EFFECTS OF EMBODIED AND SELF-REFLECTED VIRTUAL REALITY ON ENGINEERING STUDENTS' DESIGN COGNITION ABOUT NATURE

Trump, Josh;
Shealy, Tripp

Virginia Tech

ABSTRACT

The study presented in this paper investigated the impact of embodied and self-reflected virtual reality (VR) experiences on engineering design students' cognition and perception of nature-relatedness during the early conceptual design phase. Results showed that students who explored the design environment as a bird (embodied) or human (self) avatar were significantly more likely to explore a larger design space indicated by more semantically unique design concepts compared to students without the VR experience. Network graphs of the syntactic connection of design concepts revealed notable differences among the three groups. The bird avatar group showed more connections to nature-related and social concepts, while more technical concepts were central for the human avatar group, and concepts about money were more central to the control group. Finally, students who embodied the bird avatar had a significantly stronger perception of connection to nature compared to the human avatar and control group, with a small to medium effect size. The results suggest that embodied (as a bird) and self-reflected (as a human) VR experiences can enhance engineering students' design thinking and perception of connection to nature.

Keywords: Sustainability, Virtual reality, Design engineering, Decision making

Contact:
Shealy, Tripp
Virginia Tech
United States of America
tshealy@vt.edu

Cite this article: Trump, J., Shealy, T. (2023) 'Effects of Embodied and Self-Reflected Virtual Reality on Engineering Students' Design Cognition About Nature', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.158

1 INTRODUCTION

Conceptual design is an iterative process that can be enhanced through designers placing themselves "in the shoes" of the end user (Köppen and Meinel, 2015). This form of perspective-taking is often challenging to achieve, partly because there is no universal approach or agreed-upon method (Singer and Klimecki, 2014). As perspective-taking becomes more effective (meaning the designer can align his or her feelings with end users), the designer is more likely to act and create altruistically (Oswald, 1996), and this can provide tangential benefits for the end user. However, perspective-taking requires a "connection" between individuals or groups (Köppen and Meinel, 2015), which various design drawings, wish lists, pros and cons sheets, financial spreadsheets, and other sources of initial design information often fail to induce.

Traditional methods for perspective-taking often occur using inaccessible media, and the communication process between designers and end users is frequently not easily digestible to a non-technical audience (Cascetta et al., 2015). Current perspective-taking strategies could be improved by more immersive experiences that help connect different groups of people and communicate complex and technical information in a different format. Immersive experiences are imaginary scenarios that depict real-life, such as the construction of a building without physically having to be on-site (Okeil, 2010).

The benefit of immersive experiences over traditional approaches for perspective-taking, like door-to-door canvassing, visual preference surveys, professional design charrettes, and community forums, is the ability to place both the end user and designer into the design itself (Xiang et al., 2021; Xie et al., 2017). Technological improvements such as augmented and virtual reality have the capability of not only creating more immersive experiences but also providing different lenses of reality to increase perspective-taking and design critique.

Virtual reality (VR) enables designers and stakeholders to interact with the design at scale and has been increasingly utilized in the detailed design process within the last five years. VR provides an accessible vehicle, especially for the design of the built environment for architects, engineers, contractors, and the public to visually see design ideas about large physical systems and buildings before they are built (Coroado, 2015; Ma et al., 2020; Makarova et al., 2015). The use of VR in the design of the built environment is primarily used during the detailed design phase, where the ability to ideate and make changes is much lower than during the conceptual design phase.

Embodied experiences could benefit the conceptual design process by allowing the designer and the owner to literally consider a different perspective. Embodiment is a form of immersive VR that allows a VR user to interact vicariously as another person or being (Kilteni et al., 2012). The embodiment of a human or nonhuman avatar can produce feelings of empathy by considering various social perspectives (Bertrand et al., 2018; Gerry, 2017; Kors et al., 2020). Embodied experiences as avatars provide participants with the ability to "see" through a different set of eyes.

The purpose of the research presented in this paper was to explore the influence of embodiment on the conceptual engineering design process for the built environment. Specifically, testing the use of embodiment to enhance design engineers' consideration for nature. Natural elements and systems are often overlooked and undervalued in engineering design; this is particularly the case when designing in the built environment (Randolph, 2003; Rosenbloom, 2018). Past theories emphasize the imperative to build with nature for human prosperity (Besthorn and Saleebey, 2003; Grinde and Patil, 2009), which is reflected by several co-benefits not limited to high returns-on-investment, improved air and water quality, and better health outcomes (Bertram and Rehdanz, 2015). However, those involved in the design process of infrastructure systems, buildings, and urban land development commonly design without leveraging nature (Randolph, 2003; Rosenbloom, 2018). The general public also tends to overlook the value of nature (Wamsler et al., 2020). In turn, this has opened the need for better communication platforms that can facilitate conceptual design, such as virtual reality, and the use of embodiment to enable new ways of expressing the benefits of nature in design and the value designers place on it (Scurati et al., 2021).

