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Comparative SWOT analysis of virtual reality and augmented reality ship passenger evacuation technologies

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Abstract

The purpose of this paper was to assess the possibility of using modern technologies, virtual reality (VR) and augmented reality (AR), to study the evacuation of passengers from ships. The evacuation of passengers from ships is usually studied from post-accident reports, laboratory or field experiments, and/or numerical modelling. Nowadays, with the rapid development of computer resources and wearable technology, evacuation can also be studied using VR or AR. The methods used in this paper for such assessments included a literature review (tools like Web of Science, Scopus, and Google Scholar indexing platforms) and comparative strengths, weaknesses, opportunities, threats (SWOT) analysis. The results demonstrated the great potential for the implementation of VR and AR technologies within the shipping industry, similar to how they have already found applications in the research of pedestrian evacuation from buildings or open spaces. Finally, recommendations for their use in ship passenger evacuation are presented.

Introduction

Studies of ship passenger evacuations have traditionally been performed by investigating the reports and testimonies of actual accidents or performing analysis based on available documented procedures (Lozowicka & Kaup, 2017; Łozowicka, 2019). In this type of research, scientists rely on post-accident available data and rules introduced by governing bodies. The drawbacks of this approach are that some key information necessary to understand the causes of accidents might be omitted, and the replicability of the event is practically impossible.

Evacuation experiments can also be performed to study the evacuation process, whether in laboratories or in the field. A laboratory environment ensures a controlled setting and the ability to repeat experiments. Onboard field experiments are seldom performed due to high costs, concerns with the safety of participants, and repeatability.

In addition to this, the safety science community has developed several numerical evacuation models, of which the cellular automata model is the most frequently used for pedestrian evacuation modelling (Miyagawa & Ichinose, 2020). Genetic algorithms and programming can also be to solve evacuation problems from ships (Łozowicka, 2012b;

Lozowicka, 2021); however, for these simulations to be credible, some form of experimental verification is needed.

To overcome the stated challenges, researchers have used virtual reality (VR) and augmented reality (AR) technologies for pedestrian evacuation simulation and modelling. Both VR and AR technologies can immerse an occupant into a virtual environment, but they do so in different manners. VR tends to lean more towards a virtual environment, while AR strives towards a realistic environment.

In AR, a user can partially perceive the real surroundings because 2D or 3D virtual elements are superimposed or blended with them (Figure 1). AR produces a close experience to the real surroundings because it enriches them, rather than generates a complete virtuality like VR (Carmigniani et al., 2011). This augmented reality can be experienced through wearable technology like head-mounted displays (e.g., Magic Leap One, Microsoft HoloLens, Google Glass), or mobile handheld video-see-through devices (e.g., tablets or smartphones).

In VR, the environment and all objects inside it are fully computer-generated (Milgram & Kishino, 1994), so users are not conscious of their real surroundings (Figure 1). Virtual content is shown via stereoscopic displays that come in a form of wearable technology (e.g., head-mounted displays), large screens, or wall projections (e.g., virtual rooms).

The purpose of this paper was to investigate the possibility of using VR or AR to study the evacuation of passengers from ships to overcome the limitations of traditional approaches by using modern computer resources and wearable technology. VR and AR have already found applications in the research of pedestrian evacuation from buildings or open spaces, but they have not been implemented in the shipping industry, which was the main driver of this research. In this paper, a comparative strengths, weaknesses, opportunities, threats (SWOT) analysis of VR and AR evacuation technologies was performed based on a comprehensive literature review. The first part of the paper provides an overview of the literature reviewed and emphasizes the papers concerned with VR and AR on ships. Second, a larger part of the paper deals with SWOT analysis but in a comparative manner for the reader to distinguish the unique features of the two technologies. Most of the references are based on the application of these two technologies in the evacuation of buildings or open spaces, so the SWOT analysis here is performed within the context of the shipping industry to provide recommendations for their use in ship passenger evacuation. A discussion with further research is provided at the end of the paper, followed by conclusions.

The methodology used to obtain the results involved both quantitative and qualitative research. Quantitative analysis was used to perform the initial screening of available literature references across global indexing platforms and to measure and categorize the findings through statistical analysis. It uncovered relationships between the researched field and helped generalize the data. A qualitative discussion was performed afterwards using SWOT analysis to uncover the optimal match between the internal strengths and weaknesses of a given entity and environmental trends (opportunities and threats) that the entity must face (Rizzo & Kim, 2005). The SWOT strategy took advantage of the entity's opportunities by employing its strengths and by proactively addressing threats by correcting or compensating for weaknesses.

