USER PREFERENCES OF PERSPECTIVE AND DIMENSIONALITY OF TOURISM SPACE GEOVISUALISATION SUPPORTING ORIENTATION IN A NON-IMMERSIVE VIRTUAL REALITY

Alina Zajadacz [1], Łukasz Halik [2]

[1] Chair of Tourism and Recreation, Faculty of Geographical and Geological Sciences, Adam Mickiewicz in Poznań University, Poznań, Poland
[2] Department of Cartography and Geomatics, Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań, Poland

Manuscript received: July 19, 2023
Revised version: May 24, 2024

Zajadacz A., Halik L., 2024. User preferences of perspective and dimensionality of tourism space geovisualisation supporting orientation in a non-immersive virtual reality. *Quaestiones Geographicae* 43(3), Bogucki Wydawnictwo Naukowe, Poznań, pp. 77–86. 6 figs.

Abstract: The research problem was related to the search for appropriate parameters relevant to the tools that support spatial orientation in large-scale building plans. This problem was addressed by selecting the optimal (1) observation perspective (passerby perspective, bird-eye view perspective, top–down view perspective) in a non-immersive virtual reality (VR) and (2) the presentation dimensionality (2D/3D). The perception of the plans was analysed taking into account such independent variables as gender and the individual level of spatial orientation of the study participants, determined based on the Santa Barbara Sense of Direction (SBSOD) and the Mental Rotation tests (MRT). In the research conducted in 2021 on a sample of 103 people, the experimental methodology involved the comparison of preferences of the study participants in terms of geovisualisation before and after getting to know the real tourism space. The results showed the compliance of preferences, i.e. recognition as the optimal plan in 2D dimensionality and the top–down view perspective. No statistically significant differences in spatial orientation due to gender or individual predispositions measured by the SBSOD and the MRT tests were confirmed.

Keywords: user preferences, PC monitor, cartographic perspective, two-dimensional vs. three-dimensional, building plan

Corresponding author: Alina Zajadacz, alina.zajadacz@amu.edu.pl

Introduction

Orientation in the tourism space, where the visitor is often new to the visitor, is still a big problem both in open landscapes and in tourist facilities, especially in large-scale centres of mass tourism. Searching for facilities in spatial orientation, in accordance with the principles of universal design should ensure its intuitive character (Lidwell 2010), and take into account the specificity of the building's functions and the individual predispositions in the spatial orientation of visitors. Currently, virtual reality (VR), used both directly in tourist facilities and via mobile devices during the entire journey, is one of the more often used tools supporting spatial orientation. VR also has great potential in universal design (taking into consideration the needs of

https://doi.org/10.14746/quageo-2024-0027
ISSN 2082-2103, eISSN 2081-6383

the elderly, with disabilities), i.e. supporting and guaranteeing information and communication accessibility (Act on ensuring accessibility … 2019) in the tourist information system (Zajadacz 2014, 2015). The level of immersion is an important factor in which displays showing, e.g. tourist facilities are classified. Visual displays have been classified as non-immersive (PC monitors), semi-immersive (simulators) and fully immersive (head-mounted displays or computer automated virtual environments) (Slocum et al. 2001, Halik 2018, Lokka, Çöltekin 2019, Çöltekin et al. 2020). The aim of the present research was to find answers to questions about the optimal form of geovisualisation with the use of non-immersive VR in the creation of plans facilitating orientation in the tourism space. The 'optimal' form is understood as 'the best possible under the given conditions' (Słownik PWN, 2023), regarding the dimensionality and perspective of presentation, as well as the individual characteristics of tourists' perception.

Literature review

Measuring user's preferences is a very important aspect of studies in cartography (Roth et al. 2017, Herman et al. 2018). Knowing what features of building plans are important from the point of view of their users is a crucial factor, and this factor is used to create maps that intuitively support spatial orientation, referring to the ability of organisms to navigate (Chamizo, Rodrigo 2019). Nowadays, VR as a technology enables viewing geovisualisations in an interactive way, which may help support spatial orientation. This aspect is being more and more often used currently and is the focus of many studies (Bruder et al. 2012, Cirio et al. 2013, Carbonell-Carrera, Saorin 2018, Diersch, Wolbers 2019). The effectiveness of VR in relation to the markings in the real world in terms of orientation in space was analysed. Some researchers (including Pastel et al. 2021) found no significant differences in travelling the route between moving in real space and VR. Using VR has been shown to provide similar participant behaviour as that of real-world interaction. On the other hand, the research of the team of Nguyen-Vo et al. (2017) on the impact of different frames of reference of a person moving in VR on the efficiency of movement, including the ease of finding the direction of the transition, target points and the time to cover the distance (Fig. 1), showed differences in perception depending on the adopted frame of reference while moving in VR. The conclusions indicated that the simulated 'stationary room' significantly improved user performance in terms of both navigational search time and overall travel distance. It was also highlighted that adding a variant frame of reference to a VR application could be a cost-effective solution for more efficient locomotion in VR. However, according to Nguyen-Vo et al. (2017), visualisation of the virtual environment with the head-mounted display (HMD) differs from reality, and it is still unclear whether visual perception works the same in VR with different levels of immersion.

