



## OPEN 3D built virtual arctic environment increase vigor through connectedness in older people

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While the life expectancy of older people has increased significantly, this is often related to more long-term care in healthcare residences and nursing homes. Staying in these facilities can lead to a reduction in the sense of connection with others and the world around, as well as in vigor, with significant psychophysical repercussions in the long term. Although previous studies have shown that the virtual nature can benefit both, there are no significant studies that have tested its effect in generating these positive outcomes in the older population. Therefore, our study sought to investigate, in a sample of 53 older people in care at a nursing home or healthcare residence, the indirect effect of a 3D built virtual arctic environment (vs. a 3D built virtual urban environment) exposure in virtual reality on vigor through connectedness. Both the virtual scenarios were designed with a first-person view, with no translation around the environment and only in-situ rotation. Results highlighted that exposure to the 3D built virtual arctic environment leads to higher connectedness than the 3D built virtual urban environment, and this, in turn, leads to an increase in vigor. Findings were discussed based on the potential of adopting virtual nature in facilities to improve older people's sense of connectedness and, in turn, improve their well-being.

**Keywords** Virtual reality, Older people, Virtual arctic environment, Vigor, Connectedness, Virtual natural environment

The number of older people has increased as life expectancy has increased. According to the Eurostat report<sup>1</sup>, on January 1 2023, the population of the EU was estimated at 448.8 million, of which 21,3% of this were older people ( $\geq 65$ ). This signed a growth of 0.2% higher than in 2022 and an increase of 3.0% over the last 10 years. Nonetheless, a higher life expectancy and a reduction in disease mortality are not always associated with a better quality of life for older people. Indeed, elderliness is often associated with the onset or the exacerbation of mental and physical diseases<sup>2</sup>, such as depression<sup>3</sup> and chronic illness<sup>4</sup>. Due to these frail conditions (e.g., fracture, reduced mobility, multiple comorbidities, and behavioral and psychological symptoms of dementia) that might require constant care and nursing, many older people are placed in facilities such as nursing homes and healthcare residences where they often spend the last years of their lives<sup>5–9</sup>. Staying in these facilities, however, could sharpen symptoms and diseases such as reducing subjective vitality related to a sedentary lifestyle, or increasing apathy, anxiety, and depression, as shown by previous studies<sup>10–13</sup>, especially during the first six months of recovery<sup>14</sup>. Indeed, previous studies highlighted that the loss of independence associated with hospitalization in care centers might significantly affect the quality of life of older people placed in facilities<sup>15</sup>.

Among the negative aspects of being in care at facilities, the lack of or reduced contact with nature should be mentioned. The benefits of contact with nature on the psychophysical wellbeing of older people have been widely demonstrated in previous studies (e.g.,<sup>16,17</sup>). Contact with nature might be described as the human interaction with natural environments and natural components<sup>18</sup>. Thus, contact with nature can include different types of activities, such as nature walks<sup>19</sup>, garden activities<sup>20</sup>, or simply being exposed to natural environments<sup>21</sup>.

The paths behind which contact with nature can enhance human wellbeing have been firstly highlighted by the Attention Restoration Theory [ART<sup>22</sup>], and the Stress Reduction Theory [SRT<sup>23</sup>]. According to the first theory, through contact with nature, people can more easily overcome mental fatigue and restore their cognitive resources, which are usually consumed by urban stressors. SRT instead states that exposure to nature is positively related to people's affect, activating the parasympathetic nervous system and reducing their stress levels<sup>24,25</sup>. Thus,

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both theories emphasized the restorative properties of nature. Consistently with these theories, several research investigated the mechanisms through which contact with nature can produce different types of benefits (e.g.,<sup>26</sup>). Among these, exposure to nature, for example through forest walks, has been shown to increase the number and activity of anti-cancer cells, also known as natural killer (NK) cells, and to promote the expression of anti-cancer proteins<sup>27</sup>. Moreover, other research has shown that viewing nature images can increase parasympathetic nervous activity, decrease heart rate, and decrease functional connectivity with respect to the stress network (e.g.,<sup>28–30</sup>).

Previous findings highlighted that contact with nature in older people favors a perception of improved physical and mental health (e.g., feeling more vigorous), as well as an increased sense of spiritual connectedness with a broad community and loved ones<sup>31</sup>. Increasing connectedness in older people, intended as the sense of connection with others and the environment beyond the self as a result of the exposure to certain stimuli<sup>32</sup>, might be pivotal for improving their living conditions and reducing the sense of loneliness they might experience during their stay in facilities<sup>33</sup>.

Nevertheless, in certain facilities, there is no availability of natural areas, or access to natural environments may be very restricted and limited to only certain times of the day, thus reducing or compromising its abovementioned benefits (see<sup>34</sup>). It is worth mentioning that not only older people in facilities may have difficulty accessing nature. Indeed, the general older adult population may also have limited access to nature for economic, time, or logistical reasons<sup>35</sup>. However, being a facility resident may further reduce these possibilities, as access and timing of exposure to nature are often beyond the patients' will and motivation and established a priori from the facility policies<sup>36</sup>. A solution to this shortcoming has recently emerged through the use of new technologies such as Virtual Reality (VR), which is capable of providing immersive experiences of simulated environments through the use of head-mounted displays<sup>37</sup>. Previous scholars highlighted that nature exposure through VR produces benefits similar to those of exposure *in vivo* (e.g.,<sup>38</sup>). Indeed, 360-degree videos of nature through VR provide realistic exposure that enables the same mechanisms that occur during *in vivo* nature exposure<sup>39</sup>. Indeed, through VR, it is possible to achieve the same visual and auditory exposure provided by *in vivo* contact with nature, capturing people's fascination, restoring their attention levels, and reducing signs related to fatigue<sup>38,40</sup>. Moreover, previous findings highlighted the stronger effect of exposure to virtual nature via VR compared with 2D screen, as it generates a higher sense of presence, defined as a cognitive process that enables the experience of being and feeling present within an information environment<sup>41,42</sup>.