References review

Ship passenger evacuation fits within the framework of pedestrian evacuation, so this study began with this broader perspective. Web of Science

a) b)

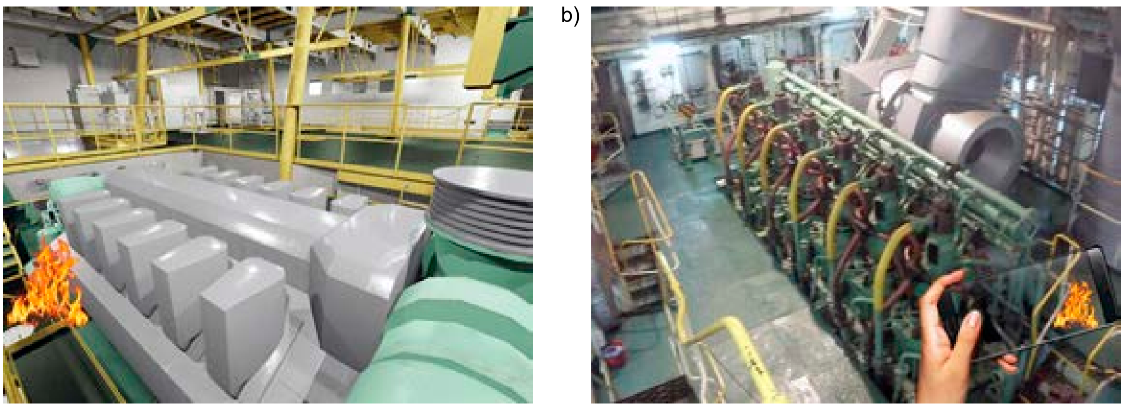

Figure 1. Virtual fire placed in a: a) VR, b) AR environment of a ship's engine room

(WoS), Scopus, and Google Scholar indexing platforms were considered for this part of the research, but the latter was omitted because it contains many non-academic sources (Martín-Martín et al., 2018). The literature review concentrated on the last decade (2011–2020) since this is the period in which VR and AR technologies emerged (Jang et al., 2019).

Many researchers have produced publications with the topic of "pedestrian evacuation" and "crowd evacuation", as shown in Figure 2. For instance, in Web of Science, there is a considerable jump in published papers, from 35 in 2011, to 277 in 2020, with the peak in 2019 of 300 papers; however, as the research presented in this paper is concerned with the use of VR and AR technology in pedestrian evacuation, this initial list of published literature was filtered using the keywords "virtual reality" or "augmented reality". This filtering significantly decreased the number of papers in Web of Science, and less than 3% of all papers dealt with these advanced technologies for pedestrian evacuation. In Scopus, this percentage was a bit higher, with almost 13% of all papers dealing with VR and AR.

Papers dealing with the topic of "pedestrian evacuation" and "crowd evacuation" were also filtered using the keyword "ship", to get insight into the research focused on ship evacuation. This search string produced just 40 (Scopus) and 28 (WoS) papers published in the last decade. If the use of VR and AR in ship evacuation was inserted into the search procedure, 11 (Scopus) and 2 (WoS) papers in the last decade were filtered.

An obvious discrepancy can be perceived between the number of papers dealing with the use of VR and AR to study pedestrian evacuation in general compared with the use of VR and AR to study the evacuation of passengers on ships. This research

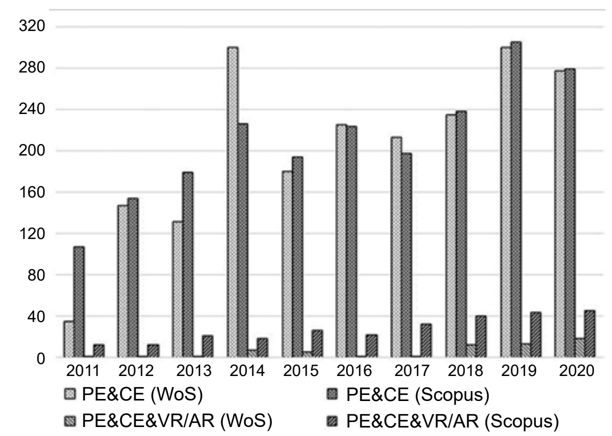

Figure 2. WoS and Scopus index records of references published in the period 2011–2020 on the topic of "pedestrian evacuation (PE)" and "crowd evacuation (CE)" with filtering using the keywords "virtual reality (VR)" and "augmented reality (AR)"

gap needs to be filled to make use of modern technologies within the specific context of the shipping industry and, eventually, to try to improve the safety of passengers on board. The following SWOT analysis serves to stress the strengths, weaknesses, opportunities, and threats standing before the implementation.