Another current research problem, apart from the reference framework, is the perspective of observation in VR. On a daily basis, we move in three-dimensional (3D) space, observing the world from the perspective of a pedestrian (Gehl 2017). The use of this perspective in the exploration of geovisualisation in VR was presented, among others, by Zagata et al. (2021). It is a natural way of getting to know the surrounding space by humans, but it stands in contrast to the cartographic way in which the arrangement of rooms in large-scale buildings is shown. The dominant way of presentation is a two-dimensional (2D) orthogonal projection from above, which reflects the contours of the rooms and their functions. Most often, such geovisualisation takes the form of a printed plan in a scale smaller than 1:1. Currently, the development of geovisualisation techniques enables the implementation of more interactive solutions indicating the layout of rooms in buildings, which the user can independently traverse in a virtual space. This gives the opportunity to test the developed plans of large-scale buildings in various observation perspectives, i.e. passerby perspective, bird-eye view perspective or top–down view perspective (Medyńska-Gulij 2021) and dimensions (2D/3D information presentation (Halik, Kent 2021). Strategies using 2D and a 2D/3D combination are more effective than those with only 3D (Carbonell-Carrera et al. 2020).

Numerous studies have highlighted the differences in spatial orientation due to individual

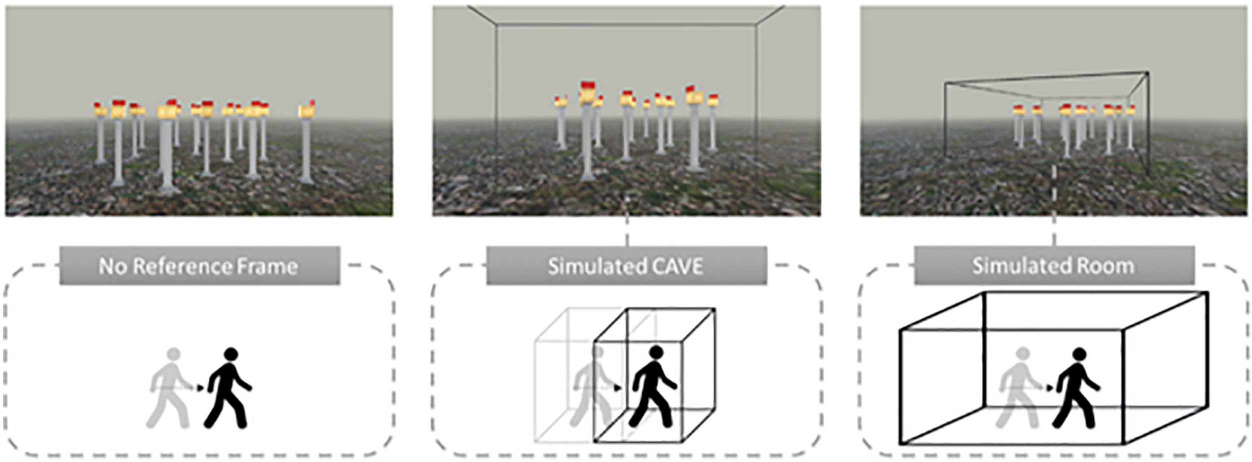

Fig. 1. Three variations of reference frames. Left: No reference frame. Middle: Egocentric reference frame or simulated Computer Automated Virtual Environment (CAVE). Right: Allocentric reference frame or simulated room according to Nguyen-Vo et al. (2017, p. 207).

characteristics, such as gender (Chamizo, Rodrigo 2019). It has been shown that in both rats and humans, males seem more likely to rely on geometrical information to reach a goal, while females are more likely to use landmarks (Ward et al. 1986, Williams et al. 1990, Silverman, Eals 1992, Sandstrom et al. 1998, Jones et al. 2003, Pacheco-Cobos et al. 2010, Vashro, Cashdan 2015, Chamizo, Rodrigo 2019). Ward et al. (1986) observed that when giving directions, women tend to use landmarks as points of reference, while men tend to use distance or cardinal directions (like North, South, East, and West). Rodríguez et al. (2013) suggested young female rats behave like males on a spatial task, while a sex difference appears only after puberty is consistent with the suggestion that sex differences in spatial cognition in humans appears due to the hormonal and cognitive changes associated with puberty.

Spatial thinking is according to Nielsen et al. (2011, p. 60) 'the ability to visualise and solve problems spatially'. It depends, as Maier (1996) points out, on individual spatial orientation skills and is defined as the ability to physically or mentally orientate oneself in space. There are numerous classifications of spatial skills (Smith 1964, Linn, Petersen 1985, Sorby 1999, Marunic, Glažar 2014, Weckbacher, Okamoto 2014) and some of them, such as those by Bodner and Guay (1997) and Tartre (1990), consider spatial orientation as the main component of spatial skills. It is measured i.a. using the spatial orientation tests – the Santa Barbara Sense of Direction (SBSOD) is a self-report scale of environmental spatial ability. It contains 15 questions regarding, e.g. the cardinal directions, reading maps and showing directions to other people (Hegarty et al. 2002) or spatial rotation. – The other test is the mental rotation test (MRT) (Vandenbert, Kuse 1978), which contains in our case a set of five rotated sets of 3D figures and the user's task is to find the same 3D figures in a given set.

Individual predispositions related to spatial orientation can be developed through education, using also VR. Through the use of behavioural modelling methods (Bailenson 2019), the creation of attitudes of VR participants can be influenced. This also applies to eliminating the identified differences in spatial orientation between men and women. According to Chamizo and Rodrigo (2019, p. 9) 'no doubt, cognitive intervention programs at schools (for example, different types of games geometric for girls and spatial memory ones for boys) could help to reduce the sex differences observed in adulthood'. Both the indicated possibilities that lie in VR in the field of supporting spatial orientation, and invariably the many difficulties in finding locations on the part of tourism space users, have become an impulse to undertake research focused on the search for the optimal form of geovisualisation of tourism space in non-immersive VR.

