis 40, CP 4.8*

Experiencing the limits of the open environment, some participants commented on the lack of actual realism (despite the graphical realism) and the fact that they could not explore further and satisfy their curiosity.

> *P: The quality is not as good as a tv screen yet. [...] The mistakes that you see. You do not expect these mistakes when everything before was so good, like when the stick is lit on fire and thereafter you lay it down in the snow, then nothing happens. Of course, you only start seeing these things because everything before was so good... […] In that case you are a bit disappointed, that... well, when the details are not correct the "being real" disappears.*
>
> *P35: male, 69y, ED mid, CD, MoCA 28, Praxis 45, CP 3.9*

Some participants also looked for a sense of purpose, i.e., a goal or challenge they had to complete.

> *P: Yes, in a certain sense there are too few options or perhaps I could not operate my buttons enough. I miss a goal. If you give a command "do this, do that" then ... […] I suddenly saw that pot standing there, ah I think I'm going to melt water on the fire. But if you cannot even move the pot….*
>
> *P25: female, 68y, ED mid, CD, MoCA 28, Praxis 46, CP 5*

> *I: So, tasks would have been better for you? Or assignments?*
>
> *P: Yes, I ask for instructions (laughs)*
>
> *P23: female, 71y, ED high, CD, MoCA 29, Praxis 46, CP 4.2*

‘Sitting down’ is also included in this chain. While older adults were asked to remain seated for their safety, four participants mentioned that it made them feel limited in their movements and explorations in the environment or being able to look around and change viewpoints.

> *P: Of course, I was immersed in it and at a certain moment I wanted to stand up and go for a walk. But that is a limitation, you must remain in your chair, however the immersion evokes a certain sensation. I: Yes, that you wanted to go explore? P: Yes, yes!*
>
> *P32: male, 71y, ED high, CD, MoCA 24, Praxis 45, CP 4*

3.2.5 MEC3: Negatively immersed

The third most dominant MEC starts from 'Negative', up to 'Negative immersion/fear', containing 'Props-Objects -Details', 'Scenery', 'Soundscape' and '(Graphical) realism'. MEC3 stands for 36 (11%) direct and 15 (5%) indirect links.

While most older adults enjoyed the immersion, five older adults also mentioned frightening moments. The VR and specific scenes and objects in combination with a perceived realism gave way to feelings of anxiety.

> *P: I sometimes had the feeling that I was on vacation. […] But a little frightening too. Maybe because of the sound, the sound of the ...*
> *I: From the wolves?*
> *P: Yes, yes, yes, yes, yes! From those wolves or from the radio. Or no, not from the radio, that was calming. It was from the wolves. I'm quite an easy scare.*

For four of the five older adults mentioning fear, this did not trigger them to stop the experience. One older adult however, stopped the VR experience, upon interaction with the water. She explained that this triggered her 'phobia'.

> *I: You took the headset off, why did you say you wanted to stop? What was bothering you?*
>
> *P: Well, because I was at the lakeside, I was scared of falling in the water. Suddenly there was water and a boat in front of me. [...] Suddenly I was lying in the water, and that's not for me!*
>
> *P7: female, 90y, ED low, NH, MoCA 18, Praxis 37, CP 1*

3.2.6 MEC4: Happy I did it, but not for me

The fourth ME chain is linked both to 'Positive' and 'Negative', and comprises 'Innovative tech', 'Curiosity', 'Applications beyond the VR exposure', 'Not for me' and 'Staying on top of things'. MEC4 contains 30 direct links (9%) and 32 indirect links (10%).

Many older adults alluded to the innovative aspect of the experience and appreciated this novel experience. Some acknowledged that they were curious about this and wanted to stay on top of things. They equally voiced how they saw such technology could contribute to applications beyond the VR experience.

> *I: What did you like about the experience?*
>
> *P: That it is fun in the sense of the innovation. I am always open to innovation, that you see "the future". You should be able to look into the future. I always say, "If you are not interested [in the future], then well (sigh)". But for me ...*
> *I: … it is important to stay on top of things?*
> *P: Yes, yes!*
>
> *P42: male, 88y, ED low, NH, MoCA 21, Praxis 36, CP 2.9*

However, five participants also explicitly voiced that this innovative technology was *not* for them.

> *P: I really liked that environment, I really wanted to go there. It stimulated me; it would be good advertisement for a travel agency. […] Whether I would do it again, I don't know. Suppose I had that at home, would I do this again, I actually don't think I would? So, it is not really something that attracts me in the sense of, wow tomorrow I'm going to the store to buy this and turn it on. […] But the experience was very nice, yes, I found it very pleasant and I am very happy that I did it. "*

P17: male, 64y, ED high, CD, MoCA 29, Praxis 45, CP 4.8

3.2.7 MEC 5: Sometimes frustrating

The fifth MEC starts from 'Negative' and leads to 'Difficult-Frustrating-Stress', comprising 'Controllers', 'Invisible hand-body' and 'Learning/Need for guidance'. MEC5 counts for 22 (7%) direct and 19 (6%) indirect links.
It was mentioned by four participants that the controllers were difficult to handle, and that it required them to learn how to handle them or get some guidance. They also commented on the fact that they could not see their own hands.