2 BACKGROUND

Strengthening pro-environmental behaviors through embodied virtual reality may help change the perceived value of nature during design. As Ahn & Bailenson (2012) discuss, pro-environmental behaviors can be enhanced through VR experiences. Ahn and & Bailenson found that asking

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press

participants to cut down a virtual tree led to subsequently greater pro-environmental self-efficacy and actual pro-environmental behavior. Participants embodying an animal harmed by pollution in VR increased their concern for biospheric health and the likelihood of promoting action to reduce emissions (Schultz, 2000).

Embodied VR works to change behavior through two lenses: self and other. The self-lens displays the VR participant as a version of him or herself. For example, a negative stereotyping of an elderly individual can be reduced by embodying young individuals as older avatars of themselves (Yee and Bailenson, 2006). The other lens allows the participant to look through the eyes of another person or being. It creates an opportunity to aid the design process and enables the view of a design concept from a different perspective. For example, by embodying a person with a mobility impairment, a design engineer can gain a better understanding of the challenges that individuals with disabilities face when navigating physical spaces. This can lead to more accessible and inclusive design solutions that benefit a wider range of individuals.

The focus of the design intervention here is on the design of the built environment because of its significant impact on human and environmental health. Buildings and infrastructure consume a large portion of global resources and energy and contribute significantly to greenhouse gas emissions and climate change. Virtual reality has been used in prior studies about the design of the built environment, for example, as a tool to enhance the interactions of stakeholders (Bartlett et al., 2005; Stauskis, 2014) and preference construction for smart cities (Jamei et al., 2017). However, the application of VR as a design intervention for the built environment to enhance design engineers' connection to nature and the subsequent effect on their design concepts remains under-explored.

The Biophilic Hypothesis suggests that humans need to coexist with nature as part of their genetic code (Kellert, 2018, 1995). Biophilic design creates a connection to nature through using elements of nature in the design of physical spaces. One example of biophilic design is green infrastructure, which uses natural systems to convey and infiltrate stormwater and creates greenness in public areas (Markevych et al., 2017). Examples of green infrastructure design are rain gardens, bioswales, porous pavements, green roofs, and stream daylighting. Green infrastructure is useful because it can help communities prepare for, absorb, recover from, and adapt to climate and weather-based threats (Van Oijstaeijen et al., 2020). Green infrastructure is commonly used in the new urbanist design approach, which makes land use more intensive and is designed to minimize sprawl (Randolph, 2003). Green infrastructure has also become a requirement for federally funded projects in the U.S., such as from consent decrees. However, the U.S. government's requirements placed on green infrastructure to capture stormwater are low. For example, Project Clean Lake in Cleveland, Ohio was required to have just one percent of incoming stormwater be absorbed through green infrastructure (EPA, 2011). This relatively limited buy-in to green-engineered systems enabled the design team in Cleveland to construct a multi-billion dollar 20-mile long underground tunnel that failed to provide any additional co-benefits for the residents or the environment (NEORSD, 2017).

The cognitive processes decision-makers use in valuing the sustainability benefits of green versus more traditional "grey" infrastructure and weighing the costs and potential risks limit its implementation (Dhakal and Chevalier, 2017; Hu and Shealy, 2020; Li et al., 2020). Monetizing the value of green infrastructure for the environment and community is also not straightforward, which adds another barrier to its implementation (Dhakal and Chevalier, 2017; Keeler et al., 2019; Vesely, 2007). Discounting the potential benefits of green infrastructure stems, in part, from a lack of familiarity with these systems, and in part, from bounded rationality. Bounded rationality explains that decision-makers are limited in their cognitive resource capacity and time availability to make an optimal decision (Kahneman, 2003). Experiences of embodiment in VR may help decision-makers overcome the barriers of bounded rationality by providing a more focused and immersive experience that allows decision-makers to see things from a new perspective and allows them to see the benefits of green infrastructure and weigh the costs and potential risks more effectively.

3 RESEARCH QUESTION

The research question this study aimed to answer was how self-reflected and embodied VR experiences influence the conceptual engineering design process. The hypothesis was that VR enhances the design ideas designers' included in their design and their perceived connection with nature. Immersive virtual reality creates a platform that allows designers and design participants to see and hear environments in a new way compared to traditional two-dimensional drawings, which will influence what and how they design (Coroado, 2015; Wang et al., 2018).

4 METHODS

The first step to assess the effects of self-reflected and embodied VR on engineering design was to create a virtual world based on a real-world case study. Cincinnati, Ohio, was mandated to address problems with their stormwater that was polluting local creeks and rivers from combined sewer overflow. Ultimately, the city implemented a series of best-management practices with green infrastructure as the focal point through the South Fairmount neighborhood known as the Lick Run Greenway (Figure 1; Project Groundwork, 2012). Beyond barren lots and irreparable public amenities, stores, and homes, South Fairmount was the largest single-point emitter of sewer overflow in Cincinnati, discharging over 200 million gallons per year. The area of South Fairmont in need of redesign is provided in Figure 1.