Purpose of the research, hypotheses

The main purpose of the research was the search for parameters for tools supporting spatial orientation in large-scale objects by selecting the optimal (1) observation perspective (passer-by perspective, bird-eye view perspective, top–down view perspective) in the non-immersive VR and (2) dimensionality presentation (2D/3D), considering such characteristics of visitors as gender and individual spatial orientation.

Until now, 2D plans are most often created due to the lower level of complexity involved in the process of recreating reality. However, an open question pertains to whether creating building plans in 3D could improve the level of spatial orientation of users since we live in 3D space, and the technology of spatial information processing allows for the quick creation of 3D studies (Biljecki et al. 2016, Halik 2018, Halik, Smaczyński 2018). What should be the optimal parameters of non-immersive VR geovisualisation, considering the perception of the addressees of this type of tools? The research was based on the following hypotheses:

H_1: Users exploring a 2D plan or a 3D plan of a high-volume building prefer a specific geovision perspective (passerby perspective, bird-eye view perspective, top–down view perspective).

H_2: Adding 3D to traditional 2D plans that can be interactively explored in VR does not increase the level of spatial orientation (the problem of obscured space).

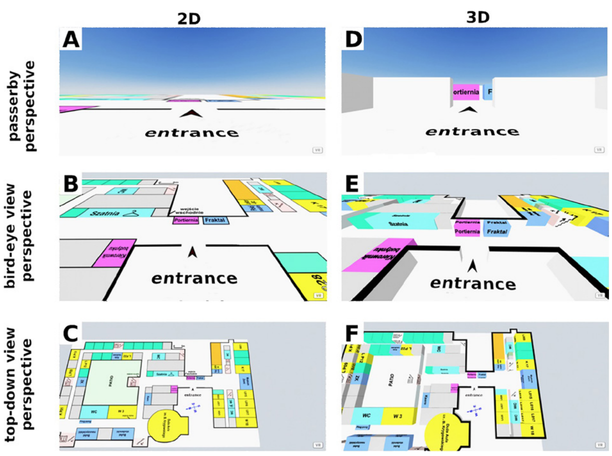

Fig. 2. Six plans for a large-scale building subjected to a user preference survey. A) 2D plan of the building in passerby perspective, B) 2D plan of the building in bird-eye view perspective, C) 2D plan of the building in top-down view perspective, D) 3D plan of the building in passerby perspective, E) 3D plan of the building in bird-eye view perspective, F) 3D plan of the building in top-down view perspective.

The detailed tasks included identifying which of the presented plans (Fig. 2) facilitates spatial orientation in the building to the greatest extent. The participants of the experiment assessed the plans twice, i.e. before and after confronting the plan with reality, the preferences regarding the plans were analysed regarding such independent variables as gender and the individual level of spatial orientation of the study participants, determined on the basis of SBSOD and MRT tests.

Experimental design

In the experiment performed, six plans of a large-area building were tested on a non-immersive PC monitor screen (Fig. 2). The developed plans were divided into two groups, which were to indicate user preferences in terms of (1) dimensionality: 2D (A, B, C) vs 3D (D, E, F) and (2) presentation perspective: passerby view (A, D), bird-eye view (B, E) and top–down view (C, F). In order to determine preferences in relation to individual features (gender, level of spatial orientation), the participants of the study completed the SBSOD and MRT tests at the beginning.

As part of the research, the respondents were asked twice about their preferences related to the presented plans in order to check whether the confrontation of the studied plans with reality would change their preferences. For the first time, participants' preferences were asked directly after viewing all six plans on the monitor screen. Then, assuming after Bailenson (2019, p. 125) that 'when people experience something directly they begin to see it in a different light', the respondents were asked to walk for a short while (max. 5 min) along the floor of the building shown on the plans and after returning they had to re-select the optimal plan. During the second study of preferences, in order to remind the respondents of the appearance of individual plans, they were presented on the A4 sheet with screenshots of all six analysed plans.

Apparatus

The research was carried out in a specially dedicated room in a large-scale building, the plans of which were presented to users. The analysed

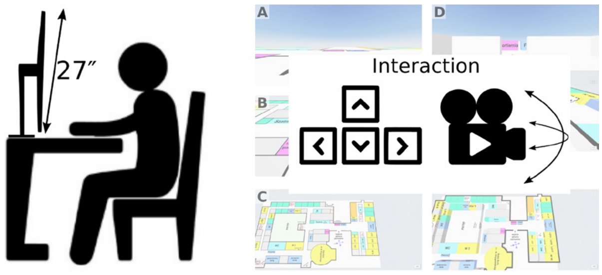

Fig. 3. Experimental setup.

six interactive plans were displayed on the screen of a 27′′ monitor (Fig. 3). Users could move freely on them: forward, backward, left and right using the directional arrows placed on the keyboard. They could also use the computer mouse to rotate the camera view relative to the height of the starting plane representing a given perspective: passerby perspective, bird-eye view perspective and top–down view perspective. The questionnaire with the six tested geovisualisations used in the research is available from the authors.