> *P: I thought that … I still had trouble operating it, I thought it wasn't very ... […] The pointing did not go so fluently. I was always just next to it. I had to try so hard to ... (makes aiming gesture). […] Um, of course it is a matter of getting used to it, these 2 buttons. It takes some time before you know which button is for what.*
>
> *P15: male, 65y, ED high, CD, MoCA 27, Praxis 46, CP 4.9*

> *P: The direction of the controllers is not easy to get, and you get little feedback on where your thumb is. So, at a certain moment I [his thumb] was too high or something, and I did not realize it.*
>
> *P22, male, 72y, ED high, CD, MoCA 29, Praxis 44, CP 4.5*

Four participants also commented on the open-endedness and a need for guidance to understand what to do.

3.2.8 MEC6: Uncomfortable headset

This last MEC starts from *'Negative'* and leads to *'Uncomfortable'*, comprising *'Headset'*. MEC6 counts for 6 (2%) direct and 3 indirect links (1%).
Three of the 37 participants mentioned that they found the headset too heavy or too warm.

> *I: You said: "I don't want it on my head for too long!" Why?*
>
> *P: No, no, no! I don't know; too heavy, disruptive, oppressive?*
>
> *P36: female, 64y, ED mid, CD, MoCA 26, Praxis 46, CP 4.1*

> *I: Um, were there some things that you didn't like about the game?*
>
> *P: The glasses (laughs) [Means headset] […]*
>
> *P: Yes, I sweated a lot underneath it.*
>
> *P17: male, 64y, ED high, CD, MoCA 29, Praxis 45, CP 4.8*

3.2.9 Summary of Laddering analysis

The Laddering study included a sample of 37 older adults who either lived independently or in care homes, differing in gender, age, cognitive status and education level. Six dominant means-end chains among participants were identified. MEC1 ("Transcending reality") that links aesthetic appeal to spatial presence and reminiscing, represents nearly 50% of all linkages. MEC 2 ("Curiosity not satisfied") addresses feelings of being limited and a lack of challenge, and represents approximately 25% of all linkages. The four remaining MECs ("Negatively immersed", "Happy I did it, but maybe not for me", "Feeing frustrated" and "Uncomfortable headset") are more limited in the number of linkages, varying from 15% to 1%. Overall, our empirical findings suggest that while many participants enjoyed the IVR experience offered to them, others found it somewhat limited.

In conclusion, this Laddering study comprises an empirical study of older adults' IVR experiences. In particular, we provided 37 older adults of diverse ages, education levels, cognitive abilities, and computer proficiency, a first IVR experience, and evaluated their experiences via short interviews, analyzing these via the Laddering method. This method yielded insight into how specific attributes of the IVR experience gave way to older adults' functional and psychosocial consequences, and even values, through a network of means-end chains. In the next section, based on the findings of the laddering study, we empirically ground and reflect on the design recommendations, and present a framework that may inform designers of future immersive VR experiences.

4 EMPIRICALLY GROUNDED DESIGN GUIDELINES

As a last research action, we leveraged the findings from our Laddering study to reflect on the set of guidelines which we initially compiled from the literature review, regarding implications for accessibility, usability, and user experience that VR provides for older adults.

4.1 Method

Four co-authors (AUTHOR1, AUTHOR2, AUTHOR3, AUTHOR5) revisited the different guidelines. We used the following five categories. *Support* (S) includes guidelines for which the interviews or observations of older adults confirmed that these were indeed good guidelines. *Not supported* (NS) points to guidelines for which the interviews or observations of older adults in our study did not provide support. *Varied responses* (V) points to guidelines where we found considerable heterogeneity within our sample. These guidelines were desirable for some participants, while other participants explicitly critiqued it. The category *inconclusive* (I) was used for guidelines for which our results did not allow to draw *firm conclusions* and that would require more attention in future studies. Last, the category *not addressed* (NA) included guidelines for which our study did not allow to draw any conclusions as the IVR environment did not encapsulate it. For instance, items about social avatars were not addressed by our study as there were no avatars in the IVR experience. Over several meetings, it was discussed how the observations and MECs from the Laddering study supported the different design guidelines, until consensus was reached.

4.2 Results

Table 5, provides a summary of reflections on the design guidelines, with the right column marked up with either Support (S), Not supported (NS), Varied responses (V), Inconclusive (I) or Not addressed (NA).

4.2.1 Accessibility

Physical changes – Musculoskeletal fatigue. We found no support for the guideline suggesting limiting head movements (A2) or to avoid the use of buttons or gestures as control input (A4), as participants did not spontaneously report limited force or difficulties in gripping controllers or pushing buttons, nor did they express a wish to limit head movements (A2). Previous design guidelines suggested to use seated experiences (A7), but in our study four older adults expressed that sitting down, even in the swiveling chair, felt limiting to them (A7, MEC2).

Physical changes – Sensory sensitivities. Although previous design guidelines suggested to increase contrast (A8), avoid using high-frequency tones (A10) and to increase vibration intensity (A11), older adults enjoyed the audiovisual virtual world and did not express feeling hampered in their audiovisual perception (MEC1), nor being overwhelmed by stimuli (A9). Moreover, participants did not mention fatigue when gesturing (A12).

Physical changes – General. Previous guidelines suggested monitoring participants for signs of cybersickness (A13) and giving participants an active role (A14). Our participants did not experience cybersickness but were indeed given an active role. Problems with glasses or hearing aids were not found, the HMD accommodated these (A15).

Cognitive changes - Attentional deficits. Although previous guidelines suggested to remove non-task critical stimuli, we did not observe participants to be overstimulated to complete tasks (A17), even in the presence of non-task critical stimuli.