SWOT analysis

In this chapter, a qualitative discussion of VR and AR as a training and research tool in ship passenger evacuation is performed using SWOT analysis (Table 1). SWOT stands for the strengths, weaknesses, opportunities, and threats of a considered product or method (Jović et al., 2020; Skoko, Lušić & Pušić, 2020). Some features of SWOT are shared by both technologies, while some stand exclusively for VR or AR (Table 1). Strengths refer to the characteristics of the tool that give it an advantage over others,

Table 1. Comparative SWOT analysis of VR and AR technologies

		Augmented reality	
	Virtual reality		
Strengths	• Controlled environment • Safety • Full virtual immersion	• Internal validity • Replicability • Flexibility • Real-time feedback	• Ecological validity • Real-world navigation • Easy programming
Weaknesses	• Simulator sickness • Demanding programming	• Experimental validation	• Limited functionality of wearable hardware • Tracking and recognition
Opportunities	• Multi-sensor simulations • Use of wearable hardware	• Scientific opportunities • Interoperability	• Intuitive UI • Blending with evacuation procedures
Threats	• Medical side-effects	• Full validity • Misleading expectations • Ethical issues	• Privacy

while weaknesses are related to the characteristics that put it at a disadvantage relative to others. Opportunities refer to conditions in the environment that the tool could exploit to its advantage, while threats are the conditions in the environment that need to be overcome.

Shared strengths

- Internal validity refers to the extent to which a study establishes a confident cause-and-effect relationship (All, Castellar & Van Looy, 2021). Although both VR and AR offer relatively high levels of experimental control, in AR there is less possibility to control the environment in which the virtual objects are placed. In VR, it is possible to completely control the environment, allowing clear causal analysis. This should be considered when choosing one technology over another onboard a passenger ship. If AR is chosen, care must be taken to ensure that the environment intended for conducting the study is secured and free from subjects or objects that could jeopardize the outcome.
- Replicability refers to the repetition of a study using the same methods (Chard et al., 2020). Both VR and AR studies offer high replicability because similar equipment is used. VR can be recreated and replicated almost completely, while the replicability of AR depends on choosing the same or similar real-world environment. Moreover, the study setting and software can be shared using cloud computing.
- Flexibility refers to the possibility of adjustments in studies (Zhao et al., 2020). Changes, variations, and alterations in VR and AR studies can be implemented relatively easily and quickly during the investigations to account for a wide range of scenarios. This can be particularly important when performing AR studies on real passenger ships. Quick adjustments can be implemented onboard to address the challenges raised during the originally planned evacuation scenario.
- Real-time feedback refers to the precise and instantaneous monitoring of various physical parameters of the participants, e.g., heart rate and fatigue, using wearable technology (Naylor et al., 2020). When performing AR studies onboard, real-time monitoring is essential since participants can enter enclosed spaces, progress along a heeled ship, or be part of a moving crowd, all of which can provoke elevated stress on a human body.

VR strengths

- A controlled environment is a specific strength of VR because studies can be performed in a safe laboratory environment (Lv et al., 2020) on a digital twin of an actual ship. In contrast, an AR study needs to be performed in a real-world environment, on an actual ship, which can be challenging for the participants and organizers of a study.
- Since the VR studies of evacuation processes can be performed in a laboratory environment, this technology offers a higher level of safety for participants than AR (Morélot et al., 2021). If performing evacuation studies that would include the heeling or listing of a vessel, the VR setting presents a safer solution for participants.
- In VR, occupants are placed into a fully virtual environment, and all objects inside of it are digitally created, enabling full immersion into the virtual reality and eliminating the ability to perceive real surroundings (Morélot et al., 2021).