In this perspective, the use of VR with older people can be an effective, accessible, and low-cost medium to enable them to obtain the benefits of contact with nature *in virtuo*, even when it is not affordable *in vivo*. The use of VR has proven to be effective in improving the psychophysical condition of older people, especially when adopting virtual natural environments [43; 44; 45; 46]. Furthermore, although VR studies have often focused on exposure to virtual natural green or liquid water environments (see<sup>47</sup>), recent authors have shown the benefits of exposure to solid water environments, such as the arctic environment<sup>48</sup>. For instance, a recent study showed that the exposure to 360-degree panoramic photos of an arctic virtual environment was more effective in generating positive outcomes when compared to an urban virtual environment<sup>49</sup>. Nonetheless, to our knowledge, no previous studies have investigated the benefits of exposure to a 3D built arctic virtual environment compared to a 3D built urban virtual environment in older people. Moreover, while previous studies considered the distinct effect of virtual nature on connectedness or vigor<sup>37,50–52</sup> no previous studies have tested their combined effect, especially in this target population. Therefore, this study aimed to investigate the indirect effect of exposure to a 3D built virtual arctic environment (vs. a 3D built virtual urban environment) on vigor through connectedness in older people in care at two different facilities.

## Theoretical framework

### Vigor

Vigor can be defined as the individual's feeling of possessing enough physical and cognitive energy<sup>53</sup>. Vigor, along with other positive feelings, has a health-protecting physiological effect, such as modulating the automatic reactivity related to the effects of negative emotions<sup>54</sup>. Moreover, vigor would seem to promote people's health and longevity<sup>55</sup>. Consistently, several previous studies highlighted that vigor positively affects both physical performance and self-perception of increased strength<sup>56,57</sup>, as much as it is considered a facet of well-being according to the World Health Organization (WHO)<sup>58</sup>. Moreover, other research showed that vigor is positively associated with happiness and the sensation of feeling good about oneself and the world<sup>59</sup>. Specifically focusing on the older population, vigor has been shown to act as a protective factor against various symptoms related to physical and cognitive decline<sup>60</sup>. However, in older people, vigor tends to decrease along with the natural reduction of physical activity<sup>61,62</sup>. Further evidence highlighted a relationship among immobility, reduction in vigor, and weight gain<sup>63</sup>. The decrease in vigor has also been related to physical and mental decline in this target population<sup>64</sup>. Therefore, based on this evidence, planning interventions aimed at increasing vigor is crucial to enhance the levels of well-being in older people. While the benefits of exposure to nature on vigor have been largely explored<sup>65–70</sup>, also with regard to older people<sup>71,72</sup>, recent studies obtained similar results with natural environments reproduced via VR<sup>37,73</sup>. Nonetheless, to our knowledge, the only study that investigated the effect of virtual natural exposure on vigor, also contemplating older people, is the study of Yu et al<sup>74</sup>. However, their sample included both middle-aged and older people, and the authors analyzed data by considering the sample as a whole. Thus, no conclusions can be drawn with regard to older participants only. Therefore, considering the abovementioned evidence, we consider it noteworthy to investigate the effect of nature exposure (i.e., arctic environment vs. Urban environment) through VR on vigor in this target population.

## Connectedness

The connectedness plays a pivotal role in older people's wellbeing. Indeed, the lack of connectedness can cause a sense of loneliness and detachment in older people and increase the perceived lack of bonding with others<sup>75</sup>. According to Yaden and colleagues<sup>32</sup>, people experience connectedness when confronted with stimuli that evoke a sense of vastness and that are difficult to encode immediately. Connectedness results in a sense of self-transcendence that allows one to get in touch with something that is perceived as superior to the self and its environment (e.g., the whole of humanity, the whole of existence, religious or spiritual aspects). This experience can favor a deeper connection with other people and things around them<sup>76,77</sup>. Previous findings have highlighted that connectedness, as a self-transcendent process, is related to several positive outcomes, both at the individual (e.g., subjective wellbeing<sup>78</sup>) and collective level (e.g., collective engagement and prosocial behaviors<sup>79,80</sup>). Improving the sense of connectedness of older people in facilities can result in higher cohesion with others (i.e., other patients and staff) and a reduced sense of alienation, with significant benefits for their psychophysical wellbeing<sup>81–83</sup>. Although recent studies have explored the potential of virtual nature in generating connectedness in older people<sup>50,51</sup>, there is a lack of studies that have deepened the relationship between virtual nature, connectedness, and vigor in this target population. Furthermore, no previous studies have explored such a relationship by comparing a 3D built virtual arctic environment with a 3D built virtual urban one.