Accessibility- General. Previous guidelines suggested to provide assistance (A22) during the IVR experience. Indeed, the psychologist who was present during the IVR experience and provided assistance, was welcomed by several older adults (MEC 5). Moreover, it was indeed necessary to monitor participants for signs of stress (A23, MEC 3). We also found strong differences among older adults in their technological understanding of and ability in VR (A24).

4.2.2 Usability

Navigation and wayfinding. Participants enjoyed being able to freely explore the open environment (MEC1), but the psychologist did verbally encourage them to interact with objects and verbally explained the interaction with the light beams for navigation. It was found this was necessary for some older adults to enable exploration in a supportive fashion (U5).

Object selection and manipulation. Natural interaction methods such as haptic gloves (U7) or salient handles on virtual objects (U8) may indeed be recommended, as some participants had difficulties in using the controllers in the IVR experience (MEC5). Participants also commented on the lack of seeing their own hands, and the orientation of the controllers.

Instructions and tasks. Previous guidelines suggested to provide verbal instructions to guide participants in the VR environment (U10, U11) or provide feedback (U12). Although most older adults were happy to explore without the need for verbal or written instructions in the VR world (MEC1), the present psychologist also provided verbal encouragements. Moreover, four older adults explicitly expressed needing guidance, in learning to work with the controller or navigating the environment (MEC5).

4.2.3 User Experience

Presence. MEC1 shows that older adults indeed enjoyed the natural elements (X2), the broad views and high altitudes (X3) and congruent, dynamic soundscapes (X5-X6). Nevertheless, older adults also commented on the lack of realism when expected interactions with objects were not possible, clarifying that ecological validity is indeed important (X1, MEC2). Guideline X4 asks that the diverse objects and details are congruent with the overall scene. Indeed, we found older adults appreciated the many detailed objects in the scenes as long as they were congruent; these were not experienced as clutter, but rather enriched their experience (MEC1).

Reminiscence. The virtual environment, while being novel, also triggered personal memories in older adults (X10, X9), which was enjoyed (MEC1). The music was also explicitly commented on, as positive, or negative when not to their liking, suggesting the need to personalize this (X12).

Shared experience. It has been suggested to allow caregivers to experience the same environment as the older adults (X13) and indeed two participants mentioned they were proud to have experienced this new technology and that they were looking forward to talking about it with their children and/or grandchildren, to show them what their 'old relative' could still do. Moreover, active inclusion of older adults (X14) is important, as older adults welcomed the active interaction with objects (MEC1). Moreover, social support (X15) was indeed important, as some older adults expressed appreciating the experimenter being present and needed reassurance.

Limitations of the ageing body. Older adults appreciated being able to experience the different worlds, and (re)visit places they were no longer physically able to (X20, MEC1). Guideline X22 suggests avoiding competitiveness, but some older adults explicitly criticized the lack of challenge in the IVR experience (MEC 2).

Purpose/content. Tailoring VR to participants idiosyncratic interests (X23) may indeed be good, as some participants expressed how they would like to use VR in the future (MEC 4). Using VR for travel (X26) was indeed supported, as older adults expressed visiting enjoying the outdoor environment and three mentioned they had always wanted to see the northern light (MEC1).

Table 5. Comparison of design guidelines and observations with the immersive experience in our study. The rightmost column indicates the extent to which guidelines are supported by the Laddering study: Support (S), Inconclusive (I), Not supported (NS), Varying responses (V) and Not addressed (NA).

ACCESSABILITY			
A1	Consider weight of HMD	Three older adults commented on a lack of comfortability of the headset (MEC 6).	S
A2	Limit head movements	Participants did not spontaneously report a wish to limit head	NS
A3	Opt for gesture-based control	Few participants mentioned problems with grip and force during the IVR experience. Most of them did not report problems.	V
A4	Avoid using buttons or gestures	Participants did not spontaneously report fatigue due to the use of the controller.	NS
A5	Minimize reaching by putting devices in ergonomic position	The psychologist observed that some participants in wheelchairs or with physical limitations were not able to reach all virtual objects.	S
A6	Use a calibration process to adjust the range of motion for each user	The psychologist moved participants so that they could reach virtual objects.	S
A7	Opt for a seated virtual experience	Four older adults expressed that sitting down felt limiting to them (MEC 2). A seated experience was necessary for some older adults.	V