Participants and procedure

In all, 103 people (59 women, 44 men) aged 20–43 years participated in the experiment voluntarily, but 96 people (57 women, 39 men) aged 20–30 qualified for the final analysis. The age range of years was used due to the aging effects on memory (Park et al. 2002). The research was carried out in September 2021 in the Collegium Geographicum, University of Adam Mickiewicz in Poznań, which houses the Earth Museum on the ground floor, visited by both individual tourists and groups of visitors. The research procedure was carried out in accordance with the principles of ethics and good practices applied in social research, with the preservation of anonymity and after obtaining the informed consent of the participants (Silwerman 2008). In order to meet the conditions for giving informed consent, the following actions were taken: (1) relevant information about the study was provided, before making a decision to participate in the project, (2) it was made sure that the subjects of the study understand the essence of the information, and (3) voluntary participation was ensured. Moreover, the study participants were asked to consent to the use of the data recorded during the transcription of the experiment (see example of the form – Silwerman 2008).

The stages and methods of the research included:

- tests for the individual levels of spatial orientation – SBSOD and MRT;
- division of the users into research groups having a specific level of spatial orientation;
- proper experiment: exploring interactive plans on the screen of a 27′′ monitor in 2D/3D mode in three designed perspectives using the protocol of thinking aloud (users could move around the presented plans: forward, backward, left, right and rotate the camera, no time limit for viewing the six tested plans);
- a survey specifying user preferences immediately after the actual experiment;
- walk to the analysed building;
- a survey specifying the preferences of users after a walk around the analysed building;
- analysis and synthesis of collected data and formulation of conclusions.

Results

The results of the analyses concerning the opinions of the surveyed persons before and after the verification of plans with reality were discussed taking into account (1) perspective and (2) dimensionality in connection with independent features of research participants (i.e. gender, individual level of spatial orientation). On this basis, the data synthesis was carried out, indicating the plan which, in the opinion of the participants of the experiment, facilitated the spatial orientation in the visited building to the greatest extent possible.

The preferred perspective plans

With regard to the perspective of the perception of the plans, preferences were taken into account due to such characteristics of the participants of the experiment as gender and the level of individual spatial orientation as measured by the SBSOD and the MRT tests (Fig. 4).

Considering drafting the plans taking into consideration the gender variable before walking through the building, due to the preferred presentation perspective (Fig. 4), the most popular of them is the top–down view (see Fig. 2) chosen by 84% of the women and by 59% of the men. After a walk inside the building, the top–down view is still the most popular presentation perspective (66% women and 49% men), although its popularity has decreased in favour of the bird-eye view by women and the passerby view by men.

Linking the preferences of the respondents with the results of the SBSOD spatial orientation test (Fig. 4) showed that before walking around the building, the most frequently chosen perspective was the top–down view indicated by 76% of the people with a low indicator SBSOD and 72% of the people with a high SBSOD rate. After a walk around the building's interior, the top–down view was still the most popular presentation perspective (62% SBSOD ≤ 4.667; 56% SBSOD > 4.667).

Data analysis for the results from the MRT spatial rotation test (Fig. 4) showed that the top–down view chosen by 82% of the people with a low MRT index is the most frequently chosen perspective before walking around the building and 63% of the people with high MRT. After a walk inside the building, the top–down view is still the most popular presentation perspective (65% MRT < 5; 52% MRT = 5).

Preferred dimension plans

Similarly, as in the case of perspective, with regard to the dimensionality of the perception of plans, preferences were taken into account due to such characteristics of the experiment participants as gender and the level of individual spatial orientation as measured by the SBSOD and MRT tests (Fig. 5).

When examining gender preferences (Fig. 5) in terms of presentation dimensionality, it was found that 2D plans (A + B + C answers, see Fig. 2) were preferred before walking through the building, which were chosen by 65% of the women and 54% of the men. After a walk in the building, women still preferred the 2D plans (66% women), but men changed their preferences to 3D plans (57%).

Taking into account the level of spatial orientation (Fig. 5) of users before walking around the building in terms of presentation dimensionality, it can be concluded that 2D plans were preferred, which were chosen by 56% of the people with a low SBSOD index and 65% of the people with a high SBSOD index. After a walk in the building, 2D plans are still preferred (54% SBSOD ≤ 4.667 and 61% SBSOD > 4.667).

Preferences regarding the level of users' spatial rotation before walking around the building in terms of the dimensionality of the presentation showed that people with a spatial orientation level lower than 5 (the maximum possible result) prefer 2D plans (71%), while people who obtained