AR strengths

- Ecological validity refers to the degree of coincidence between the study methods and the real-world scenario (Lovreglio & Kinateder, 2020). The ecological validity of AR is significant because the user is immersed in a real-world environment, and a blend of virtual and real elements is relatively easy to accomplish. Also, the ecological validity of AR can be improved by adding multiple physical stimuli (e.g., olfactory and tactile).
- Real-word navigation is a specific strength of AR, as it offers a participant an experience closer to the real environment because it enhances the physical real-world environment rather than constructing a computer-generated virtual world, like in VR. This is of particular importance to operations that are conducted on a ship (Grabowski, 2015) because of the complexity of the systems, which include passengers of different abilities, professional crew, and a challenging sea environment.
- AR environments can be programmed relatively easily. For an introduction into AR, several mobile applications exist, which can be complemented with 3D objects available in commercial repositories (Bandara et al., 2020); however, for advanced and experienced users, serious knowledge of programming is necessary. Compared with VR, AR typically requires fewer 3D models.

This allows for relatively effortless implementation within real ship architecture.

Shared weaknesses

- Experimental validation refers to performing non-computational investigations to reproduce scientific findings obtained by computational methods. As the VR and AR technologies are relatively new, some form of validation is needed for the study results to be accepted; however, several studies have shown that VR and AR can improve the realism of the training (Picallo et al., 2021). A distinct weakness of the experimental validation of VR and AR in ship passenger evacuation is that onboard field experiments are demanding in terms of time, resources, and safety of participants.

VR weaknesses

- Simulator sickness is a significant weakness of VR technology because users have often reported this when participating in VR studies (Keshavarz et al., 2021). In simulations of onboard evacuation processes, this can be further emphasized if the VR setting is complemented with the ship motion simulations (Pettijohn et al., 2020).
- VR requires the creation of a full 3D environment. This type of content creation is associated with a significant workload and computer resource demand. For example, a whole ship or large sections of a ship need to be created in VR to perform the study, while AR uses the real-world environment and places digital objects over them; however, this workload can be reduced if the digital twin concept of a ship is used to build the VR environment (Mikulić & Parunov, 2019).

AR weaknesses

- The limited functionality of wearable hardware is a primary concern of AR technology. AR hardware comes in a form of wearable technologies like head-mounted displays, whose main disadvantage is that they offer a relatively small field of view (Xiong et al., 2020). If AR is used on a ship, this limited view field can endanger the participant and, if AR is used within a group of participants, limit the cooperation of the group.
- Since the user of AR technology is moving in a real environment, the AR application needs to continuously position the user and track their movement. Tracking can be accomplished via GPS sensors built into the AR devices, but GPS availability can be limited in closed spaces (Garbett, Hartley & Heesom, 2021). Another option is the use of markers placed in an environment when an AR device is continuously searching for them as reference points. A secondary challenge, the recognition of the surroundings, needs to be answered to reconstruct the shape of the environment to be able to add virtual elements. This is especially important in enclosed spaces (corridors, halls, and rooms) onboard a ship, when a user cannot rely on a GPS signal. The recognition of surroundings requires an adjusted numerical algorithm, along with powerful computing resources.

Shared opportunities

- Scientific opportunities mean that the VR and AR technologies open up new horizons for scientists and researchers. Relatively affordable equipment, open-source codes for programming, and intuitive use of existing applications and hardware open paths for future research that are not necessarily time- and resource-consuming like field investigations on ships.
- Interoperability assumes the exchange of virtual settings, environments, scenes, and/or experiments. A significant amount of time and resources can be spared when research teams deal with VR and AR technologies to share their achievements through exchange platforms or cloud computing (Khan et al., 2021).

VR opportunities

- Multi-sensor simulations provide the opportunity to incorporate stimuli beyond visual and auditory stimuli. In a safe laboratory environment in which VR studies can be performed, additional stimuli can be added, e.g., tactile, olfactory, thermoceptive (Kang, Sah & Lee, 2021). Adding heat as an element to study fire rescue procedures could help achieve a better blend of VR environments and actual settings.
- In VR, virtual content is typically shown via stereoscopic displays in the form of large screens, wall projections, or wearable hardware (e.g., head-mounted displays). The use of wearable hardware can significantly improve the user experience, especially with the use of intuitive user interfaces (Ameen, Hosany & Tarhini, 2021). This allows for free motion and better

interaction of participants moving along the VR ship environment.