A8	Increase contrast ratios and illumination	Older adults enjoyed the audiovisual virtual world (MEC 1) and did not spontaneously express feeling hampered in their audiovisual perception. However, we did not explicitly ask whether they were able to see or hear everything.	I
A9	Block out irrelevant stimuli	Older adults did not report feeling overwhelmed by stimuli and appreciated many audiovisual details in the IVR experience (MEC 1).	NS
A10	Avoid use of high frequency tones for feedback and 3D localization	Older adults enjoyed the audiovisual virtual world (MEC 1). However, we did not explicitly ask whether participants were able to hear everything.	I
A11	Opt for tactile feedback where possible but increase vibration intensity compared to normal	Vibration intensity was not adjusted and some older adults explicitly commented on the vibrations. However, we did not explicitly ask each participant whether they felt the vibrations.	I
A12	Consider trade-offs: gestures cause less fatigue but lack haptic	Participants did not spontaneously mention fatigue when gesturing.	NS
A13	Monitor for simulator sickness	Our participants did not report cybersickness, but participants were in control of their movements in the IVR environment.	I
A14	Avoid vertigo by providing an active role to user when navigating	Participants had an active role when navigating and did not report cybersickness.	S
A15	Verify that the IVR system accommodates for glasses and hearing aids	Problems with glasses or hearing aids were not found, the HMD accommodated these. Note that a cochlear implant and severe nearsightedness were reasons for exclusion.	S
A16	Use the full spectrum of sensory experiences	Older adults commented on the visual, auditory and tactile stimuli in the IVR experience (MEC 1). However, we did not explicitly ask which sensory stimuli they noticed most.	I
A17	Remove stimuli that are non-task critical, avoid overstimulation	We did not observe participants to be overstimulated to complete tasks, but there was no time pressure or pressure to perform (MEC 2).	NS
A20	Use positive feedback for controls to be memorized	The psychologist gave positive feedback to participants to learn to use the controls (MEC 5).	S
A22	Provide assistance if necessary	The presence and assistance of the psychologist during the VR experience was welcomed by the participants (MEC 5).	S
A23	Monitor older adults for symptoms of stress	The psychologist monitored participants for signs of stress (MEC 5). For instance, one participant was fearful of virtual water and the psychologist helped to remove the headset at that moment (MEC 3).	S
A24	Bear in mind the heterogeneous, diverse technological understandings	We found large differences among older adults in their technological understanding of IVR and ability in IVR. Some expressed appreciating this novel experience, while at the same time, saying this was 'not for them' (MEC 4).	S
USABILITY			
U2	Use landmarks obvious in function	Many older adults did not intuitively understand that the beam of light in the IVR experience could be used to navigate to a new scene. Thus, a landmark with a more obvious function may have been better.	S

U5	Enable exploration in a supportive fashion	The psychologist encouraged participants to interact in the IVR experience and this was appreciated by the older adults.	S
U6	Provide verbal prompts when transitioning between VR scenes	Some participants responded surprised when switching to a new scene and therefore the psychologist explained to participants where they were	S
U7	Consider natural interaction methods, i.e. 'haptic gloves' that track hand movements and provide feedback about virtual objects when pointed at.	The requested combination of orienting the controller in a certain direction while pushing a button to pick up objects was problematic for some older adults. They also commented on the lack of seeing their own hands (MEC 5). This suggests that different, more user-friendly techniques may be required.	S
U8	Use tasks that implicitly signify how to interact with objects	When an object was selected, it turned blue and participants could grasp it by pressing the trigger. For some participants, the object turning blue was not sufficiently clear to indicate that they could grasp it. Thus, a less abstract visualization may have been better.	S
U9	When moving objects, directly attach objects to the hand, and when target location is reached, directly remove objects from the hand at target locations.	The combination of orienting the controller in a certain direction while pushing a button to pick up objects was problematic for some older adults. These complex sequence of steps made it difficult for some participants to pick up, hold, and let go of objects in a controlled manner. They also commented on the lack of seeing their own hands (MEC 5). This suggests that different, more user-friendly techniques may be required.	I
U10	Provide verbal prompts before the transition from real world to VR	The psychologist explained to participants when they transitioned from the real world to the VR world.	S
U11	Provide verbal instructions that bring users into the scene and task, in a gentle, casual, and storytelling fashion	Older adults were given explanation about the IVR experience before starting it. During the IVR experience, some older adults were happy to explore without the need for instructions in the IVR world (MEC 1). Yet, it has to be acknowledged that the psychologist also provided verbal encouragements.	S
U12	Clearly indicate when a task has been successfully accomplished.	Some older adults clearly asked for feedback from the psychologist guiding them (MEC 5).	S
U13	Prevent or avoid users to make errors	Some participants had difficulties interacting with objects, but there were no negative consequences (e.g. losing points) related to this. When participants felt like they were not doing well, the psychologist reassured them that they did not need to worry about their performance.	I
USER EXPERIENCE			
X1	Present ecologically valid items	Older adults commented on the lack of realism when expected interactions with objects were not possible (MEC 2).	S
X2	Provide nature-oriented elements and details (birds, flowers, water)	Older adults enjoyed the natural elements (MEC 1).	S
X3	Provide scenic value (broad views, distant locations, high altitudes...)	Older adults enjoyed the general scenic value which included altitudes and broad views (MEC 1).	S

