



Making Virtual Reality (VR)/Augmented Reality (AR) Possible to Strengthen Disaster Risk Reduction among Communities at Risk of Tsunami

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Abstract

This paper aims to seek a deeper understanding of the intention to use Virtual Reality (VR)/ Augmented Reality (AR) to strengthen disaster risk reduction using the technology acceptance model (TAM) among people at risk of a tsunami. Kuta, Bali, Indonesia, was selected as a case study due to its high tsunami risk and dense tourism activities. Data is collected by interviewing 148 households living along the coast who were selected purposively based on the hazard map of the tsunami and the location of tsunami drills in the past, including the proportion of migrants and non-migrants. Studies show that technology is needed to better prepare for future tsunami risks. Despite having experience in tsunami drills, understanding evacuation routes still needs to improve. People perceived VR/AR could provide integrated knowledge and information about tsunamis, including evacuation routes and shelters. Moreover, the VR/AR technology is also perceived to complement existing knowledge and information about coastal protection generated from ecosystem services. The result shows that the intention to use VR/AR is described by the perceived usefulness and perceived ease of use. Significant differences appear among different age groups and are not merely based on migrant's status. This study has an essential impact on policymakers, particularly in proposing the implementation of VR/AR to plan disaster risk reduction effectively.

Keywords: VR/AR; tsunami; community resilience; disaster risk reduction; technology acceptance model.

Introduction

The use of advanced technology, namely Virtual Reality (VR) and Augmented Reality (AR), to strengthen disaster management, particularly in the area of built environments, has increased in recent decades (Zhu & Li, 2021). VR technology is an application of a virtual environment that simulates physical objects. In contrast, the technology of AR consists of a real environment that can interactively respond to the user Field (Anderson et al., 2021) and has been used for disaster prevention, evacuation preparedness, disaster emergency and post-recovery (Khanal et al., 2022; Ruggiero, 2018). The evacuation drills using VR can offer various scenarios and evacuation simulations to prepare a better response to disaster (Sharma et al., 2014). The technology of VR can manage integrative data from various sources and effectively support during emergencies (Lai et al., 2012). Moreover, VR provides interactive techniques to support disaster simulations, training response and recovery, and public awareness (Brown et al., 2023; García et al., 2021).

The experience of using VR tools can improve perceptions of risk, help people understand how to carry out coping strategies, recognise emotions that arise during disasters, and support the formation of behaviour to make



investments in reducing disaster risk (Mol et al., 2022). Risk perception is important to frame people's readiness and preparation to face disaster. Sendai framework 2015-2030 highlights the priority of risk reduction investment. The study shows that the closer to the experience, the more the people decide to invest to reduce risk (Mol et al., 2022). Still, more research is needed to determine how well users embrace this immersive technology, particularly regarding reducing disaster risk (Khanal et al., 2022). The use of advanced technology in VR/AR is currently growing in developing countries following the various utilisations in developed countries (Cipresso et al., 2018). The early uses of VR technology are mainly among the prominent investors' big companies (Cipresso et al., 2018). The primary inquiry concerns the optimal strategies for successfully integrating cutting-edge technology inside vulnerable communities in emerging and underdeveloped nations (Angus et al., 2004; Mehrabi et al., 2021). These communities have limited access to and capability for creating virtual reality (VR) and augmented reality (AR) technologies, which are crucial for enhancing catastrophe risk reduction efforts.

A series of studies have shown the advantages of VR/AR in enhancing the efficacy of disaster evacuation simulations, early warning systems, and post-disaster recovery efforts (see Khanal et al., 2022; Velev et al., 2019). The technology bridges the disparity between information and real-life occurrences by offering consumers immersive and engaging experiences through simulations that closely resemble reality (Franchi, 1994). We argue that accepting VR/AR technology is necessary to support decision-makers and related stakeholders in investing in technology for risk reduction programs. This study investigates the potential for integrating virtual reality (VR) and augmented reality (AR) technologies inside communities in high-risk tsunami areas where access to modern technological resources is limited. Our argument posits that the efficacy of technology is contingent not only upon its capacity to be provided but also upon the acceptance of Individuals to utilise technology. This acceptance is influenced by their perception of the necessity to employ technology and its effectiveness in mitigating risk (Davis, 1989). Hence, our research investigates individuals' inclination to utilise technology before engaging in simulated practical activities.