AR opportunities

- AR systems nowadays offer user interactions via hand gestures, voice commands, or input devices. Hand gestures need to be easy and intuitive to perform, while also precise enough so that the system can interpret the user input appropriately (Kyriazakos & Moustakas, 2016). Voice commands promise complete hands-free navigation and interaction with the device, but challenges in speech recognition remain. Input devices can be paired with AR systems to ensure the direct and correct transmission of input signals and to allow for a wider and more flexible range of input opportunities.
- As for the blending of AR with evacuation rescue procedures, training can be performed using AR navigation and tracking elements placed over a real-world video feed (Goldiez, Ahmad & Hancock, 2007). Various scenarios can be developed to train rescue crews in emergency situations involving fire or smoke in enclosed spaces (Xu et al., 2014), such as on a ship. In general, a comparison of experiments performed using AR technologies with field or laboratory experiments (Haghani, 2020a) and real case studies (Haghani, 2020b) show that the real-life behavior of people can be relatively accurately tested and observed using AR technologies.

Shared threats

- The biggest threat to VR and AR as a research tool is the failure to demonstrate their validity. These new technologies can prove useful only in case they are comparable to what might be expected in a real-world environment (Duarte, Rebelo & Wogalter, 2010). As the technologies are developing, and new applications are still being discovered, systematic validation has still not been performed; therefore, future studies will be necessary, especially in a complex system like passenger ships.
- VR and AR are emerging technologies, and users must be aware of their limitations, some of which have been discussed here. Otherwise, misleading expectations could be built on the side of participants (Alamäki, Dirin & Suomala, 2021) and also the funders of the study. This is important for when these new technologies are to be introduced to the shipping industry so that they do not fail to meet the expectations of the shipping companies, which may cause a loss of interest in a technology with great potential.
- Even though most participants are aware that no serious threat comes from virtual hazards in VR and AR, some may still experience discomfort (Royakkers et al., 2018). Long-term consequences should be avoided, e.g., traumatization or fear. Care must be taken to eliminate participants that cannot differentiate between virtual and real-world environments.

VR threats

- Care must be taken to avoid the development of medical side-effects for participants suffering from pre-existing medical conditions. In relation to the already-elaborated motion sickness in VR, virtual reality can cause specific phobias (of enclosed spaces, heights, etc.). On the other hand, researchers have reported studies where exposure to a controlled VR environment helps overcome specific phobias (Malbos, Burgess & Lançon, 2020).

AR threats

- AR devices can be used to measure, store, and share user-specific biometric data, which raises concerns over privacy and security (Ameen, Hosany & Tarhini, 2021). In order to establish trust in this technology, a protocol must be defined to determine how the data will be collected, stored, and shared.

Discussion

A major specific strength of VR is the fully-immersive environment, while a major strength of AR is real-world navigation. The major shared weakness of both technologies is experimental validation. These features lead to answers to the question: What can(not) we study using VR and AR technologies?

VR and AR can be used to design complex study cases of passenger evacuation, allowing evacuation scenarios to be designed in detail. They allow studying how pedestrians react to fire, smoke, or flood, and behavioral data can be monitored and collected. What sets VR apart from AR is the fact that VR can be used to study evacuation scenarios even before a new ship has been built. That way, VR allows the identification of potentially challenging evacuation routes in the project stage of a new ship. AR, on the other hand, can be more successfully employed in training exercises for passengers and crew as it offers high levels of virtual content immersion in real-world surroundings. Further research should concentrate on applying VR technologies in the design stage of developing a new passenger ship and applying AR in exercise routines on board.

It is important to bear in mind that virtual and augmented reality are not reality. Occupants will, to a greater or lesser extent, be aware that they are in an artificial environment. That means that only observations from real events (to a greater extent) and unannounced drills (to a lesser extent) can provide insight into the reactions of occupants in stressful situations. This is the already-mentioned major weakness of the technologies, in which the obtained findings must be validated experimentally. That, however, doesn't limit the use of VR and AR in the field of ship passenger evacuation. The public is especially sensitive to maritime accidents and crises (Gračan & Agbaba, 2021), so the cruise industry does everything it can to ensure the safety of its passengers (Vassalos & Paterson, 2021). These new technologies now offer the possibility to act as a complementary means to study evacuations and have prospects to take the lead in the field in the future.

Conclusions

The relatively small number of publications on VR and AR in evacuation modelling shows that these technologies are still not widely adopted; however, the ever-increasing number of publications in the last decade suggests that the topic has the interest of researchers. To date, VR and AR are commonly used for evacuation training in buildings and open spaces. Their application to improve ship evacuation procedures has not been investigated to the same extent.