Figure 1. Left is the South Fairmount neighborhood before the construction of the Lick Run Greenway; right is the South Fairmount neighborhood after the construction of the Lick Run Greenway.

A virtual representation of South Fairmount before the construction of the Lick Run Greenway was developed in VR. Two different "perspectives" were developed for the virtual world. Participants could enter the virtual world as a human avatar or a bird avatar. The bird avatar used a flight locomotion script to navigate through the virtual world. The human and bird avatar were both navigated using handheld controllers. Toggles on the controllers were used to move the avatar around the South Fairmount neighborhood. The virtual world and the objectives in the virtual world were the same for both avatars.

The objective was a wayfinding exercise. Participants in the human and bird groups were asked to gather rings conspicuously placed throughout the South Fairmount neighborhood. To collect the rings, participants either used teleportation as the human, or flew through the site as a bird. The use of rings required the participants to experience the virtual setting in more detail than just walking through the site (Markopoulos et al., 2015). Furthermore, this presented an element of gamification (Kim, 2014; Villagrasa et al., 2014), which was implemented to increase enjoyment and overall immersion.

In total, 46 fourth-year civil engineering undergraduate students were recruited for the study and randomly assigned to one of three groups: control (n=16), human avatar (n=16), or bird avatar (n=14). These students were months away from being part of engineering teams helping make such informed design decisions on real-world projects. The control group did not receive any virtual reality experience. The control group was provided with the case study details and two-dimensional drawings of the current area of interest in South Fairmount. Before the human and bird avatars experienced the virtual world, students received a brief instructional course about how to operate an avatar in a virtual world.

The time spent in the virtual world was not limited, but on average, participants in both groups spent 10-15 minutes collecting rings throughout South Fairmount. Longer immersion times can induce cybersickness (Cobb, 1999, p. 199; Giroux et al., 2013; Kourtesis et al., 2019; Martirosov and Kopeček, 2017; Murata and Miyoshi, 2000), but this was not experienced by any of the participants in both VR groups. Prior to receiving the case study information, all participants were asked to complete the Nature Connectedness Scale (Mayer and Frantz, 2004). Participants in all groups were asked to re-take the Nature Connectedness scale at the end of the experiment.

After the VR experiment or reviewing the two-dimensional drawings, participants were instructed to redesign the area of interest presented in the drawings or in the virtual world. They were told about the problem of the combined stormwater overflow and asked to minimize it and improve the surrounding

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press

area. Participants spoke aloud as they developed design ideas and were recorded during this process. Audio files were then transcribed.

Semantic analysis using natural language processing was used to measure the effects of the VR experience on designers' cognition. Punctuation, stop words, and repeated words were removed from the design transcripts. Repeated words were removed because a second instance of a word would not represent an attempt to expand the design space utilized by the design engineer. The intent of this approach was to assess participants' ability to connect seemingly remote concepts and develop new perspectives and design ideas. Semantic similarity scores were then calculated for each pair of words in the engineers' design descriptions. The mean semantic similarity score was then calculated for each participant and compared between groups using analysis of variance (ANOVA) and a posthoc Tukey HSD test.

Semantic analysis was conducted in python. Scores were calculated utilizing spaCY's "en_core_web_lg" pipeline package, with vectors generated by the word2vec algorithm (Honnibal et al., 2020). The model works by scoring the similarity between two words giving them a score on a scale of 0 to 1, in which 1 represents the maximum similarity (i.e., the same word). To further assess the effect of the VR intervention on designers' cognition, the semantic similarity between each word used in the design descriptions and the word "park" and "pipe" was also calculated. The word "park" represents green spaces that provide opportunities for people to engage with nature and outdoor recreation. This includes features such as trees, lawns, gardens, and pathways. The word "pipe" represents urban infrastructure, including features such as water and sewage pipes, electrical conduits, and transportation systems. By comparing the semantic similarity between each word used in the design descriptions and the word "park" and "pipe," the measure could determine whether the VR intervention encouraged designers to consider integrating sustainable infrastructure and environmental considerations into their designs. Table 1 shows an example of semantic similarity scores for different pairs of words. ANOVA with a posthoc Tukey HSD test was used to compute the comparisons between the three groups. Cohen's D was calculated to measure the effect size.

Table 1. Examples of pairwise comparison between words extracted from design explanations in the pilot study.

Word 1	Word 2	Semantic Similarity Score
"tanks"	"water"	0.491
"tanks"	"playground"	0.180
"filtered"	"sewage"	0.306
"filtered"	"water"	0.381

A network of the syntactic connections between design concepts was also created for each group. The network graphs represented the engineering design space and were developed using prior methods outlined by Gero and Milovanovic (2022). The nodes were the unique design concepts, and edges were the syntactic connections between concepts. The network encompasses all the concepts that emerged during that design session for all participants in each group. The structure of the design space is unique to the group. The number of nodes, edges, the density of the network, and the unique shape are reported as a descriptive statistic of the differences in design space explored between groups.