## The present study

The present study sought to investigate the indirect effect of exposure to two 3D built virtual reality (VR) environments (i.e., a 3D built VR arctic condition vs. a 3D built VR urban condition) on vigor through connectedness in a sample of older people. The choice to examine the mediating role of connectedness in the relationship between a 3D built arctic environment- compared to a 3D built urban environment – on vigor mainly lies on two evidence. Firstly, a previous study using VR highlighted that, when compared to a 360-degree panoramic photo of an urban environment, a 360-degree panoramic photo of a real arctic environment was more effective than other 360-degree panoramic photos of natural environments (i.e., green park and lacustrine environments) in indirectly increasing subjective vitality<sup>49</sup>, a positive state that is highly correlated with vigor<sup>84</sup>. Secondly, recent studies have shown that spacious and unexplored natural environments are strongly linked to a social mindset, prosocial behavior, and associated positive emotions (e.g.,<sup>80</sup>). It can be argued that spacious nature scenes, in which one feels insignificant compared to something larger, foster social aspirations and prosocial behavior by reducing self-centeredness. This might promote a more inclusive sense of self and a broader perspective (i.e., a “collective” rather than a “small” self).

Nonetheless, it is possible to notice that the few studies available in literature mainly focused on the direct relationship between exposure to nature and connectedness and/or vigor. Nonetheless, there is a lack of studies on the underlying process behind the relationship between nature exposure and vigor in the target population. Moreover, to the best of our knowledge, there are no previous studies that assessed the effect of the exposure to 3D built environments on vigor in older people, exploring the mediating role of connectedness. Based on this evidence, it has been hypothesized that:

- H1: The 3D built VR arctic condition, compared to a 3D built VR urban condition, significantly enhances connectedness, which in turn determines greater vigor.

A graphical representation of the hypothesized model is reported in Fig. 1.

Moreover, we have included the following covariates in the mediation model hypothesized: age, gender, trait awe (defined as the disposition to experience intense emotional responses to perceptually broad stimuli that transcend one's ordinary frame of reference<sup>85</sup>), and vigor pre-exposure. The inclusion of covariates in the mediation model was based on previous recommendations for experimental designs<sup>86</sup>.

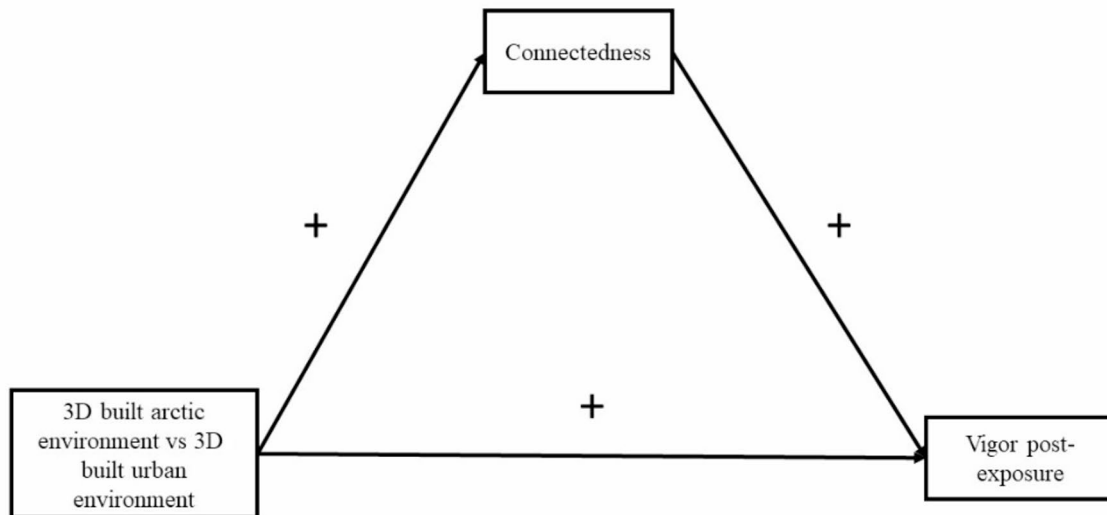
## Results

### Preliminary analyses

We conducted a series of chi-squares tests concerning gender, marital status, educational qualification, and working status before retirement/before entering the host facility, and a one-way analysis of variance (ANOVA) concerning age to check whether the distribution of the participants was equal across conditions in terms of socio-demographic variables. Results revealed that the distribution of participants was balanced for gender  $\chi^2(2, 53) = 0.951, p = .622$ , marital status  $\chi^2(3, 53) = 5.873, p = .118$ , educational qualification  $\chi^2(3, 53) = 0.975, p = .807$ , and working status  $\chi^2(3, 53) = 1.945, p = .584$ . Furthermore, the ANOVA results revealed that participants were equally distributed by age  $F(1, 52) = 2.872, p = .096, \eta_p^2 = 0.053$ . We then verified if the sense of presence was comparable among conditions. The ANOVA results revealed no differences among conditions for the sense of presence:  $F(1, 52) = 0.740, p = .394, \eta_p^2 = 0.014$ . Finally, ANOVA results revealed that the distribution of participants across conditions was equal for Mini-Mental State Examination (MMSE) score  $F(1, 52) = 1.204, p = .278, \eta_p^2 = 0.023$ .

### Mediation analysis

To test our hypothesis, we conducted a mediation analysis with observed variables using the IBM SPSS macro Process 4.2 version<sup>87</sup>. We inserted the condition, coded as 1 = 3D built urban environment and 2 = 3D built arctic environment, as the independent variable, connectedness as the mediator, and vigor post-exposure as the dependent variable. Moreover, we included age, gender, trait awe, and vigor pre-exposure as covariates in the mediation model. A percentile bootstrap procedure with 5,000 resamples and 95% confidence intervals (CI) was used for indirect effects. According to Hayes<sup>87</sup>, significant indirect effects are detected when confidence intervals do not include zero. The results of the mediation model are reported in Fig. 2.