X4	Ensure that the diverse objects and details are congruent with the scene, to be perceived as a ‘whole’.	Older adults enjoyed the aesthetic appeal of mountains and snow landscape, but also appreciated the many congruent detailed objects in the scenes. These details were not experienced as clutter, rather they enriched the experience (MEC 1).	S
X5	Provide congruent soundscapes.	Older adults enjoyed the congruent, dynamic soundscapes (MEC 1).	S
X6	Use dynamic and interactive sounds	Older adults enjoyed the congruent, dynamic soundscapes (MEC 1).	S
X7	Use exaggeration in sounds, make them more prominent than in reality	Some sounds in the IVR experience were more prominent than in real life and this contributed to feelings of presence. For instance, participants expressed feelings of fear when they heard howls of wolves (MEC 3) or feelings of warmth when they heard the fire.	S
X9	Allow to go back in time and recollect personal experiences	The virtual environment triggered personal memories in older adults which they enjoyed (MEC 1).	S
X10	Merge aspects of familiar experiences with new settings	The virtual environment, while being novel, triggered personal memories (MEC 1).	S
X12	Add music to personalize the experience.	The music was also explicitly commented on, as positive, or negative when not to their liking, suggesting the need to personalize this.	S
X13	Aim for a shared experience, allow carers to experience the same environment	Two participants mentioned they were proud to have experienced this new technology and that they were looking forward to talking about it with their children and/or grandchildren, to show them what their ‘old relative’ could still do.	S
X14	Ensure active inclusion of the person with dementia, avoid turning them into passive observers	Older adults welcomed the active interaction with objects (MEC 1) and commented that they liked being able to have experienced the IVR. Some also mentioned feeling proud that they could stay on top of things (MEC 4).	S
X15	Involve caretakers for social support	Some older adults expressed appreciating the psychologist being present and needed reassurance (MEC 5).	S
X20	Exploit VR’s ability to overcome limitations of physical body	Older adults appreciated being able to experience the different worlds, and (re)visiting places they were no longer physically able to (MEC 1).	S
X22	Avoid competitiveness, emphasize achievement	Some older adults explicitly criticized the lack of challenge in the IVR experience (MEC 2).	V
X23	Have older adults tailor VR experiences to their own interest	Some participants talked about their ideas for future VR applications. And expressed what they would want to use it for (MEC 4).	S
X26	Travel to new places	Older adults expressed enjoying visiting the outdoor environment and three mentioned they had always wanted to see the northern light (MEC 1).	S
X27	Stimulate self-education	One participant mentioned that this could be used to visit museums or check future holiday locations (MEC 4).	I

5 DISCUSSION

Older adults constitute an increasing proportion of the world's population and are increasingly targeted as an audience for novel technologies (Czaja et al., 2009), including immersive VR. Such novel applications targeting older adults are often designed from the perspective of maintaining and enhancing older adults' health, and limited to the clinical realm. At the same time, there is a call for a more holistic approach to designing for older adults that does not limit old age to mitigating age-related decline and illness (Durick et al., 2013; Knowles et al., 2019; Vines et al., 2015). Our work explored how to guide the design of immersive VR, catering to the diverse abilities, needs and preferences of older adults, so that they can access, use and enjoy it,

The *literature review on IVR and older adults* revealed multiple epistemological approaches, ranging from experimental evaluations of early prototypes (e.g., Bruun-Pedersen, Serafin, & Kofoed, 2016; Eisapour, Cao, Domenicucci, et al., 2018) to theoretical reviews rooted in basic human factors studies (e.g., McGlynn & Rogers, 2017; Reis et al., 2013). Additionally, studies were characterized by different foci: increasing motivation to exercise (e.g., Bruun-Pedersen, Serafin, Maculewicz, et al., 2016; Eisapour, Cao, Domenicucci, et al., 2018), fostering opportunities for social participation (e.g., Baker, Waycott, Carrasco, et al., 2019; Baker, Waycott, Vetere, et al., 2019), supporting wayfinding (Flynn et al., 2003; Van Schaik et al., 2008). Finally, research on IVR and older adults focused on either community dwellers (Korsgaard et al., 2019; Van Schaik et al., 2008), care home residents (Reis et al., 2013; Van Schaik et al., 2008), or persons with dementia (Eisapour, Cao, & Boger, 2018; Flynn et al., 2003; Hodge et al., 2018). As a consequence, the derived guidelines differ in granularity and focus. Additionally, the majority of studies did not report extensive profiles of their participants regarding cognition, praxis, computer proficiency and technology experience. Such generalizing approaches risk to fall prey to a discourse of homogeneity (Vines et al., 2015), neglecting diversity among older adults that extends beyond living status or medical diagnosis.

Out of 67 design guidelines included in this paper, 40 are related to accessibility and usability, and focus on age-related change and the need to compensate for age-related limitations. In contrast, 27 guidelines aim to inform design for an engaging user experience. These highlight how to improve presence, promote reminiscence, create a shared experience, exploit VR as a means to overcome the ageing body, and offer content that aligns with older adults' interests.

Our empirical study of the guidelines suggests that broad audiences of older adults can successfully engage with current commercial VR devices and that older adults experience and enjoy the presence IVR offers. This contrasts with the focus of guidelines on increasing accessibility and usability. More importantly, our findings also demonstrate that simplistic VR environments may not offer sufficient challenge and depth for everyone. This highlights the importance of moving beyond accessibility and usability concerns, leaving behind the deficit-focused perspective that calls for simplistic VR for older adults (e.g., (McGlynn & Rogers, 2017)).

Challenges and Opportunities for the Design of Immersive VR for Older Adults

Our work has implications for the way that existing guidelines for the design of VR for older adults need to be approached. Our findings support the relevance of many of the existing guidelines, but also reveal a number of tensions that designers need to disentangle when creating VR experiences for older people. Most importantly, our work suggests that guidelines need to be applied in a nuanced way, i.e., aligning the goal of the IVR with the specific group of older adults that is targeted. Below, we discuss the main tensions that emerged during our study, formulated as recommendations to guide designers of future immersive VR.

 # Recommendation 1: Balance Rich Experiences and Simple Interactions

Accessibility guidelines emphasize that IVR needs to be attuned to age-related changes, e.g., increasing visual and auditory thresholds, removing non-critical stimuli, and relying on gestures rather than physical controllers because of a lesser grip and force. Yet, our empirical study suggests that current commercial VR hardware and (well-designed) environments can support an older audience, without a need for special measures with respect to audiovisual perception. Current hand presence technology, finger tracking and ray-casting, which is now mainstream and supported in the commercial Oculus CV1, (but not yet implemented in the VR environment we used), may further resolve issues older adults had with controlling, in particular the invisible hand.