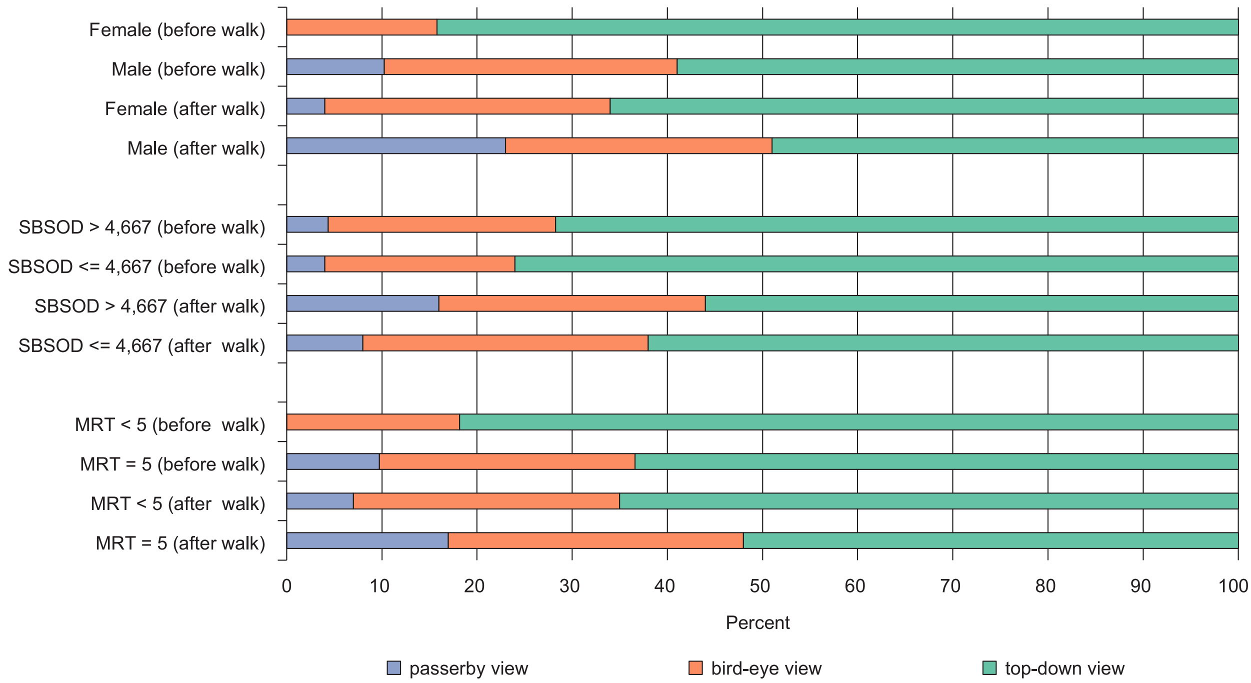

Fig. 4. The preferences of the respondents regarding the presentation perspective in terms of gender and the results of the Santa Barbara Sense of Direction and mental rotation tests.

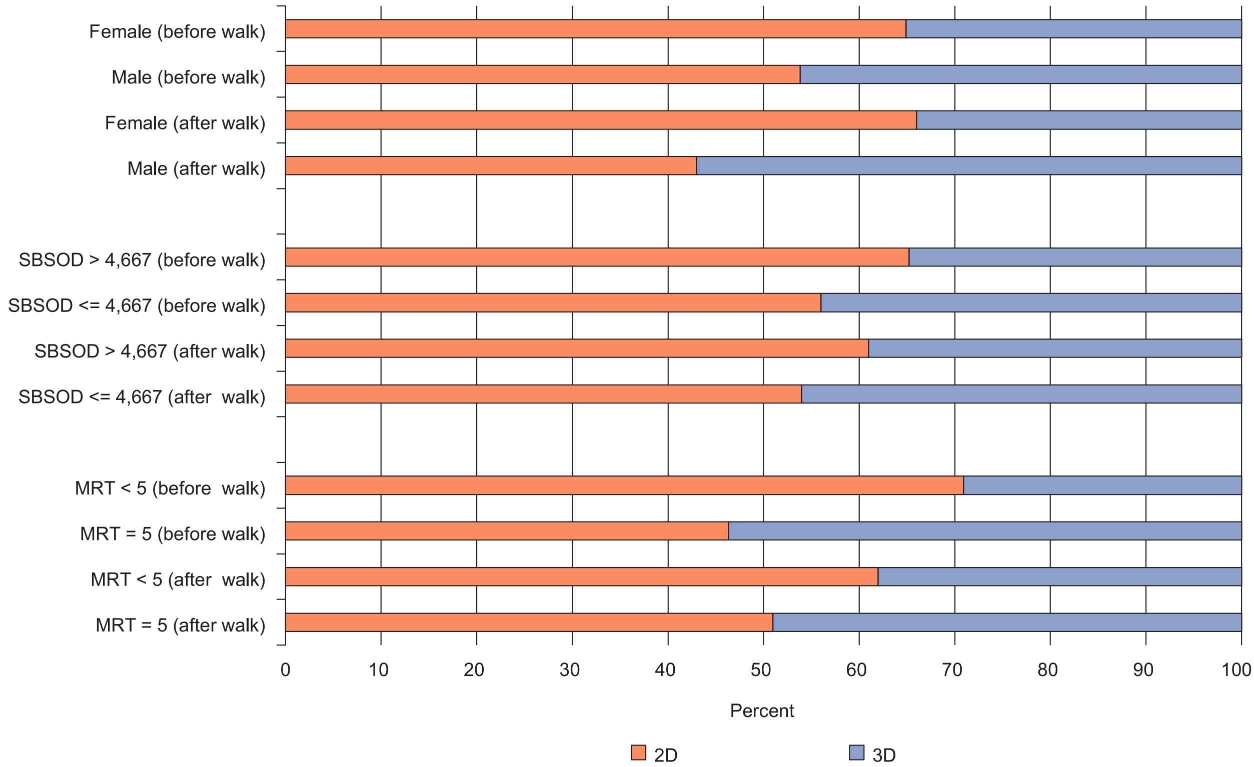

Fig. 5. The preferences of the respondents regarding the dimensionality of the presentation in terms of gender and the results of the Santa Barbara Sense of Direction and mental rotation tests.

the maximum result in the MRT test preferred 3D plans (54%). However, after walking inside the building, 2D plans were preferred in both study groups (62% MRT < 5; 51% MRT = 5).

Synthesis and discussion of research results

By analysing the totality of the presented results (Fig. 6), it can be concluded that the plan that facilitates orientation in space the most is plan C (2D top–down view perspective). This conclusion is in line with the results presented by Carbonell-Carrera et al. (2020), who showed that strategies using 2D and a 2D/3D combination are more effective than those with only 3D.