**Fig. 1.** Hypothesized mediation model. The experimental conditions were coded as 1 = 3D built urban environment and 2 = 3D built arctic environment. The sign ‘+’ indicates the expected positive directions of the paths shown in the figure.

In the first step, the experimental conditions, coded as 1 = 3D built urban environment and 2 = 3D built arctic environment, together with covariates (i.e., age, gender, trait awe, and vigor pre-exposure), were posed as predictors of connectedness. The model explained 26% of the variance of the outcome ( $R^2 = 0.26$ ,  $F = 3.34$ ,  $p < .05$ ). In particular, results revealed that the exposure to the 3D built arctic environment - compared to the 3D built urban environment - led to greater connectedness (see Fig. 2, paths a). In the second step, the experimental conditions, connectedness, and covariates were included as predictors, while vigor post-exposure was considered as the outcome. Findings showed that the second model explained 65% of the variance of the outcome ( $R^2 = 0.65$ ,  $F = 14.45$ ,  $p < .001$ ), attesting that connectedness enhanced vigor over and beyond the experimental conditions (see Fig. 2, path b).

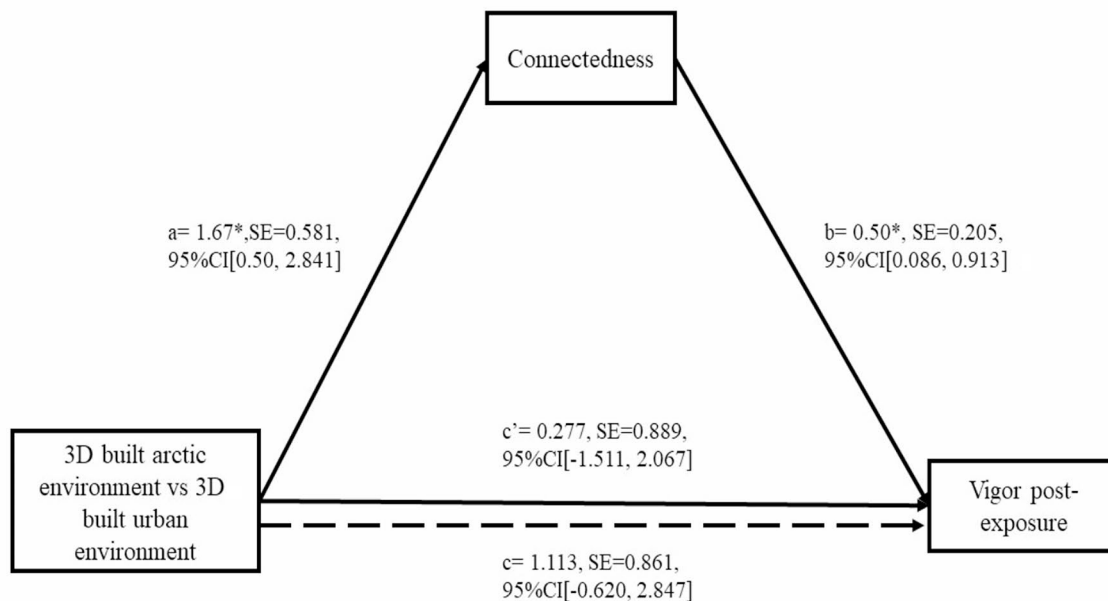
The indirect effect of the experimental conditions on vigor through connectedness was positive and significant (point estimate = 0.835,  $SE = 0.417$ , [95% percentile CI = 0.118, 1.737]). Specifically, this result revealed that the exposure to the 3D built arctic environment - compared to the 3D built urban environment - led to greater connectedness, which in turn increased vigor. Our findings further revealed that both the total and direct effects were non-significant (see Fig. 2, path c and c'). However, Hayes and other scholars (e.g.,<sup>88</sup>), recommend that “researchers do not require a significant total effect before proceeding with tests of indirect effects. (...) A failure to test for indirect effects in the absence of a total effect can lead to you missing some potentially interesting, important, or useful mechanisms by which X exerts some kind of effect on Y”<sup>89</sup> (pp. 414–415). Taken together, our results showed that the 3D built arctic environment, compared to the 3D built urban environment, enhanced vigor through connectedness.

Finally, as a further check, we verified, through one-way ANOVAs, whether there were differences between the two residence structures in which participants were treated for connectedness and vigor. Results revealed no significant differences between the two residence structures for connectedness and vigor (see Supplementary Materials – Appendix B for further details).

## General discussion

Nowadays, an increasing number of older people are placed in facilities such as nursing homes and healthcare residences due to their frail conditions (e.g., reduced mobility); in these facilities, they often spend the last years of their lives<sup>5–9</sup>. Nevertheless, several previous evidence highlighted that staying in these structures often leads to harmful consequences such as reduced subjective vitality<sup>10–12,15</sup>. Thus, it is noteworthy to find effective and low-cost strategies that can influence positive outcomes in this target population. Thus, this study sought to examine the indirect effect of exposure to two distinct 3D built environments (i.e., a 3D built arctic environment vs. a 3D built urban environment) on vigor through connectedness in a sample of older people in care at two facilities.