While assistive guidelines argue for removal of non-critical stimuli, thus simplifying the VR environment, this may be detrimental to the user experience of those older adults. Our findings show that congruent audiovisual elements are welcomed by older adults. In general, it has been found that such visual embellishments or *juicy elements* (Hicks et al., 2019) actually create engagement. We also found that the embodied nature of IVR increased expectations of realism among older adults, which were not met for all participants; some participants commented on the lack of realism. Hence, we recommend that designs of future IVR for older adults invest in offering visually engaging environments, without increasing complexity of interaction.

 # Recommendation 2: Find the right trade-Off Between Health & Safety and Presence

Previous guidelines clearly recommended that older adults need to be seated to experience IVR (and this was also something required by our own ethics committee), yet some older adults commented that seated play, even in a swivel chair, had negative implications for their sense of presence and overall experience. While we would like to emphasize the importance of *safe* use of VR for older adults, this draws attention to an interesting challenge: do these restrictions on physical involvement fundamentally alter the experience of the older VR user, and what degree of risk is acceptable? In fact, in *movement* games (Isbister & Mueller, 2015), risk as a thrill has been a strategy to exploit and not avoid. While we do not argue to ignore safety criteria, we emphasize that rather than ‘flattening’ VR by removal of part of the embodied experience (e.g., removing stimuli and tasks that are not critical, and restricting interaction paradigms), researchers should scaffold VR experiences, not just in terms of interaction within the virtual environment, but also extending to the involvement of the entire body in this interaction. Hence, we recommend exploring how to offer bodily engagement, without compromising on safety.

Recommendation 3: Value Restorative Environments to Prompt Reminiscence and Increase Engagement, but beware of triggering Vulnerabilities

The chosen VR experience encapsulated guidelines on restorative environments (i.e., nature-based environments, with scenic value and congruent soundscapes (Bruun-Pedersen, Serafin, & Kofoed, 2016; Depledge et al., 2011)). Participants within our study confirmed the aesthetic appeal and the presence it brought about. Interestingly, this choice for restorative environments also triggered personal memories. Participants reflected on their own outdoor experiences, enjoying how this novel experience supported reliving old memories. This suggests that even without personalized environments, the use of nature-based environments can support reminiscing. At the same time, such environments may trigger anxiety or unpleasant memories. In our study, water was a particularly challenging item that caused worry among a small number of users. Here, we recommend for caution, particularly when designing VR experiences for vulnerable groups of older adults (e.g., persons living with dementia).

#Recommendation 4: Consider the Heterogeneity among older adults beyond Cognitive Status

Many of the existing guidelines underscore the role of cognitive ability in older adults' appreciation of VR. Participants in our study exhibited a broad spectrum of cognitive abilities (20 out of 37 participants had signs of mild cognitive impairment on the *MoCA* (Nasreddine et al., 2005), however this did not directly impact technical proficiency or their appreciation of IVR. While some participants did express a need for more guidance and experienced problems in controlling and interacting with the VR experience, other participants found the VR experience somewhat limiting and expressed a wish for being challenged more. However, regardless of cognitive abilities, most older adults in our sample did appreciate the VR experience, suggesting that enjoyment of VR can be achieved among diverse groups of older adults. Yet, a number of participants expressed that they did not consider VR personally *useful*, reminding us of earlier studies on non-use (Knowles & Hanson, 2018). Hence, even when all guidelines are met, VR may not be found as engaging by all older adults. These findings also point to the importance of personalization to cater to the diverse group of older adults (Durick et al., 2013; Knowles et al., 2019; Sarcar et al., 2018). Hence, our final recommendation is to respect this diversity and tailor IVR to a heterogeneous audience of older adults.

6 LIMITATIONS AND FUTURE WORK

A number of limitations for our study need consideration. A first limitation addresses the choice for the commercial IVR environment, 'Perfect' software from nDreams (nDreams, 2016). This commercial IVR environment was purposefully chosen, because of its overall high quality in aesthetics and interaction (sometimes lacking in VR environments created by research labs), in discussion with care providers. However, we acknowledge this IVR environment did not lend itself to meaningfully validating *all* guidelines. Most importantly, the IVR environment used in our study did not support social interactions through the interface, nor did it present avatars or advanced body tracking. Therefore, we cannot reflect on recommendations related to social VR (Baker, Waycott, Carrasco, et al., 2019) or avatar customization (Baker, Waycott, Vetere, et al., 2019), despite the prevalence of design guidelines on offering a shared experience. Future work may aim to further investigate how to design for such shared experiences, building on the work of Baker et al. (2019) and Korsgaard et al. (2019). In addition, experimental research comparing different IVR applications is needed to further clarify which specific IVR design features affect the user experience, usability and accessibility of IVR applications for older adults. This initial set of design guidelines, presented in this study can and should be further extended and refined by such studies.

A second limitation addresses the research method and analysis chosen, i.e., UX Laddering. This method has its merits in combining qualitative open-ended interviews with a quantitative analysis, resulting in a network of linkages between product attributes and consequences (as depicted in a hierarchical value map). However, it also presents shortcomings. In particular, the UX Laddering interviews are short, focusing on saliency rather than depth and exhaustiveness. In this study, interviews were on average 5.5 minutes. The focus on salient answers mitigates chances of participants fabricating associations that are not the result of introspection but rather to please the interviewer, which are known to be problematic in UX research (Zaman & Vanden Abeele, 2010). However, this comes at the expense of depth in the interview.