SWOT analysis of VR and AR in the cruise ship industry shows that the strengths and opportunities outweigh their weaknesses and threats. A number of shared strengths and opportunities implies the similarity and interchangeability of both technologies. Specific features that distinguish them, however, exist, and they are based mostly on the way in which the virtuality is perceived and what type of hardware is used. The development of wearable technology that will put VR and AR in the hands of a single user is the biggest opportunity for the industry.

VR and AR can be used to model practically every parameter of the advanced evacuation analysis of a ship. The layout of the escape routes can be relatively easily altered. Age, gender, physical attributes, and response durations of the passengers can be altered artificially. Static and dynamic conditions of the ship that influence the passengers' moving speed can also be modified. A great advantage is that studies can be performed without any actual danger to the participants. It is expected that the number of cruise ships will increase (Oniszczuk-Jastrząbek & Czermański, 2019), and the results obtained by using these technologies (Vukelic, Vizentin & Francic, 2021) can be used in the modern ship design process (Szelangiewicz & Żelazny, 2020), to improve safety procedures (Łozowicka, 2012a), or even for post-accident analysis (Bayazit, Toz & Buber, 2020).

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References

1. Alamäki, A., Dirin, A. & Suomala, J. (2021) Students' expectations and social media sharing in adopting augmented reality. *International Journal of Information and Learning Technology* 38(2), pp. 196–208.
2. All, A., Castellar, E.N.P. & Van Looy, J. (2021) Digital Game-Based Learning effectiveness assessment: Reflections on study design. *Computers and Education* 167, 104160, doi: 10.1016/j.compedu.2021.104160.
3. Ameen, N., Hosany, S. & Tarhini, A. (2021) Consumer interaction with cutting-edge technologies: Implications for future research. *Computers in Human Behavior* 120, 106761, doi: 10.1016/j.chb.2021.106761.
4. Bandara, D., Woodward, M., Chin, C. & Jiang, D. (2020) Augmented reality lights for compromised visibility navigation. *Journal of Marine Science and Engineering* 8(12), 1014, doi: 10.3390/jmse8121014.
5. Bayazit, O., Toz, A.C. & Buber, M. (2020) Spatial distribution analysis of ship accidents in the Canakkale Strait. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie*, 62(134), pp. 9–17, doi: 10.17402/414.
6. Carmigniani, J., Furht, B., Anisetti, M., Ceravolo, P., Damiani, E. & Ivkovic, M. (2011) Augmented reality technologies, systems and applications. *Multimedia Tools and Applications* 51(1), pp. 341–377, doi: 10.1007/s11042-010-0660-6.
7. Chard, K., Gaffney, N., Hategan, M., Kowalik, K., Ludäscher, B., McPhillips, T., Nabrzyski, J., Stodden, V., Taylor, I., Thelen, T., Turk, M.J. & Willis, C. (2020) Toward enabling reproducibility for data-intensive research using the whole tale platform. In *Advances in Parallel Computing*, IOS Press BV, pp. 766–778, doi: 10.3233/APC200107.