Finally, students completed the Nature Connectedness scale pre and post-design. The scale was developed by Nisbet et al. (2009). It can be used as a metric to measure designers' perceived connection to nature. The change in nature connection was compared using ANOVA with the posthoc Tukey test and Cohen's D to measure the effect size.

5 RESULTS

Embodied and self-reflected VR experiences during the early conceptual design phase had a significant effect (statistic = 435.6, $p < 0.0001$) on engineering students' design cognition. Engineering design students who explored the design environment as a human or bird avatar were significantly more likely to explore a larger design space indicated by more semantically unique words. These differences are illustrated in Figure 2. A post-hoc Tukey HSD test identified significant results between all three groups, though the effect sizes were small, below 0.2.

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press

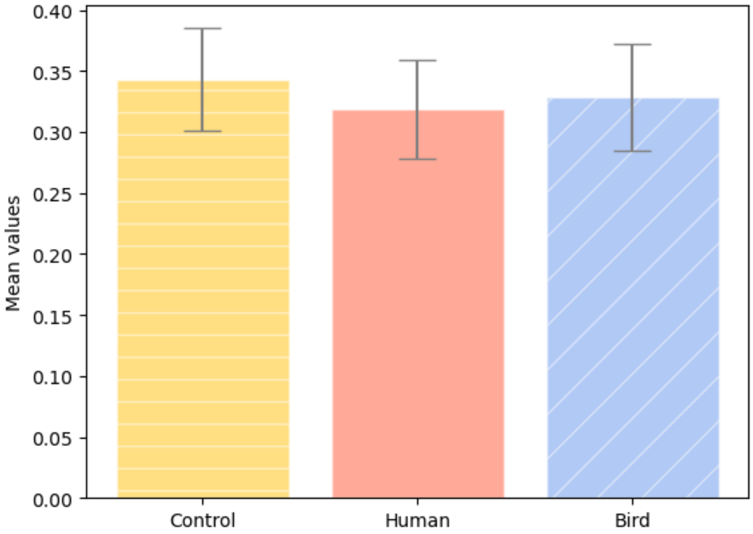

Figure 2: Spacy semantic distance as a proxy for the size of the design using spacy semantic distance; the smaller the value the larger the semantic distance.

The engineering students who experienced the self-reflected and bird embodiment VR were also significantly more likely to use words similar to "park" when describing their design ideas compared to the control group (statistic 4.0, p = 0.02) and significantly less likely to use words similar to "pipe" (statistic = 4.1, p = 0.016). A score closer to one suggest more similarity to "park" or "pipe." The mean semantic similarity score for the control group, when compared to "park," was 0.275 (STD = 0.09), and for "pipe," it was 0.22 (STD = 0.09). The mean score for the human avatar group for "park" was 0.29 (STD = 0.1) and 0.21 (STD = 0.08) for "pipe." The mean score for the bird group was 0.28 (STD = 0.09) for "park" and 0.21 (STD = 0.08) for "pipe." The effect size between groups was small, below 0.2.
The network analysis of the syntactic connections between design concepts revealed notable differences among the three groups. The control group had a network density of 0.15 with 315 nodes and 7586 edges, while the human group had a lower network density of 0.11 with 382 nodes and 8072 edges. The bird group had a network density of 0.15 with 298 nodes and 6768 edges. Upon further examination, the nodes with the most edges within each group differed. The nodes with the most edges in the bird group included concepts, such as, "child," "family," "redesign," and "prevent." The nodes with the most edges among the human group included concepts such as "sewer," "business," and "stormwater." The nodes with the most edges among the control group included concepts, such as, "cost," "amount," "runoff," and "basketball." These differences in nodes and connections are illustrated in Figure 3. The differences in the cluster of concepts within each network are worth highlight. The cluster of ideas in the control group is less than the human avatar and bird group.