Consistent with recent studies that have shown the benefits of exposure to solid water environments<sup>48</sup> also through the VR medium<sup>49</sup>, our findings highlight that the 3D built arctic environment - compared to the 3D



**Fig. 2.** Mediation model results. Note. The two 3D built environments were coded as 1 = 3D built urban environment and 2 = 3D built arctic environment; a, b, c, and c' are unstandardized regression coefficients; c' = direct effect; c = total effect; \* $p < .05$ . Covariates were not included in the graphical representation for clarity purposes.

built urban environment - has a positive effect on vigor through connectedness. The results of the current research further enrich ART and SRT, showing the stronger beneficial effects of natural environments compared to urban ones. Indeed, while both theories highlighted the role of nature in promoting human wellbeing through its restorative properties, our results suggest that natural environments can determine positive psychological outcomes via the promotion of a sense of connectedness. Natural environments, both through in vivo and *in virtuo* exposures, are able to generate a sense of self-transcendence that leads people to feel a dissolution of self-boundaries on one side and to establish a connection with something beyond the self that increases the feelings of being part of something greater, on the other [e.g., the whole universe<sup>79</sup>. Specifically considered the distinctive characteristics of the arctic environment, its wild nature elicits the desire for exploration and new experiences<sup>22,90</sup>, which, in turn, might enhance a sense of deep connection with others and the whole universe<sup>80</sup>. Furthermore, partially in line with previous evidence<sup>91–93</sup>, our findings point out that connectedness, in turn, has a positive effect on vigor levels in older people. Although future studies should explore the impact of exposure to other types of 3D built natural environments, it might be possible to speculate that since the 3D built arctic environment represents an unfamiliar and extreme environment, it is able to induce higher levels of fascination and feeling of being away<sup>49,94</sup>; thus, positively promoting connectedness as a process of self-transcendence. This expression of self-transcendence has been shown to be positively related to health, mental wellbeing, and human functioning [95; 96] as much as it is considered a significant factor that contributes to successful aging<sup>97</sup>. Indeed, it exerts a significant and positive effect on vigor. Enhancing vigor levels in older people is a critical outcome. Vigor is related to physical performance and self-perception of the increase in strength<sup>56,57</sup>, and it represents a facet of wellbeing according to the WHO conceptualization<sup>58</sup>. Usually, people tend to increase their levels of vigor through physical activities<sup>98</sup>, but physical activity might not be an effective means for older people who are placed in facilities often due to their reduced mobility<sup>5–9</sup>. Therefore, our findings pave the way to possible alternative strategies that are effective in promoting vigor and, more generally, wellbeing in older persons.

Despite the promising results, four main limitations of the present study must be acknowledged. First of all, our sample was imbalanced for gender, with a clear majority of women. However, it is noteworthy to underline that this gender imbalance is in line with the datum showing that, on average, women tend to live 5,5 years more than men in EU (ISTAT). Second, exposure to the 3D built environment lasted 4 min and was a single exposure. Future studies should investigate longer exposures or multiple exposures, with the aim to investigate their long-term effects. Third, we did not assess for motion sickness symptoms after the VR exposure. Motion sickness could be a side effect of VR exposure, which might include symptoms such as nausea and dizziness<sup>99</sup>. However, it is noteworthy to point out that the safety of participants was guaranteed at every stage of the experiment, and

a trained and qualified researcher was always present in case of need. Participants, indeed, could abandon the experiment at any moment and for any reason, including feelings of discomfort and side effects that they might have experienced during the VR exposure. No side effects have been orally reported after the VR exposure. Nonetheless, 3 participants withdrew from the study before exposure to the conditions due to discomfort related to the use of VR. This suggests that factors related to the use of immersive technology, such as VR-induced anxiety or discomfort, may influence participation, especially in this target population, and should be further taken into consideration in future studies. Fourth, we only adopted two 3D built scenarios (i.e., the arctic environment vs. the urban environment). Further studies could consider testing the effect of different types of environments (e.g., forest, mountain, desert etc.) on connectedness and, in turn, on vigor. Moreover, in the future, the effects of these environments could be tested on older people of other nations to deepen how cultural differences can affect the perception and preference of these scenarios. For example, the 3D built urban environment containing buildings typical of Italian architecture could elicit more positive effects for people who are not familiar with that kind of urban architecture. Furthermore, it might also be interesting to evaluate the effects that exposure to these 3D built environments could have on caregivers in order to assess the possible benefits for professional or family caregivers. Finally, it might be useful to use different tools to measure vigor in older people, such as objective measures of a possible increase in physical vigor.

Our findings lead to several potential practical implications that might benefit the lives of older people. First of all, the use of VR, and in particular the exposure to 3D built ad hoc scenarios, can be employed to improve the condition of older people, especially for those who are in nursing homes or rest homes. Indeed, the results of our study encourage the use of these scenarios to elicit self-transcendence processes and, in turn, vigor levels in older people. An increase in the wellbeing of older people entails an increase in their expectations and quality of life, thereby reducing social costs. In addition, the improvement of the wellbeing of older people might exert a spillover effect, leading to an enhancement in the wellbeing levels of family and professional caregivers, thereby mitigating their stress and/or burnout. Indeed, it has been shown that non-pharmacological treatments, when effective, help to create more positive connections between older people, staff, and families<sup>100–102</sup>. Another practical implication lies in the possibility of bringing the benefits of exposure to natural environments to people otherwise unable to experience them *in vivo*. This type of exposure also allows older people to not take risks (e.g., falls, infections, allergies, etc.) to which they might be exposed in vivo exposure. Finally, an increment in connectedness and vigor can improve the wellbeing of older people, also helping them positively accept their current condition, especially if placed in a nursing or rest home.