Plan C was indicated by 50% of the experiment participants after viewing all six proposals (immediately before walking around the building) and by 41% of the respondents immediately (after walking through the analysed building). Considering the plans in terms of the preferred presentation perspective, the most popular of them is the top–down view (A + C answers), chosen by 74% of the respondents before the walk and 59% after the walk. When examining the preferences in terms of presentation dimensionality, 2D plans (A + B + C answers) were preferred, which were chosen by 60% of the people before the walk and 57% of the respondents after the walk.

The research showed that the preferences of the participants of the experiment did not change statistically significantly after walking through the analysed building, in the case of choosing an individual plan; *p*-value = 0.73 and grouping plans in terms of dimensionality, *p*-value = 0.66. However, there is a statistically significant difference between the plans grouped in terms of *p*-value = 0.0051 perspective. This means that the confrontation of plans with reality during the walk had an influence on the change of preferences of the respondents in terms of the preferred perspective, i.e. people who previously chose the top–down view perspective changed their preferences to bird-eye view or passerby view.

The analysis of the respondents' preferences in terms of gender (Fig. 6) before walking around the building showed that both in the opinion of women (56%) and men (41%) the plan that best presents the arrangement of the rooms is plan C.

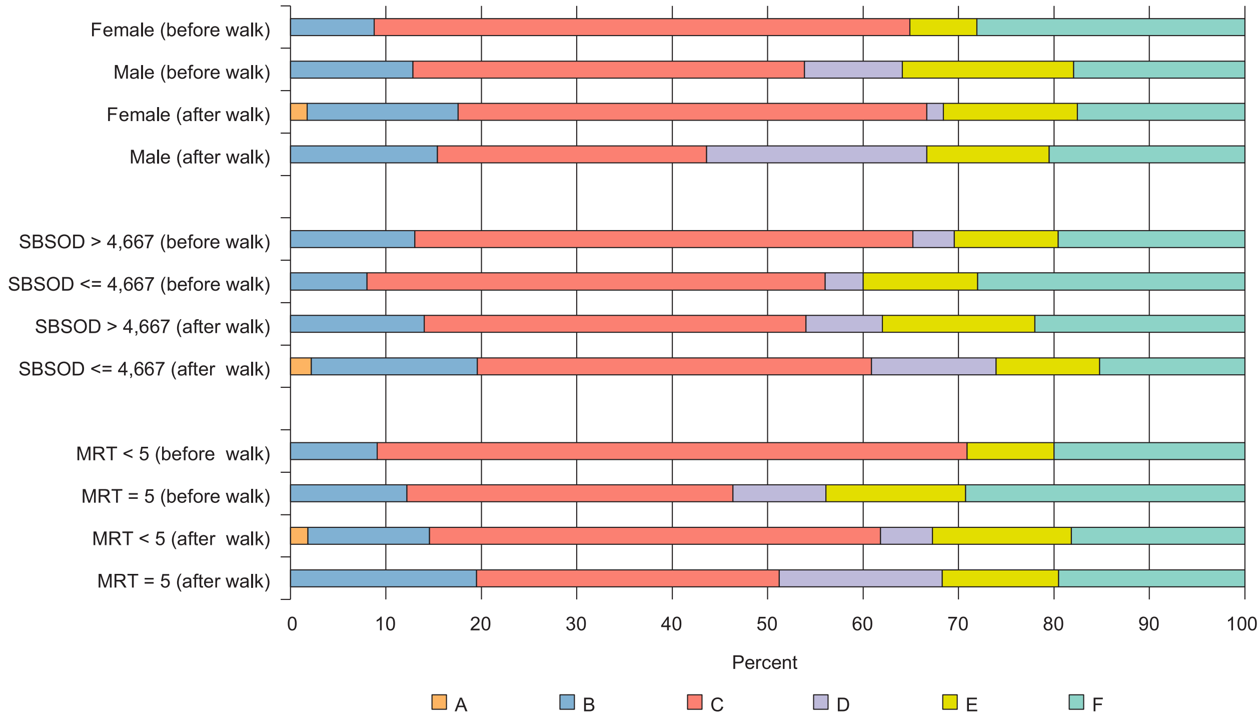

Fig. 6. Preferences in terms of plans, including independent variables (gender and Santa Barbara Sense of Direction and mental rotation tests results).

The most popular plan was plan C (49% of indications of women and 28% of indications of men) although its popularity decreased, especially in men in favour of plan D. The differences were not statistically significant; therefore, the differences in spatial orientation presented in the literature were not confirmed due to gender (Ward et al. 1986, Williams et al. 1990, Silverman, Eals 1992, Sandstrom et al. 1998, Jones et al. 2003, Pacheco-Cobos et al. 2010, Rodríguez et al. 2013, Vashro, Cashdan 2015, Chamizo, Rodrigo 2019).

Generalisation of the conclusions in terms of individual spatial orientation measured by the SBSOD (Hegarty et al. 2002) and the MRT (Vandenbert, Kuse 1978) tests in the study group indicates the agreement of views (Fig. 6). The results of the SBSOD spatial orientation test before walking around the building showed that, in the opinion of both people with low and high rates (48% and 52% of the responses, respectively), the layout of the rooms was best presented in plan C. Also, after a walk in the building, plan C was still the most popular plan (40% SBSOD > 4.667; 41% SBSOD ≤ 4.667). Also, the analysis of the preferences of the respondents in terms of the result obtained from the MRT spatial rotation test before walking around the building showed that both people with a low MRT index (62%) and people with a high MRT index (34%) preferred plan C. Plan C was still the most popular walk in the building (47% MRT < 5; 32% MRT = 5).