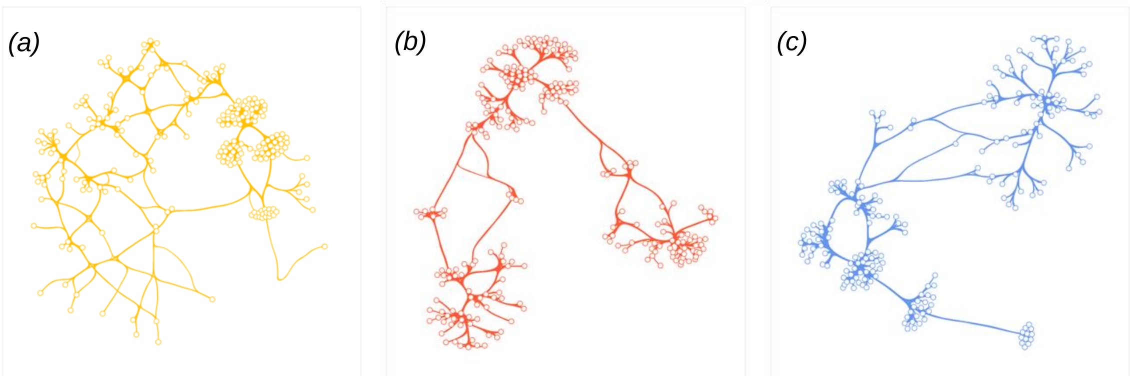

Figure 3: Representation of the structure of the design space for each group where nodes represent the first occurrences of unique concepts and edges represent the syntactic connections between concepts. The groups are (a) control, (b) human, and (c) bird.

Embodied and self-reflected VR experiences influenced not only students' design cognition but also their perceived nature connection. Students that embodied the bird avatar were significantly more

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press

likely to hold stronger perceived connections to nature compared to the human and control groups ($F = 0.44$, $p < 0.0001$), with a small to medium effect size. The score and effect size for each group is provided in Table 2.

Table 2: Nature connectedness score pre and post design intervention

Group	Pre-Score (STD)	Post-Score (STD)	Cohen's D (comparison group)
Control	3.36 (0.37)	3.5 (0.37)	0.69 (Bird); 0.21 (Human)
Human	3.45 (0.48)	3.56 (0.52)	0.42 (Bird)
Bird	3.66 (0.48)	3.77 (0.48)	-

6 DISCUSSION

The results of this study provide evidence that embodied and self-reflected virtual reality experiences can have a significant impact on engineering students' design cognition during the early conceptual design phase. The findings demonstrate that students who explored the design environment as a human or bird avatar were significantly more likely to explore a larger design space, as indicated by their use of more semantically unique words. The post-hoc Tukey HSD test revealed significant results between all three groups, although the effect sizes were small. The differences in the types of words used and the network analysis revealed notable differences among the three groups. This increase in design space exploration could result from self-reflected and embodiment's effects on cognition. As a VR user becomes more attuned to themselves or another embodied being, the user is more likely to speak and act on behalf of the embodied (Ahn & Bailenson, 2012; Kors et al., 2020).

Students who experienced the self-reflected VR and bird embodiment were also significantly more likely to use words similar to "park" when describing their design ideas than the control group, indicating a stronger connection to nature-related concepts. The embodiment of a bird also enhanced design students' perceived connection to nature. This aligns with prior research on embodiment in virtual reality. Past experiments with an embodiment in VR found participants feeling imminence with the natural environment, which was used to help spur subsequent involvement with environmental issues (Ahn & Bailenson, 2012; Ahn et al., 2016). Similarly, physiological arousal was observed when a virtual avatar was running, and this virtual activity induced increased exercise after exposure (Fox et al., 2012).

These findings suggest that embodied and self-reflected VR experiences may offer unique benefits for engineering design students, such as expanding their design thinking and enhancing their perception of connection to nature. These benefits may also translate to other domains beyond engineering. However, important to note, the effect sizes were small. Further research is needed to replicate these findings and investigate potential mechanisms underlying these effects. Future studies should also explore the potential of incorporating multiple embodied and self-reflected VR experiences at different stages of the design process and how these interventions can be tailored to meet the specific needs and goals of different groups of designers. Future research should also begin to use a combination of neuroimaging techniques, to investigate the neural mechanisms underlying the observed effects of embodied and self-reflected VR experiences on design cognition and perceived relatedness to nature. These techniques could provide insights into how the brain processes and integrates sensory information from the virtual environment, and how this information may influence cognitive processes related to design thinking.

7 CONCLUSION

In conclusion, this research study highlights the impact of embodied and self-reflected virtual reality experiences on engineering design students' cognition and nature-relatedness. The findings suggest that exploring the design environment as a bird or human avatar significantly increased the likelihood of students exploring a larger design space and using more semantically unique words to describe their design ideas. The network analysis further revealed notable differences among the groups, indicating that each group prioritized different concepts. Additionally, the study found that students who embodied the bird avatar were more likely to have a stronger perceived connection to nature than those in the human and control groups. The small to medium effect sizes found in the study suggest that these differences are meaningful, although further research is needed to confirm the generalizability of the results. Overall, the study provides new insights into the potential benefits of

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press

embodied and self-reflected VR experiences in engineering design and highlights the importance of considering the impact of such experiences on students' cognition and nature-relatedness.

ACKNOWLEDGMENTS

This material is based upon work supported by Virginia Tech's Interdisciplinary Graduate Education Program BioBuild.

REFERENCES

Ahn, S.J., Bailenson, J. (2012), "Embodied Experiences in Immersive Virtual Environments: Effects on Proenvironmental Self-Efficacy and Behavior". Available at: https://stanfordvr.com/mm/2011/VHIL-technical-report.pdf (Accessed: 02 April 2023).