8. Duarte, E., Rebelo, F. & Wogalter, M.S. (2010) Virtual Reality and its potential for evaluating warning compliance. *Human Factors and Ergonomics in Manufacturing & Service Industries* 20(6), pp. 526–537, doi: 10.1002/hfm.20242.
9. Garbett, J., Hartley, T. & Heesom, D. (2021) A multi-user collaborative BIM-AR system to support design and construction. *Automation in Construction* 122, 103487, doi: 10.1016/j.autcon.2020.103487.
10. Goldiez, B.F., Ahmad, A.M. & Hancock, P.A. (2007) Effects of augmented reality display settings on human wayfinding performance. *IEEE Transactions on Systems, Man and Cybernetics Part C: Applications and Reviews* 37(5), pp. 839–845, doi: 10.1109/TSMCC.2007.900665.
11. Grabowski, M. (2015) Research on wearable, immersive augmented reality (WIAR) adoption in maritime navigation. *Journal of Navigation* 68(3), pp. 453–464. doi: 10.1017/S0373463314000873.
12. Gračan, D. & Agbaba, R. (2021) Analysis of crisis situations in nautical tourism. *Scientific Journal of Maritime Research* (*Pomorstvo*) 35(1), pp. 16–22, doi: 10.31217/P.35.1.2.
13. Haghani, M. (2020a) Empirical methods in pedestrian, crowd and evacuation dynamics: Part I. Experimental methods and emerging topics. *Safety Science* 129, 104743, doi: 10.1016/j.ssci.2020.104743.
14. Haghani, M. (2020b) Empirical methods in pedestrian, crowd and evacuation dynamics: Part II. Field methods and controversial topics. *Safety Science* 129, 104760, doi: 10.1016/j.ssci.2020.104760.
15. Jang, H.J., Lee, J.Y., Kwak, J., Lee, D., Park, J.-H., Lee, B. & Noh, Y.Y. (2019) Progress of display performances: AR, VR, QLED, OLED, and TFT. *Journal of Information Display* 20(1), pp. 1–8. doi: 10.1080/15980316.2019.1572662.
16. Jović, M., Tijan, E., Perić Hadžić, A. & Karanikić, P. (2020) Economic aspects of automation innovations in electronic transportation management systems. *Scientific Journal of Maritime Research* (*Pomorstvo*) 34(2), pp. 417–427, doi: 10.31217/p.34.2.22.
17. Kang, N., Sah, Y.J. & Lee, S. (2021) Effects of visual and auditory cues on haptic illusions for active and passive touches in mixed reality. *International Journal of Human Computer Studies* 150, 102613, doi: 10.1016/j.ijhcs.2021.102613.
18. Keshavarz, B., Murovec, B., Mohanathas, N. & Golding, J.F. (2021) The Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ): Estimating Individual Susceptibility to Motion Sickness-Like Symptoms When Using Visual Devices. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 1872082110086, doi: 10.1177/00187208211008687.
19. Khan, T., Sohail, A., Qureshi, K.N., Iqbal, S. & Jeon, G. (2021) Multipath transport control protocol for 5G mobile augmented reality networks. *International Journal of Communication Systems* e4778, doi: 10.1002/dac.4778.
20. Kyriazakos, V. & Moustakas, K. (2016) A User-Perspective View for Mobile AR Systems Using Discrete Depth Segmentation. In *Proceedings – 2015 International Conference on Cyberworlds, CW 2015*, pp. 69–72. doi: 10.1109/CW.2015.67.
21. Lovreglio, R. & Kinateder, M. (2020) Augmented reality for pedestrian evacuation research: Promises and limitations. *Safety Science* 128, 104750, doi: 10.1016/j.ssci.2020.104750.
22. Lozowicka, D. & Kaup, M. (2017) Analysis of the Possibility of Safe Evacuation of Passengers from a Ship Moored in the River-Sea Port Szczecin. *Naval Engineers Journal* 129(3), pp. 117–124.
23. Lv, Z., Chen, D., Lou, R. & Song, H. (2020) Industrial Security Solution for Virtual Reality. *IEEE Internet of Things Journal* 8(8), pp. 6273–6281, doi: 10.1109/jiot.2020.3004469.
24. Łozowicka, D. (2012a) Organization of evacuation from passenger ships – a concept of safety enhancement. *Scientific Journals Maritime University of Szczecin, Zeszyty Naukowe Akademia Morska w Szczecinie* 32 (104), z. 2, pp. 110–114.
25. Łozowicka, D. (2012b) Using genetic algorithms and genetic programming in solving problems related to safety and evacuation of people from ships and land facilities. *Scientific Journals Maritime University of Szczecin, Zeszyty Naukowe Akademia Morska w Szczecinie* 29 (101), pp. 130–133.
26. Łozowicka, D. (2019) The Development of Methods For Effective Evacuation From the Ship Using Graph Theory and Optimization. *Naval Engineers Journal* 131(1), pp. 83–92.
27. Łozowicka, D. (2021) The design of the arrangement of evacuation routes on a passenger ship using the method of genetic algorithms. *PLoS ONE* 16(8), e0255993, doi: 10.1371/journal.pone.0255993.
28. Malbos, E., Burgess, G.H. & Lançon, C. (2020) Virtual Reality and Fear of Shark Attack: A Case Study for the Treatment of Squalophobia. *Clinical Case Studies* 19(5), pp. 339–354, doi: 10.1177/1534650120940014.
29. Martín-Martín, A., Orduna-Malea, E., Thelwall, M. & López-Cózar, E.D. (2018) Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *Journal of Informetrics* 12(4), pp. 1160–1177, doi: 10.1016/j.joi.2018.09.002.
30. Mikulić, A. & Parunov, J. (2019) A review of artificial intelligence applications in ship structures. In *Trends in the Analysis and Design of Marine Structures – Proceedings of the 7th International Conference on Marine Structures, MARSTRUCT 2019*, pp. 515–523, doi: 10.1201/9780429298875-59.
31. Milgram, P. & Kishino, F. (1994) A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems* E77-D, 12, pp. 1321–1329.
32. Miyagawa, D. & Ichinose, G. (2020) Cellular automaton model with turning behavior in crowd evacuation. *Physica A: Statistical Mechanics and its Applications* 549, 124376, doi: 10.1016/j.physa.2020.124376.
33. Morélot, S., Garrigou, A., Dedieu, J & N'Kaoua, B. (2021) Virtual reality for fire safety training: Influence of immersion and sense of presence on conceptual and procedural acquisition. *Computers & Education* 166, 104145, doi: 10.1016/j.compedu.2021.104145.
34. Naylor, M., Morrison, B., Ridout, B. & Campbell, A. (2020) Augmented experiences: Investigating the feasibility of virtual reality as part of a workplace wellbeing intervention. *Interacting with Computers* 31(5), pp. 507–523, doi: 10.1093/iwc/iwz033.
35. Oniszczuk-Jastrząbek, A. & Czermański, E. (2019) Global trends in maritime cruise fleet development. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 60 (132), pp. 154–160, doi: 10.17402/384.
36. Pettijohn, K.A., Peltier, C., Lukos, J.R., Norris, J.N. & Biggs, A.T. (2020) Virtual and augmented reality in a simulated naval engagement: Preliminary comparisons of simulator sickness and human performance. *Applied Ergonomics* 89, 103200, doi: 10.1016/j.apergo.2020.103200.