## Conclusion

This study aimed to investigate, in a sample of older residents in a nursing home and a health care residence, the indirect effect of a 3D built arctic virtual environment (vs. a 3D built urban virtual environment) on vigor through connectedness. Findings show that exposure to the 3D built arctic virtual environment enhances connectedness, which in turn leads to an increase in vigor levels, confirming our initial hypothesis. Our results encourage to continue investigating the effects of exposure to 3D built natural scenarios through VR in this target population in order to improve their psychophysical conditions. This, in turn, might indirectly help the professional caregivers, too. Finally, our study highlights that the use of VR can be an effective, relatively affordable solution to improve the conditions of older people who reside in facilities. Indeed, although the use of VR is not to be understood as a substitute for in vivo nature exposure<sup>35</sup>, VR is useful for people in frail conditions, as in the case of older people. To summarize, our findings highlight the importance of further investigating the effects of exposure to virtual nature in older people, with the final aim of improving their psychophysical wellbeing.

## Methods

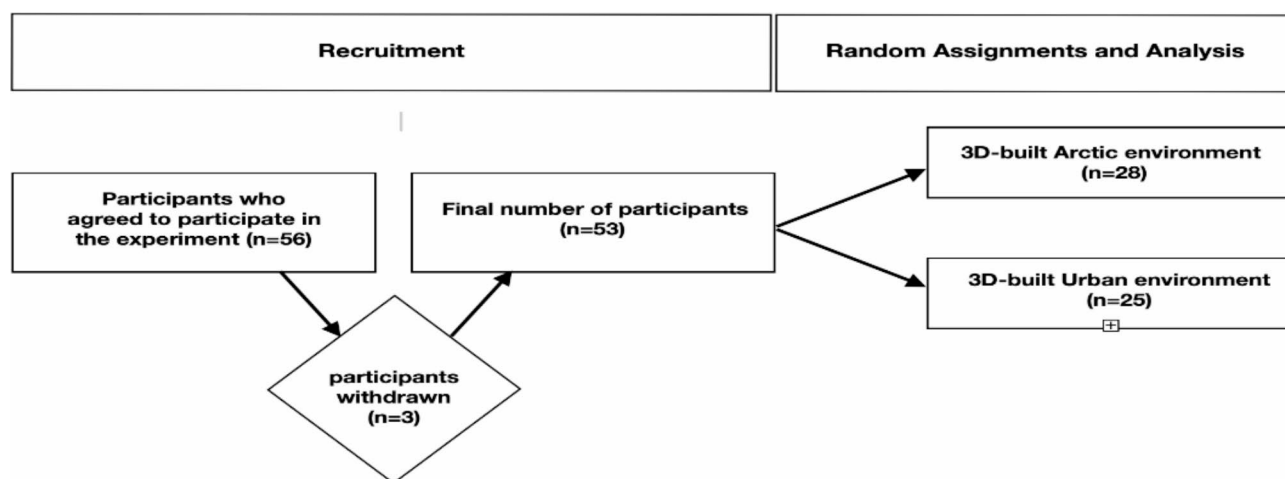
### Participants

The research involved older people in care at a healthcare residence San Michele Hospital (Lazio, Italy) and at a nursing home Casa di Cura la Rocca located in (Lazio, Italy). The facilities were similar in size and amount of green spaces available. Both facilities had a garden accessible to residents. However, not all residents had regular access to open spaces, partly because of their health conditions. Photos of the facilities can be seen at [<https://osf.io/pcvbr/>]. To test our hypothesis, we designed a between-subjects design with two experimental conditions to which participants were randomly assigned. The study followed a single-blind approach. Block randomization was employed and the procedure was carried out using the online software Research Randomizer (<https://www.randomizer.org/>). According to the World Health Organization (WHO) definition of 65 years of age as the transition to “older age”<sup>103</sup> and in line with previous studies (e.g.,<sup>104,105</sup>), only participants with  $\geq 65$  years of age were included in the study. A further inclusion criterion was the achievement of a score of  $\geq 18$  on the MMSE (Mini-Mental State Examination<sup>106</sup>), which has been shown by previous studies to be an acceptable threshold (e.g.,<sup>107–110</sup>). Individuals with a score  $< 18$  on the MMSE, individuals with sensory deficits of an audio and/or visual nature, not supported by an adequate hearing or optical aid, individuals with severe psycho-physical impairment unable to use the visor (e.g., fully assisted and/or totally bedridden patients), as well as individuals with epilepsy and holding pacemakers were excluded from the study. Only participants who signed the informed consent were included, and confidentiality and anonymity standards were guaranteed during all the study phases. The selection of participants was done with the cooperation of the facilities’ health staff. Specifically, facility psychologists collaborated with the research team to identify participants who agreed to participate in the study and who fell within the inclusion criteria. Data collected was processed following Article 13 of EU Regulation No.679/2016 of 27.04.2016 “General Data Protection Regulation” and Legislative Decree No.196/2003 “Personal Data Protection Code”, as amended by Legislative Decree No.101 of 10.08.2018.