Ahn, S.J., Bostick, J., Ogle, E., Nowak, K.L., McGillicuddy, K.T., Bailenson, J.N. (2016), "Experiencing Nature: Embodying Animals in Immersive Virtual Environments Increases Inclusion of Nature in Self and Involvement with Nature", *Journal of Computer-Mediated Communication*, Vol. 21, pp. 399–419. https://doi.org/10.1111/jcc4.12173

Bartlett, W.K., Neumann, A., Meiforth, J. (2005), "Interactive Landscape Planning–Results of a pilot study in Koenigslutter am Elm, Germany". Available at: https://archive.corp.at/cdrom2005/archiv/papers2005/CORP2005_WARREN_NEUMANN_MEIFORTH.pdf (Accessed 28 March 2023).

Bertram, C., Rehdanz, K. (2015), "The role of urban green space for human well-being", *Ecological Economics*, Vol. 120, pp. 139–152. https://doi.org/10.1016/j.ecolecon.2015.10.013

Bertrand, P., Guegan, J., Robieux, L., McCall, C.A., Zenasni, F. (2018), "Learning Empathy Through Virtual Reality: Multiple Strategies for Training Empathy-Related Abilities Using Body Ownership Illusions in Embodied Virtual Reality", *Frontiers in Robotics and AI*, Vol. 5. https://doi.org/10.3389/frobt.2018.00026

Besthorn, F.H., Saleebey, D. (2003), "Nature, Genetics and the Biophilia Connection: Exploring Linkages with Social Work Values and Practice", *Advances in Social Work*, Vol. 4, No. 1, pp. 1–18. https://doi.org/10.18060/39

Cascetta, E., Cartenì, A., Pagliara, F., Montanino, M. (2015), "A new look at planning and designing transportation systems: A decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods", *Transport Policy*, Vol. 38, pp. 27–39. https://doi.org/10.1016/j.tranpol.2014.11.005

Cobb, S.V.G. (1999), "Measurement of postural stability before and after immersion in a virtual environment", *Applied Ergonomics*, *Vol.* 30, pp. 47–57. https://doi.org/10.1016/S0003-6870(98)00038-6

Coroado, L.P. (2015), "VIARMODES: Visualization and Interaction in Immersive Virtual Reality for Architectural Design Process", in: Martens, B, Wurzer, G, Grasl T, Lorenz, WE and Schaffranek, R (Eds.), *Real Time - Proceedings of the 33rd ECAADe Conference*, Vienna, Austria, 16-18 September, Vol. 1, pp. 125-134.

Dhakal, K.P., Chevalier, L.R. (2017) "Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application", *Journal of Environmental Management*, Vol. 203, pp. 171–181. https://doi.org/10.1016/j.jenvman.2017.07.065

EPA, 2011. Cleveland Consent Decree. Available at: https://www.epa.gov/sites/default/files/2013-09/documents/neorsd-cd.pdf (Accessed 27 March 2023).

Fox, J., Bailenson, J.N., Ricciardi, T. (2012), "Physiological responses to virtual selves and virtual others", *Journal of CyberTherapy & Rehabilitation*, Vol. 5, pp. 69–72.

Gero, J., Milovanovic, J. (2022), "Creation and characterization of design spaces", DRS Biennial Conference Series, *DRS2022: Bilbao*, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.265

Gerry, L.J. (2017), "Virtual Reality as a Tool to Facilitate Empathy: Embodied Simulations and Perspective Taking in the Body of Another" Available at: https://josemariapoveda.com/images/facilitate.pdf (Accessed: 22 April 21).

Giroux, I., Faucher-Gravel, A., St-Hilaire, A., Boudreault, C., Jacques, C., Bouchard, S. (2013), "Gambling Exposure in Virtual Reality and Modification of Urge to Gamble", Available at: https://home.liebertpub.com/cyber (Accessed: 20 March 22)

Grinde, B., Patil, G.G. (2009), "Biophilia: Does Visual Contact with Nature Impact on Health and Well-Being?", *International Journal of Environmental Research and Public Health* Vol. 6, pp. 2332–2343. https://doi.org/10.3390/ijerph6092332

Honnibal, M., Montani, I., Van Landeghem, S., Boyd, A. (2020), "spaCy: Industrial-strength Natural Language Processing in Python" Available at: https://github.com/explosion/spaCy (Accessed: 10 February 2022)

Hu, M., Shealy, T. (2020), "Overcoming status quo bias for resilient stormwater infrastructure: empirical evidence in neurocognition and decision-making", *Journal of Management in Engineering*, Vol. 36, No. 4. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000771

Jamei, E., Mortimer, M., Seyedmahmoudian, M., Horan, B., Stojcevski, A. (2017) "Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities", *Sustainability*, Vol. 9. https://doi.org/10.3390/su9112006