Additionally, the laddering study presented was a single-point-in-time observation and a first-ever experience for older adults. Likely, experiences of older adults may change over time, as they learn the intricacies of interacting with VR and at the same time, novelty wears off. Therefore, it may be of particular interest to investigate the extent to which design recommendations support long-term use of recreational VR in older adults.

Finally, our sample purposefully included a broad group of older adults. Consequently, methodologically, we also found certain sub-groups (e.g., older adults without cognitive impairment) generating more ladders, and more elements per ladder. This may have introduced bias in the findings, giving a larger weight to the experiences elicited from certain participants, at a disadvantage of vulnerable older adults. We did not explicitly compare user experiences between sub-groups of older adults. This was a conscious decision, as in this study there was no a priori research question or guiding theory to justify such a binary division. Without appropriate rationale, any such division may be accused of a simplified view of the ageing process where it can be abstracted to static and discrete categories of impairments (Vines et al., 2015). This ignores the transitional quality of ageing (Durick et al., 2013) and how different abilities intersect (Hofmann et al., 2020). However, adhering to the agenda of "sensitive HCI" (Waycott et al., 2018), future studies may consider designs that can remediate such unequal contributions without stigmatizing specific participant groups.

7 CONCLUSION

In contrast to concerns that older adults may not engage in the VR experiences, we found that older adults clearly expressed feelings of presence in the VR environment. Moreover, in contrast to deficit-focused guidelines that have recommended simplifying VR experiences, we found that older adults were highly perceptive of audiovisual elements in the scenes, that they expressed a need for challenges and that some older adults felt too restricted in their interactions with the VR environment. This shows that IVR does not necessarily need to be simplified in order for it to be accessible or usable by older adults. As the application of VR grows, such an understanding of how to design immersive systems for older adults is an important step in ensuring that novel technologies remain accessible for broad audiences. At the same time, our study cautions against a deficit-focused, reductionist perspective on designing VR for older adults.

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A APPENDICES

A.1 Implication Matrix

Table 6: Implication matrix with linkages between core elements (direct links | indirect links). Centrality, a measure of the popularity of the element, represents the ratio of ingoing + outgoing direct links for the element, divided by the total number of links.

	Core elements	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	sum out	sum in+out	Central ity
Co	01 Positive (72)	1|0	1|0	3|0	24|1	16|7		3|1	2|5	0|6	11|2	6|12		0|2	0|3			1|2			0|18	0|10	0|5				1|13	1|5	0|4	2|5	0|5		0|2	72|108	72|108	0.111
	02 Negative (52)	8|0	3|0	3|0	10|0	4|0	7|0	0|1	1|0	3|2	3|1	6|7	1|3	0|2	1|0	1|16	0|5	0|6	0|3	0|11			0|1	0|4	0|4	0|5	0|4		0|4		1|1	0|5		52|85	52|85	0.08
Concrete at.	03 Controllers (9)										1|0		2|0			1|0		3|1						1|3								0|1		8|5	17|5	0.026
	04 Headset (4)																		3|0															3|0	7|0	0.011
	05 Music (6)				1|0				0|1			0|1								2|0							0|1			1|0		1|0		5|3	11|3	0.017
	06 Props-Objects-Details (36)					7|0		0|1	0|4	2|3	1|1	17|1				0|5	0|1			1|1	1|4	0|1	1|3		0|2	1|2	2|6	0|2	2|3	0|2				35|42	70|43	0.108
	07 Scenery (27)							2|0	4|0	3|0	1|0	0|1		1|0						1|1	10|7		0|3			0|1	2|3	1|3	1|2	0|2	0|1			26|24	53|31	0.082
	08 Sitting down (7)											1|0		2|0		4|3									0|2		0|2							7|7	14|7	0.022
	09 Soundscape (5)									1|0		1|0														1|0	2|0							5|0	10|3	0.015
Abstract at.	10 Different viewpoints (8)											1|0			1|0			0|1		1|0	3|0		0|1				1|1							7|3	14|13	0.022
	11 (Graphical) realism (11)											2|0								3|0	2|0					2|0	1|1	0|1	0|1					10|3	19|14	0.029
	12 Innovative tech (17)											1|0		1|0				1|0			0|1	7|0	1|1								2|2	3|1	0|2	16|7	33|11	0.051
	13 Interaction with env-objects (34)												1|0		2|0	10|0	4|2	0|1		1|1	1|0	1|1	1|1		0|3		3|3		0|2	0|1	0|2			24|17	59|39	0.091
	14 Invisible hand-body (4)																	1|0		2|0				1|1			0|1							4|2	8|5	0.012
	15 Looking around (4)															2|0											1|0							3|0	7|4	0.011
	16 Open-endedness (4)																1|0	2|1				0|1												3|2	7|5	0.011
Funct. C.	17 Being limited (18)																2|0								4|0		3|0				0|1			9|1	27|25	0.042
	18 Lack of challenge (7)																	1|0											1|0		2|0			4|0	11|8	0.017
	19 Learning process/Need for guidance (9)																					2|0		2|0								1|0		5|0	14|12	0.022
	20 Uncomfortable (3)																																		3|3	0.005
	21 Unrealistic (11)																										2|0		1|0					3|0	14|14	0.022
PsycSoc C.	22 Aesthetic appeal (18)																						3|0				2|0	2|0	1|0	2|0	0|1			10|1	27|31	0.042
	23 Curiosity (10)																														1|0		1|1	2|1	12|14	0.019
	24 Surprise (6)																									1|0					1|0			2|0	8|15	0.012
	25 Difficult - Frustrating - Stress (4)																																		4|8	0.006
	26 Curiosity not satisfied (4)																																		4|11	0.006
	27 Negative immersion - fear (5)																												1|0					1|0	6|8	0.009
	28 Spatial presence (19)																											2|0		1|1				3|1	23|36	0.036
	29 Traveling, experiencing...(6)																												1|0	0|1	1|0			2|1	8|12	0.012