Conclusion

The results of the research showed a significant polarisation of the preferences of plans in terms of optimal spatial orientation in terms of room arrangement. Undoubtedly, the plan that, according to the participants of the experiment, best presents the layout of the rooms is plan C (top–down view and 2D objects) as indicated in all the analysed categories (i.e. gender, SBSOD, MRT). Therefore, the adopted hypotheses were confirmed:

1. Users exploring a 2D plan or a 3D plan of a large-scale building prefer a specific geovision perspective (passerby perspective, bird-eye view perspective, top–down view perspective);
2. Adding 3D to traditional 2D plans that can be interactively explored in VR does not increase the level of spatial orientation (the problem of obscured space).

It should be emphasised that the presented research results refer to geovisualisation with a low level of immersion; hence, the question is still open as to whether visual perception works the same in VR with different levels of immersion. Moreover, the participants of the experiment represented one age group (20–30 years old) and were non-disabled people. The research needs to be continued in terms of the diversity of the given sample in terms of age, being mindful of all generations of adults. Their results will broaden inference and allow for the identification of intergenerational differences. On the other hand, taking into account the principles of designing universal tourism space, it is also important to recognise the perception and preferences of plans supporting spatial orientation, considering the opinions of people with disabilities.

Author's contribution

Conceptualisation: A.Z., Ł.H.; methodology: A.Z., Ł.H.; software: A.Z., Ł.H; validation: A.Z., Ł.H.; formal analysis: A.Z., Ł.H.; investigation: A.Z., Ł.H., writing – original draft preparation: A.Z., Ł.H., writing – review, and editing: A.Z., Ł.H., visualisation: A.Z., Ł.H.; supervision: A.Z., Ł.H. The authors declare no conflict of interests in this study. All authors have read and agreed to the published version of the manuscript.

Acknowledgement

The research was carried out as part of the grant endowed to the Faculty of Geographical and Geological Sciences, Adam Mickiewicz University in Poznań: Supporting spatial orientation in large-scale facilities by optimising the perspective of 2D/3D geovision observation in a virtual reality system. Project manager – Prof. Alina Zajadacz; contractor Dr Łukasz Halik.

References

Act on ensuring accessibility, 2019. Ustawa z dnia 19 lipca 2019 r. o zapewnianiu dostępności osobom ze szczególnymi potrzebami. Dz. U. 2019 poz. 1696.

Bailenson J., 2019. Wirtualna rzeczywistość. Doznanie na żądanie. Helion, Gliwice.

Biljecki F., Ledoux H., Stoter J., 2016. An improved LOD specification for 3D building models, computers. *Environment and Urban Systems* 59: 25–37.

Bodner G., Guay R., 1997. The Purdue visualization of rotations test. *The Chemical Educator* 2(4): 1–17.

Bruder G., Interrante V., Phillips L., Steinicke F., 2012. Redirecting walking and driving for natural navigation in immersive virtual environments. *IEEE Transaction on Visualization and Computer Graphics* 18(4): 538–545.

Carbonell-Carrera C., Saorin J.L., Hess-Medler S., 2020. spatial orientation skill for landscape architecture education and professional practice. *Land* 9: 1–16.

Carbonell-Carrera C., Saorin J.L., 2018. Virtual learning environments to enhance spatial orientation. *EURASIA Journal of Mathematics Science Technology Education* 14: 709–719. DOI 10.12973/ejmste/79171.

Chamizo V.D., Rodrigo T., 2019. Spatial orientation. In: Vonk J., Shackelford T. (eds), *Encyclopedia of animal cognition and behavior*. Springer, Cham, pp. 1–11.

Cirio G., Olivier A.-H., Marchal M., Pettré J., 2013. Kinematic evaluation of virtual walking trajectories. *IEEE Transaction on Visualization and Computer Graphics* 19(4): 671–680. DOI 10.1109/TVCG.2013.34.

Çöltekin A., Lochhead I., Madden M., Christophe S., Devaux A., Pettit Ch., Lock O., Shukla S., Herman L., Stachon Z., Kubícek P., Snopková D., Bernardes S., Hedley N., 2020. Extended reality in spatial sciences: A review of research challenges and future directions. *International Journal of Geo-Information* 9(7): 439. DOI 10.3390/ijgi9070439.

Diersch N., Wolbers T., 2019. The potential of virtual reality for spatial navigation research across the adult lifespan. *Journal of Experimental Biology* 222: 1–9. DOI 10.1242/jeb.187252.

Gehl J., 2017. *Miasta dla Ludzi*, Tłum. Szymon Nogalski. Wydawnictwo RAM Sp. z o. o, Kraków.

Halik Ł, Kent A.J., 2021. Measuring user preferences and behaviour in a topographic immersive virtual environment (TopoIVE) of 2D and 3D urban topographic data, *International Journal of Digital Earth* 14(12): 1835–1867. DOI 10.1080/17538947.2021.1984595.

Halik Ł., 2018. Challenges in converting Polish topographic database of built-up areas into 3D virtual reality geovisualization. *The Cartographic Journal* 55(4): 391–399. DOI 10.1080/00087041.2018.1541204.

Halik Ł., Smaczyński M., 2018. Geovisualization of relief in a virtual reality system on the basis of low aerial images. *Pure and Applied Geophysics* 175(9): 3209–3221. DOI 10.1007/s00024-017-1755-z.

Hegarty M., Richardson A., Montello D., Lovelace K., Subbiah, I., 2002. Development of a self-report measure of environmental spatial ability. *Intelligence* 30(5): 425–447.