This paper aims to understand the importance of utilising technology to reduce the risk of tsunamis and examine people's intention to use it based on their perception of the usefulness and ease of using VR/AR technology. This study examines the significance of modifying behaviours before adopting VR/AR to raise awareness of the risk of tsunamis. The introduction of advanced technology to local communities' respect for local practices and behaviours (Fong & Harris, 2015). This study considers the existing local initiatives of mangrove conservation to enhance the understanding of the need for technology in building coastal resilience. We employ a framework based on the Technology Acceptance Model (TAM) proposed by Fred D. Davis in 1989. It aims to gain insights into the factors influencing the intention to use VR/AR, particularly among those considered at risk (Davis, 1989). The TAM has been investigated to predict attitudes and satisfaction in an effective way (Al-Gahtani & King, 1999). An extensive study that applies Davis's framework shows a different contribution of both variables. In activating intention to use, perceived usefulness was significantly influenced compared with perceived ease of use (Sagnier et al., 2020). The pragmatic quality complements the perceived ease of use.

The research location of Kuta was selected due to its status as a region with a high risk of tsunamis (Wegscheider et al., 2011) and its historical significance as the site of the deployment of the Indonesian Tsunami Early Warning System (InaTews) in 2009 (Spahn et al., 2014). Moreover, the Kuta district is also known as one of the famous tourism destinations in Bali (Sunarta et al., 2021). This research employs a quantitative data-gathering method by interviewing 148 families residing within the District of Kuta. Respondents were selected based on purposive sampling procedures. We consider the distance to the coast, the migrant's status, and the distance to the mangrove conservation areas.

This paper is organised accordingly. In the introduction, we outline the importance of understanding the technology acceptance model to introduce VR/AR technology in disaster risk reduction. In section 2, we review

the role of VR/AR technology and the application of the TAM model. Section 3 describes the methodology, including the data collection and analysis procedure. The results and discussion part are presented in section 4. In the final section, we outline our conclusion and policy recommendation to introduce and apply VR/AR technology in Bali and Indonesia's case in a broader context.

Literature Review

The Role of VR/AR

Virtual Reality (VR) combines technologies that immerse the user in a simulated 3D digital environment, allowing them to interact with the environment and other users. In a VR simulation, players can communicate, move around, perform actions, operate machinery, drive vehicles, and interact with objects, events, and other players in real time in a digital environment that resembles reality. Players can see each other and their actions and respond accordingly. The simulation can be monitored by "masters" who can remotely observe the operators' actions, create localised events, or introduce new challenges (Chau, 1996). Augmented Reality (AR), on the other hand, is a combination of technologies that enhance reality in the real world. AR can provide additional information about an object, guide the user along a path, design systems within a specific spatial context, or view the profile of a remote person as if they were in the same environment as the user.

VR/AR technology development for community resilience needs to be improved. Despite this, AR technology has seen a surge in global interest across various sectors such as healthcare, retail, digital marketing, education, and disaster risk reduction (Azuma et al., 2001; Wu et al., 2018). In 2020, research showed that investment in AR and VR applications reached \$12 billion and is projected to increase to \$72.8 billion by 2024. Augmented reality is a real-world context overlaid with virtual information sensitive to location or context. As identified, three key characteristics distinguish AR learning systems from others. The first is the combination of virtual and real objects in a natural environment. The second is the interactive and simultaneous use of human resources. The third is the degree of alignment and compatibility between real and virtual objects. In other words, AR applications can interact with virtual objects and the physical environment, helping students actively engage in the learning process (Benssam et al., 2016; Carby, 2018).

The various advantages inherent in virtual reality (VR) and augmented reality (AR) confer several benefits for the field of disaster risk management, particularly in the realm of disaster training as a supplementary approach to conventional simulation methodologies (Brown et al., 2023). The use of virtual reality (VR) and augmented reality (AR) technologies has the potential to enhance the decision-making process in emergencies by mitigating cognitive interpretation and prejudice among users, specifically in the realm of information interpretation (Chen & Truc, 2008). Virtual reality (VR) and augmented reality (AR) have the potential to mitigate perceived risks due to their near similarities to real-life events. However, the usefulness of technology is contingent upon the level of acceptance and intention to utilise it (Alimamy et al., 2018).