Kahneman, D. (2003), "A perspective on judgment and choice: mapping bounded rationality", *American Psychology* Vol. 58, pp. 697–720. https://doi.org/10.1037/0003-066X.58.9.697

Keeler, B.L., Hamel, P., McPhearson, T., Hamann, M.H., Donahue, M.L., Meza Prado, K.A., Arkema, K.K., Bratman, G.N., Brauman, K.A., Finlay, J.C., Guerry, A.D., Hobbie, S.E., Johnson, J.A., MacDonald, G.K., McDonald, R.I., Neverisky, N., Wood, S.A. (2019), "Social-ecological and technological factors moderate the value of urban nature", *Nature Sustainability*, Vol. 2, pp. 29–38. https://doi.org/10.1038/s41893-018-0202-1

Kellert, S.R. (2018), *Nature by Design: The Practice of Biophilic Design*. Yale University Press.

Kellert, S.R. (1995), The Biophilia Hypothesis. Island Press.

Kilteni, K., Groten, R., Slater, M. (2012), "The Sense of Embodiment in Virtual Reality", *Presence: Teleoperators and Virtual Environments* Vol. 21, pp. 373–387. https://doi.org/10.1162/PRES_a_00124

Kim, S. (2014), "Decision Support Model for Introduction of Gamification Solution Using AHP", *The Scientific World Journal*, e714239. https://doi.org/10.1155/2014/714239

Köppen, E., Meinel, C. (2015), "Empathy via Design Thinking: Creation of Sense and Knowledge", in: Plattner, H., Meinel, C., Leifer, L. (Eds.), *Design Thinking Research: Building Innovators, Understanding Innovation*, Springer International Publishing, Cham, pp. 15–28. https://doi.org/10.1007/978-3-319-06823-7_2

Kors, M., Spek, E., Bopp, J., Millenaar, K., Teutem, R.L. van, Ferri, G., Schouten, B. (2020), "The Curious Case of the Transdiegetic Cow, or a Mission to Foster Other-Oriented Empathy Through Virtual Reality", *CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, Honolulu, HI, pp. 1-13. https://doi.org/10.1145/3313831.3376748

Kourtesis, P., Collina, S., Doumas, L.A.A., MacPherson, S.E. (2019), "Validation of the Virtual Reality Neuroscience Questionnaire: Maximum Duration of Immersive Virtual Reality Sessions Without the Presence of Pertinent Adverse Symptomatology", *Frontiers in Human Neuroscience*, Vol. 13. https://doi.org/10.3389/fnhum.2019.00417

Li, L., Collins, A.M., Cheshmehzangi, A., Chan, F.K.S. (2020), "Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China", *Urban Forestry & Urban Greening*, Vol. 54, 126770. https://doi.org/10.1016/j.ufug.2020.126770

Ma, Y., Wright, J., Gopal, S., Phillips, N. (2020), "Seeing the invisible: From imagined to virtual urban landscapes", *Cities*, Vol. 98, 102559. https://doi.org/10.1016/j.cities.2019.102559

Makarova, I., Khabibullin, R., Belyaev, E., Bogateeva, A. (2015), "The application of virtual reality technologies in engineering education for the automotive industry", *International Conference on Interactive Collaborative Learning (ICL)*, Firenze, Italy, 20-24 September, pp. 536–544. https://doi.org/10.1109/ICL.2015.7318086

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A.M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M.J., Lupp, G., Richardson, E.A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., Fuertes, E. (2017), "Exploring pathways linking greenspace to health: Theoretical and methodological guidance", *Environmental Research*, Vol. 158, pp. 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Markopoulos, A.P., Fragkou, A., Kasidiaris, P.D., Davim, J.P. (2015), "Gamification in engineering education and professional training" *International Journal of Mechanical Engineering Education*. https://doi.org/10.1177/0306419015591324

Martirosov, S., Kopeček, P. (2017), "Cyber Sickness in Virtual Reality - Literature Review", Annals of DAAAM & Proceedings, pp. 0718–0726. https://doi.org/10.2507/28th.daaam.proceedings.101

Mayer, F.S., Frantz, C.M. (2004), "The connectedness to nature scale: A measure of individuals' feeling in community with nature", *Journal of Environmental Psychology* Vol. 24, pp. 503–515. https://doi.org/10.1016/j.jenvp.2004.10.001

Murata, A., Miyoshi, T. (2000), "Effects of duration of immersion in a virtual environment on postural stability", *IEEE International Conference on Systems, Man and Cybernetics*, pp. 961–966. https://doi.org/10.1109/ICSMC.2000.885974

NEORSD, 2017. About Project Clean Lake – Northeast Ohio Regional Sewer District. Available at: https://www.neorsd.org/community/about-the-project-clean-lake-program/ (Accessed: 20 November 2020).