Herman L., Juřík V., Stachoň Z., Vrbík D., Russnák J., Řezník T., 2018. Evaluation of user performance in interactive and static 3D maps. *ISPRS International Journal of Geo-Information* 7(11): 415. DOI 10.3390/ijgi7110415.

Jones C.M., Braithwaite V.A., Healy S.D., 2003. The evolution of sex differences in spatial ability. *Behavioral Neuroscience* 117: 403–411.

Lidwell W., 2010. *Universal principles of design.* Rockport Publishers Inc., Gloucester.

Linn, M.C., Petersen A.C., 1985. Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development* 56(6): 1479–1498.

Lokka I.E., Çöltekin A., 2019. Toward optimizing the design of virtual environments for route learning: Empirically assessing the effects of changing levels of realism on memory. *International Journal of Digital Earth* 12: 137–155.

Maier P., 1996. Spatial geometry and spatial ability: How to make solid geometry solid. In: *Proceedings of the Annual Conference of Didactics of Mathematics* (GDM), Regensburg, Germany, 4–8 March 1996: 69–68.

Marunic G., Glažar V., 2014. Improvement and assessment of spatial ability in engineering education. *Engineering Rev*iew 34(2): 139–150.

Medyńska-Gulij B., 2021. *Kartografia i geomedia*. Wydawnictwo Naukowe PWN, Warszawa.

Nguyen-Vo T., Riecke E.B., Stuerzlinger W., 2017. Moving in a box: Improving spatial orientation in virtual reality using simulated reference frames. In: 2017 IEEE Symposium on 3D User Interfaces (3DUI), Los Angeles, CA, USA, 2017: 207–208. DOI 10.1109/3DUI.2017.7893344.

Nielsen C.P., Oberle A., Sugumaran R., 2011. Implementing a high school level geospatial technologies and spatial thinking course. *Journal of Geography* 110(2): 60–69.

Pacheco-Cobos L., Rosetti M., Cuatianquiz C., Hudson R., 2010. Sex differences in mushroom gathering: Men expend more energy to obtain equivalent benefits. *Evolution and Human Behavior* 31: 289–297.

Park D.C., Lautenschlager G., Hedden T., Davidson N.S., Smith A.D., Smith P.K., 2002. Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging* 17(2): 299–320. DOI 10.1037/0882-7974.17.2.299.

Pastel D., Bürger D., Chen C.H., Petri K., Witte K., 2021, Comparison of spatial orientation skill between real and virtual environment. *Virtual Reality* 26: 91–104.

Rodríguez C.A., Chamizo V.D., Mackintosh N.J. 2013. Do hormonal changes that appear at the onset of puberty determine the strategies used by female rats when solving a navigation task? *Hormones and Behavior* 64: 122–135.

Roth R.E., Çöltekin A., Delazari L., Filho H.F., Griffin A., Hall A., Korpi J., Lokka I., Mendonça A., Ooms K., van Elzakker C., 2017. User studies in cartography: opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography* 3: 61–89, DOI 10.1080/23729333.2017.1288534.

Sandstrom N.J., Kaufman J., Huettel, S.A., 1998. Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research* 6: 351–360.

Silverman I., Eals M., 1992. Sex differences in spatial abilities: Evolutionary theory and data. In Barkow J.H., Cosmides L., Tooby J. (eds), *The adapted mind: Evolutionary psychology and the generation of culture*. Oxford Press, New York: 531–549.

Silwerman D., 2008. *Interpretacja danych jakościowych*. PWN, Warszawa.

Slocum T.A., Blok C., Jiang B., Koussoulakou A., Montello D.R., Fuhrmann S., Hedley N.R., 2001. Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science* 28(1): 61–75. DOI 10.1559/152304001782173998.

Słownik PWN, 2023. Online: https://sjp.pwn.pl/slowniki/optymalny.html (accessed 28 December 2023).

Smith I.M., 1964. *Spatial ability: Its educational and social significance*. University of London Press, London, UK: 1964.

Sorby S.A., 1999. Developing 3-D spatial visualization skills. Engineering Design Graphics Journal 1999(63): 21–32.

Tartre L.A., 1990. Spatial orientation skill and mathematical problem solving. *Journal for Research in Mathematics Educatio*n 21(3): 216–229.

Vandenbert S.G., Kuse A.R., 1978. Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills* 47: 599–604.

Vashro L., Cashdan E., 2015. Spatial cognition, mobility, and reproductive success in northwestern Namibia. *Evolution and Human Behavior* 36: 123–129.

Ward S.L., Newcombe N., Overton W.F., 1986. Turn left at the church, or three miles north: A study of direction giving and sex differences. *Environment and Behavior* 18: 192–213.

Weckbacher L.M., Okamoto Y., 2014. Mental rotation ability in relation to self-perceptions of high school geometry. Learning and Individual Differences 30: 58–63. DOI 10.1016/j.lindif.2013.10.007.

Williams C.L., Barnett A.M., Meck W.H., 1990. Organizational effects of early gonadal secretions on sexual differentiation in spatial memory. *Behavioral Neuroscience* 104: 84–97.

Zagata K., Gulij J., Halik Ł., Medyńska-Gulij B., 2021. Mini-map for gamers who walk and teleport in a virtual stronghold. *International Journal of Geo-Information* 96: 1–17. DOI 10.3390/ijgi10020096.

Zajadacz A., 2014. Sources of tourist information used by deaf people. Case study: The Polish deaf community. *Current Issues in Tourism* 17(5): 434–454.

Zajadacz A., 2015. Evolution of models of disability as a basis for further policy changes in accessible tourism. *Journal of Tourism Futures* 1(3): 189–202.