An initial sample of 56 participants agreed to participate in the study. Previous to the exposure to the experimental conditions or before the post-test, 3 participants retired their participation and were excluded

Variables		
	M	(SD)
Age	83.85	7.73
MMSE	24.32	4.45
<b>Gender</b>	N	%
Men	18	34
Women	34	64.1
Non-Binary	1	1.9
<b>Educational qualification</b>	N	%
Elementary school diploma	33	62.3
High school diploma	10	18.8
Middle school diploma	9	17
Master degree	1	1.9
<b>Marital status</b>	N	%
Widowers	41	77.4
Single	6	11.3
Divorced	4	7.5
Married or civilly united	2	3.8
<b>Professions before retiring</b>	N	%
Employed	31	58.5
Self-employed	11	20.8
Housewares	9	17
Entrepreneurs	2	3.7

**Table 1.** Socio-demographic/Informational table. Note. M = mean; SD = Standard Deviation; N = number; % = percentage.



**Fig. 3.** Participants recruitment process.

from further analysis. The 3 participants withdrew from the study due to concerns related to the virtual reality headset. Specifically, they expressed discomfort and apprehension about wearing the device and decided not to proceed with the experiment. Participants' socio-demographic information are presented in Table 1. Additional socio-demographic information of participants divided by residence structures is reported in Supplementary Materials – Appendix A. The final number of participants for each experimental condition was as follows: 28 for the 3D built arctic environment and 25 for the 3D built urban environment (see Fig. 3 for details of participants recruitment process). Based on a recent systematic review concerning virtual nature via VR in older people<sup>46</sup>, our sample size greater than most studies in the field, and it is in line with the sample size of the studies with the highest number of participants included in the review (i.e.<sup>111,112</sup>). Moreover, our sample size is beyond the mean when considering the sample size of all the studies included in the review ( $M = 29.42$ ).

## Measures

In the present study, trait awe and vigor pre-exposure were included in the pre-exposure questionnaire. We then adopted the following measures for the post-exposure questionnaire: connectedness (i.e., the mediator), vigor post-exposure (i.e., the dependent variable), along with sense of presence and socio-demographic variables.

### Measures included in the pre-exposure questionnaire

#### *Trait Awe*

To measure trait awe, we used the Awe Subscale (6 items) of the Dispositional Positive Emotion Scales (DPES<sup>113</sup>). The items were translated into Italian using the back-translation method. An example of items is: “*I feel wonder almost every day*”. The response scale ranged from 1 = Totally disagree to 7 = Totally agree. Cronbach’s alpha and McDonald’s omega were both 0.70.

#### *Vigor*

To assess vigor pre-exposure, we adopted the vigor-activity dimension of the EDITS Profile of Mood Scale (EPOMS)-Brief<sup>114</sup>. The items were translated into Italian using the back-translation method. The vigor-activity dimension encompasses 5 items on a 5-point Likert scale (0 = Not at all, 4 = Very much). An example of an item is: “*Energetic*”. Cronbach’s alpha and McDonald’s omega were both 0.91.

### Measures included in the post-exposure questionnaire

#### *Connectedness*

To measure connectedness, we adopted the connectedness dimension of the Awe Experience Scale (AWE-S<sup>115</sup>). It consists of 5 items on a 7-point Likert scale (1 = Totally disagree, 7 = Totally agree). The items were translated into Italian using a back-translation method. An example of items is: “*I felt a sense of communion with all living things*”. Cronbach’s alpha and McDonald’s omega were both 0.95.

#### *Vigor*

To assess vigor post-exposure, we adopted the same instruments used in the pre-exposure questionnaire and described above, i.e., the vigor-activity dimension of the EDITS Profile of Mood Scale (EPOMS)-Brief<sup>114,116</sup>. Cronbach’s alpha was 0.89, and McDonald’s omega was 0.90.

#### *Sense of presence*

In this study, the sense of presence was assessed using 12 items from the Igroup Presence Questionnaire (IPQ<sup>117</sup>). The IPQ has already been used in previous studies with Italian samples<sup>42,49</sup> (For more information on the scale anchors and full list of items, please see: <https://www.igroup.org/pq/ipq/download.php>). An example of an item is: “*I felt present in the virtual space*”. Cronbach’s alpha was 0.80 and McDonald’s omega was 0.85.

#### *Socio-demographic variables*

We collected information on age, gender, marital status, educational qualification, and type of employment before retirement or before entering the host facility.

## Experimental stimuli

The two environments were developed using Unity Software v. 2020.3.33f and with 2048 × 2048 texture size. Both the environments were designed with a first-person view and the participant is not replaced by avatars during the exposure. Moreover, the scenarios shown included neither people nor animals, and the participant could not move within them. Both scenarios depict sunny days with the sun high in the sky and no clouds. The descriptions of the two virtual environments are shown below and images of the described environment are available at: [<https://osf.io/pcvbr/>].