	30 Triggering personal memories and hobbies (8)																													1|0				1|0	9|16	0.014
	31 Unwinding-Soothing-Escapism (7)																																		7|12	0.011
Values	32 Applications beyond the VR exp (8)																																1|0	1|0	9|13	0.014
	33 Not for me (5)																																		5|7	0.008
	34 Staying on top of things (2)																																		2|5	0.003
	sum in	9|0	4|0	6|0	35|1	27|7	7|0	5|3	7|10	9|11	17|4	35|22	4|3	4|4	4|3	18|24	7|8	9|12	3|3	11|14	17|30	10|13	6|15	4|8	4|11	5|8	20|35	6|11	8|16	7|12	8|13	5|7	2|5	323|313	626|616	1

A.2 Hierarchical Value Map

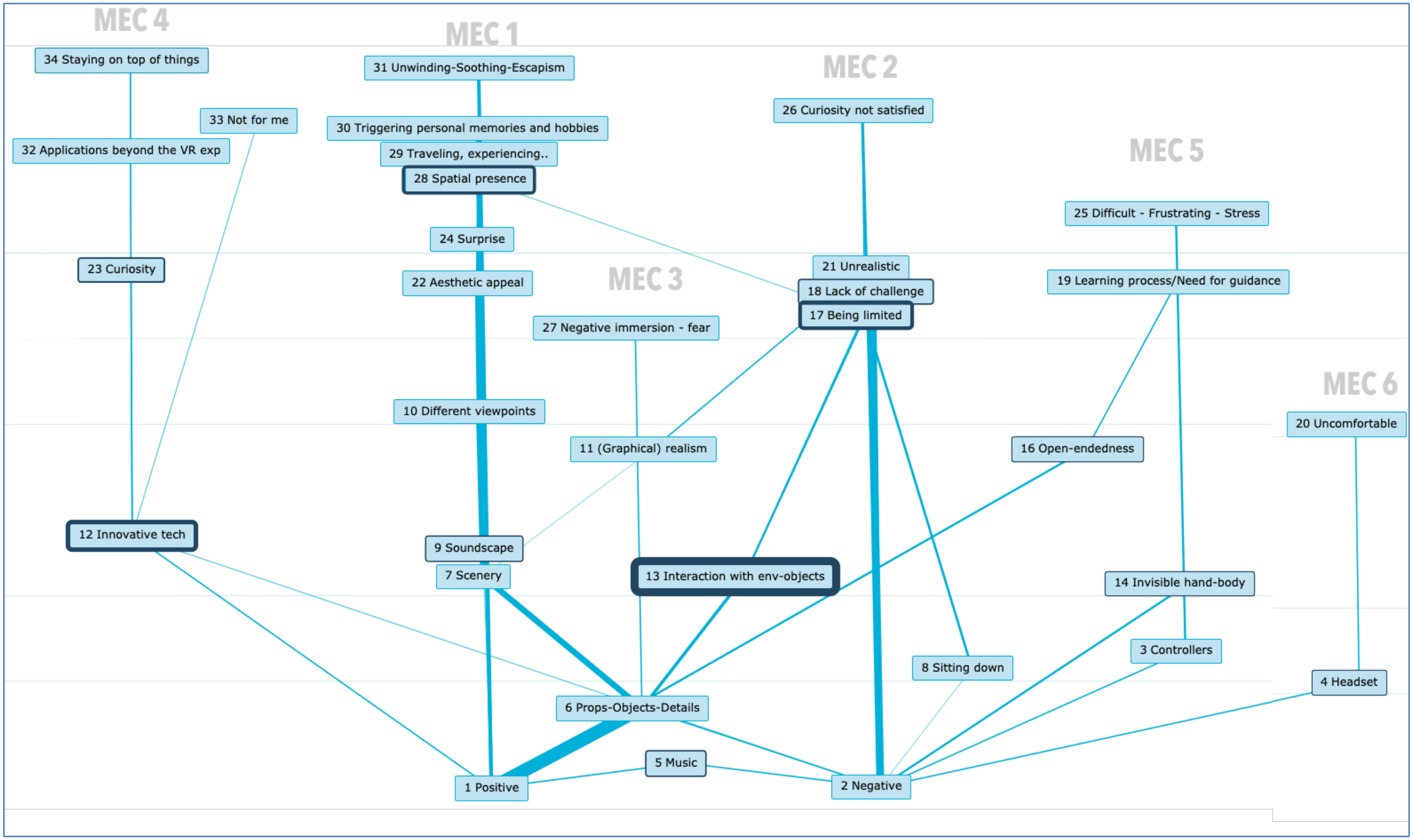

Figure 5: Overview of the Hierarchical Value Map, showing six different MEC's, numbered according to percentages of links they represent. Line thickness represents link strength, border thickness represents centrality of the element.