Nisbet, E.K., Zelenski, J.M., Murphy, S.A. (2009), "The Nature Relatedness Scale: Linking Individuals' Connection With Nature to Environmental Concern and Behavior", *Environment and Behavior* Vol. 41, pp. 715–740. https://doi.org/10.1177/0013916508318748

Okeil, A. (2010), "Hybrid design environments: immersive and non-immersive architectural design", *Journal of Information Technology in Construction* Vol. 15, pp. 202–216. https://doi.org/10/16

Oswald, P.A. (1996), "The Effects of Cognitive and Affective Perspective Taking on Empathic Concern and Altruistic Helping", *The Journal of Social Psychology* Vol. 136, pp. 613–623. https://doi.org/10.1080/00224545.1996.9714045

Project Groundwork, 2012. Lick Run Master Plan. Available at: https://www.projectgroundwork.org/downloads/lickrun/lick_run_master_plan.pdf (Accessed: 15 April 2023)

Randolph, J. (2003), *Environmental Land Use Planning and Management*, Island Press, Washington.

Rosenbloom, J. (2018), "Fifty Shades of Gray Infrastructure: Land Use and the Failure to Create Resilient Cities", *Washington Law Review*, Vol. 93, pp. 317. Available at: https://digitalcommons.law.uw.edu/wlr/vol93/iss1/7/ (Accessed: 20 March 2020)

Schultz, P.W. (2000), "Empathizing With Nature: The Effects of Perspective Taking on Concern for Environmental Issues", *Journal of Social Issues*, Vol. 56, No. 3, pp. 391-406. https://doi.org/10.1111/0022-4537.00174

Scurati, G.W., Bertoni, M., Graziosi, S., Ferrise, F. (2021), "Exploring the Use of Virtual Reality to Support Environmentally Sustainable Behavior: A Framework to Design Experiences", *Sustainability* Vol. 13, pp. 943. https://doi.org/10.3390/su13020943

Singer, T., Klimecki, O.M. (2014) "Empathy and compassion", *Current Biology* Vol. 24, pp. R875–R878. https://doi.org/10.1016/j.cub.2014.06.054

Stauskis, G. (2014), "Development of methods and practices of virtual reality as a tool for participatory urban planning: a case study of Vilnius City as an example for improving environmental, social and energy sustainability", *Energy, Sustainability, and Society*, Vol. 4, No. 7. https://doi.org/10.1186/2192-0567-4-7

Van Oijstaeijen, W., Van Passel, S., Cools, J. (2020), "Urban green infrastructure: A review on valuation toolkits from an urban planning perspective", *Journal of Environmental Management*, Vol. 267, 110603. https://doi.org/10.1016/j.jenvman.2020.110603

Vesely, É.-T. (2007), "Green for green: The perceived value of a quantitative change in the urban tree estate of New Zealand", *Ecological Economics*, Vol. 63, 605–615. https://doi.org/10.1016/j.ecolecon.2006.12.019

Villagrasa, S., Fonseca, D., Durán, J. (2014), "Teaching case: applying gamification techniques and virtual reality for learning building engineering 3D arts", *Second International Conference on Technological Ecosystems for Enhancing Multiculturality - TEEM*. ACM Press, Salamanca, Spain, pp. 171–177. https://doi.org/10.1145/2669711.2669896

Wamsler, C., Alkan-Olsson, J., Björn, H., Falck, H., Hanson, H., Oskarsson, T., Simonsson, E., Zelmerlow, F. (2020), "Beyond participation: when citizen engagement leads to undesirable outcomes for nature-based solutions and climate change adaptation", *Climatic Change*, Vol. 158, pp. 235–254. https://doi.org/10.1007/s10584-019-02557-9

Wang, P., Wu, P., Wang, J., Chi, H.-L., Wang, X. (2018), "A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training", *International Journal of Environmental Research and Public Health* Vol. 15, pp. 1204. https://doi.org/10.3390/ijerph15061204

Xiang, Y., Liang, H., Fang, X., Chen, Y., Xu, N., Hu, M., Chen, Q., Mu, S., Hedblom, M., Qiu, L., Gao, T. (2021), "The comparisons of on-site and off-site applications in surveys on perception of and preference for urban green spaces: Which approach is more reliable?", *Urban Forestry & Urban Greening*, Vol. 58, 126961. https://doi.org/10.1016/j.ufug.2020.126961

Xie, J., Chen, H., Liao, Z., Gu, X., Zhu, D., Zhang, J. (2017), "An integrated assessment of urban flooding mitigation strategies for robust decision making", *Environmental Modelling & Software* Vol. 95, pp. 143–155. https://doi.org/10.1016/j.envsoft.2017.06.027

Yee, N., Bailenson, J. (2006), "Walk A Mile in Digital Shoes : The Impact of Embodied Perspective-Taking on The Reduction of Negative Stereotyping in Immersive Virtual Environments" Available at: https://stanfordvr.com/mm/2006/yee-digital-shoes.pdf (Accessed: 22 April 2021).

https://doi.org/10.1017/pds.2023.158 Published online by Cambridge University Press