### 3D built arctic environment

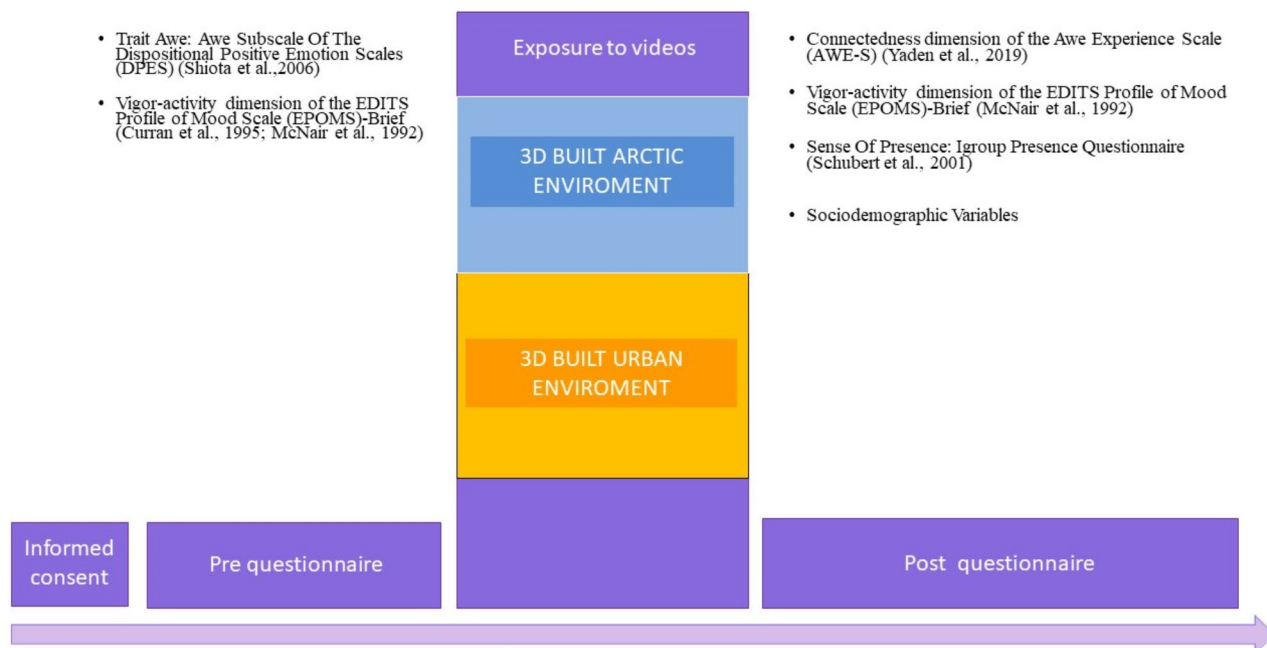
The VR arctic environment included a rocky shoreline overlooking a frozen sea and a small basin. Participants were seated on a rocky shoreline consisting of small stones, surrounded by the frozen sea and ice breaking on the shoreline. Ice sheets, small icebergs, and glaciers were visible in the distance, while icy rocks were placed near the participant’s location. Behind the participant’s back, a cobblestone path expanded, leading to snowy mountains.

### 3D built urban environment

The VR urban environment featured a square with an oval shape that was surrounded by buildings, including a tall obelisk in the middle and an entrance to the metro station. The square had benches around its perimeter, and when the simulation started, the participants felt as if they were sitting on one of the benches, with the metro station’s entrance positioned nearby to the right and the and obelisk to the left.

## Procedure

The research was conducted from July 2023 to September 2023, and the experimental procedure was as follows. In the two facilities that joined the research, two rooms were respectively set up and used solely for the purpose of the experimental procedure. For exposure to the experimental conditions, a swivel chair was placed in the center of both rooms so that the participants could explore the virtual environment in 360 degrees. In order to prevent the swivel chair from moving to the four cardinal points due to the rotation, boundaries were set on the floor of both rooms. In the case of participants in wheelchairs, depending on their willingness, they were either helped by the facilities staff to move to the swivel chair or allowed to remain in the wheelchair within the confines previously set up on the floor, ensuring that they were able to turn the wheelchair independently.



**Fig. 4.** Graphical Representation of the Experimental Procedure.

Eligible participants were accompanied to their designated rooms by the staff of their respective facilities. Once there, the researcher made them sign the informed consent. Then, a first questionnaire was administered in face-to-face administration mode. In this first and pre-exposure questionnaire, we included two control variables, namely trait awe and vigor pre-exposure. After this phase, participants were invited to sit on the swivel chair and helped to wear a Head-Mounted Display (HMD) for virtual reality, namely Oculus Quest 2. Moreover, they were told that, during the exposure, they were allowed to turn their head around and move the chair 360 degrees to explore the environment. The participants were then randomly exposed to one of two experimental conditions, namely (1) a 3D built VR arctic environment and (2) a 3D built VR urban environment (see <https://osf.io/pcvbr/> for an example of a photo per environment). Based on previous studies<sup>42,47,49</sup>, the duration of exposure to the virtual condition was set at 4 min. Since the two environments were designed with a first-person view, avatars do not replace the participant during the exposure. Furthermore, no other persons or avatars were present in the virtual scenario. After this phase, a second questionnaire was administered in face-to-face administration mode. In this second and post-exposure questionnaire, we included our dependent variables (i.e., connectedness and vigor post-exposure), along with other control variables. Specifically, we included sense of presence, system usability, and socio-demographic variables. The Oculus Quest2 was sterilized using an ultraviolet instrument (UV 59 S Sterilizer) at the end of each experiment and before the arrival of the next participant. At least one member of the research team and one of the facilities staffs was present in case of need during the entire duration of each experiment.

The research protocol follows the Declaration of Helsinki of 1964 and its latest versions, and the method applied in the study was approved by the institutional ethics committee of the European University of Rome (prot. n. 08/2023).

A graphical representation of the experimental procedure is shown in Fig. 4.

### Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on request. The experimental conditions are available upon request. A sample of 3D virtual environment images and a pictures of facilities are available to: <https://osf.io/pcvbr/>.

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### Author contributions

D.C. and A.P. developed the original idea; D.C., C.R. and A.P. contributed to the conceptualization of the study; D.C. and A.P. designed the experiment and edited the methodology; D.C., L.R. and C.R. wrote the original manuscript, organized the data and performed the statistical analysis; L.R. and A.P. contributed to the development of virtual environments; D.C. has carried out the data collection; D.C. has acquired the resources; G.C., and A.P. were the project managers; G.C., and A.P. acquired the necessary funding; All authors contributed to the revision of the manuscript; A.P. supervised. All authors have read and approved the submitted version.

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### Declarations

#### Competing interests

The authors declare no competing interests.

#### Ethics declarations

The study was approved by the institutional ethics committee of the European Univeristy of Rome (prot. n. 08/2023). All methods were performed in accordance with the Declaration of Helsinki for studies involving human participants.

#### Additional information

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