37. Picallo, I., Vidal-Balea, A., Blanco-Novoa, O., Lopez-Iturri, P., Fraga-Lamas, P., Klaina, H., Fernández-Caramés, T.M., Azpilicueta, L. & Falcone, F. (2021) Design and Experimental Validation of an Augmented Reality System with Wireless Integration for Context Aware Enhanced Show Experience in Auditoriums. *IEEE Access* 9, pp. 5466–5484, doi: 10.1109/access.2020. 3048203.
38. Rizzo, A. & Kim, G.J. (2005) A SWOT analysis of the field of virtual reality rehabilitation and therapy. *Presence: Teleoperators and Virtual Environments* 14(2), pp. 119–146, doi: 10.1162/1054746053967094.
39. Royakkers, L., Timmer, J., Kool, L. & van Est, R. (2018) Societal and ethical issues of digitization. *Ethics and Information Technology* 20, pp. 127–142, doi: 10.1007/s10676-018-9452-x.
40. Skoko, I., Lušić, Z. & Pušić, D. (2020) Commercial and strategic aspects of the offshore vessels market. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 62 (134), pp. 18–25, doi: 10.17402/415.
41. Szelangiewicz, T. & Żelazny, K. (2020) Unmanned ships – maritime transport of the 21st century. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 64 (136), pp. 14–21, doi: 10.17402/449.
42. Vassalos, D. & Paterson, D. (2021) Towards unsinkable ships. *Ocean Engineering* 232, 109096, doi: 10.1016/j.oceaneng.2021.109096.
43. Vukelic, G., Vizentin, G. & Frančić, V. (2021) Prospects for use of extended reality technology for ship passenger evacuation simulation. *Scientific Journal of Maritime Research* (*Pomorstvo*) 35(1), pp. 49–56, doi: 10.31217/p.35.1.6.
44. Xiong, J., Tan, G., Zhan, T. & Wu, S.-T. (2020) Breaking the field-of-view limit in augmented reality with a scanning waveguide display. *OSA Continuum* 3(10), 2730, doi: 10.1364/osac.400900.
45. Xu, Z., Lu, X.Z., Guan, H., Chen, C. & Ren, A.Z. (2014) A virtual reality based fire training simulator with smoke hazard assessment capacity. *Advances in Engineering Software* 68, pp. 1–8, doi: 10.1016/j.advengsoft.2013.10.004.
46. Zhao, X., Liu, C., Xu, Z., Zhang, L. & Zhang, R. (2020) SSVEP Stimulus Layout Effect on Accuracy of Brain-Computer Interfaces in Augmented Reality Glasses. *IEEE Access* 8, pp. 5990–5998, doi: 10.1109/access.2019.2963442.

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