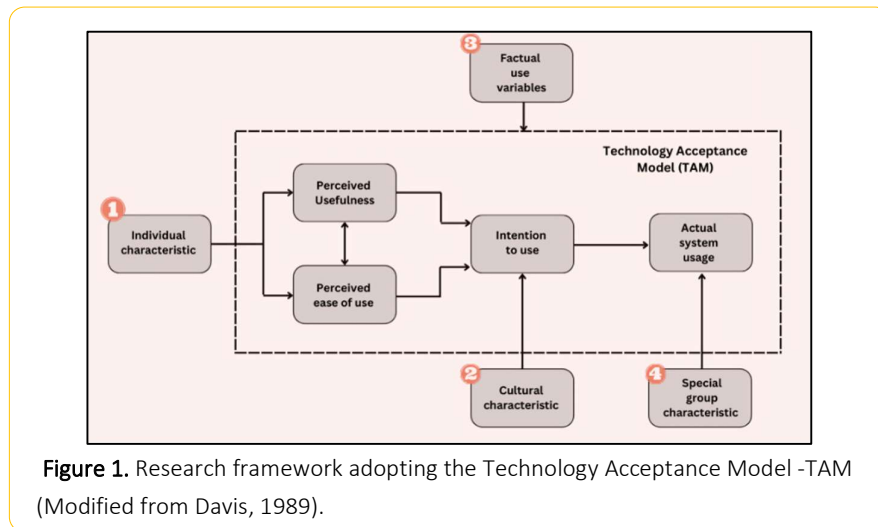
The Role of TAM

Adopting technology is the first indicator of an individual's intention to utilise it. The measure to predict the adoption of computers was first devised by Davis, who identified two primary variables: perceived utility and perceived ease of use. The present study posits and provides empirical evidence for the significance of perceived utility and perceived usability as primary factors influencing user adoption of a novel technology under the Technology Acceptance Model (TAM) (Davis, 1989).

Multiple scale measurements have been identified in the literature, highlighting the benefits and drawbacks of such measures (Davis, 1989; Klopfer & Squire, 2008; Schwambach et al., 2022). The value of the Technology Acceptance Model (TAM) lies in its exact methodology for describing the application of technology to user communities. On the other hand, a limitation of this method is its inability to elucidate the dynamics of behavioural changes, particularly the anticipated alterations in habits following the implementation of

technology. The Technology Acceptance Model (TAM) 's primary emphasis is the alignment between technology and users, which is determined by their knowledge and facilitates the decision-making process in the technology adoption (Baaren et al., 2011). Hence, the Technology Acceptance Model (TAM) provides a framework for evaluating technology's efficacy in disaster risk management, as evidenced by earlier studies (Benssam et al., 2016; Rialti et al., 2022).

The choice of a person to accept and utilise the information offered by technology is influenced by the impression of the user's resources (Mathieson et al., 2001). The level of trust affects the adoption of developing technologies for digital rights management (DRM) (Mathieson et al., 2001). The influence of demographic features, justice, and inclusion on the Technology Acceptance Model (TAM) is significant. Asserts that incorporating inclusion and integration is paramount in utilising technology for disaster risk reduction (DRR) (Carby, 2018).



Framework of Research

Virtual reality (VR) has many applications, yet fewer studies have been conducted on how people adopt this immersive technology, specifically concerning mitigating catastrophe risks. We propose expanding the Technology Acceptance Model (TAM) to incorporate supplementary factors particular to virtual reality (VR) technology.

Prior research has placed significant emphasis on the utilisation of virtual reality and augmented reality (VR/AR) technologies, as evidenced by the works of previous studies (Ordaz et al., 2015; Tüzün & Özdiñç, 2016). However, there is a need for more studies that employ the Technology Acceptance Model (TAM) framework, as initially proposed by Davis (1989), to investigate the acceptance and adoption of VR technology. Few researchers who have employed the TAM framework examined VR technology. However, these studies have limitations in their exploration of the characteristics of potential beneficiaries within the Technology Acceptance Model (TAM) framework.

Several adjustments will be made to adopting the Technology Acceptance Model (TAM) framework for this study. This article employs external elements, precisely demographic background, to enhance the comprehensiveness and depth of information on technological acceptance. The sample will include categories of vulnerable groups such as the elderly and disabled, as Field Basak et al. (2008) and Charness & Boot (2009) mentioned. The information on disabilities is explored through in-depth interviews with the local community. The variable of migrants' status is chosen as an additional variable regarding the uniqueness of local customs that only apply to

Balinese people. The customs play several aspects in the lives of local people that will influence their decision-making process.

Methods

With its positivist nature, this study used a quantitative research approach to test its model and confirm its main hypotheses combined with the qualitative approach through semi-structured interviews with selected local leaders and residents. Quantitative data was collected through a questionnaire survey (Bhattacharjee & Premkumar, 2004). This study was conducted using face-to-face structured interviews in Kuta Sub-District, Bali Province, Indonesia, from May to June 2023. A proposed virtual reality and augmented reality acceptance model was developed to examine the factors explaining household opportunities to implement VR/AR in communities that live at risk of tsunamis but have limited access to advanced technology. A questionnaire was used to be filled out by the head of the household or household member older than 18+ years of age. The following subsections present the study's sample, the questionnaire, the data collection, and the analysis procedure.

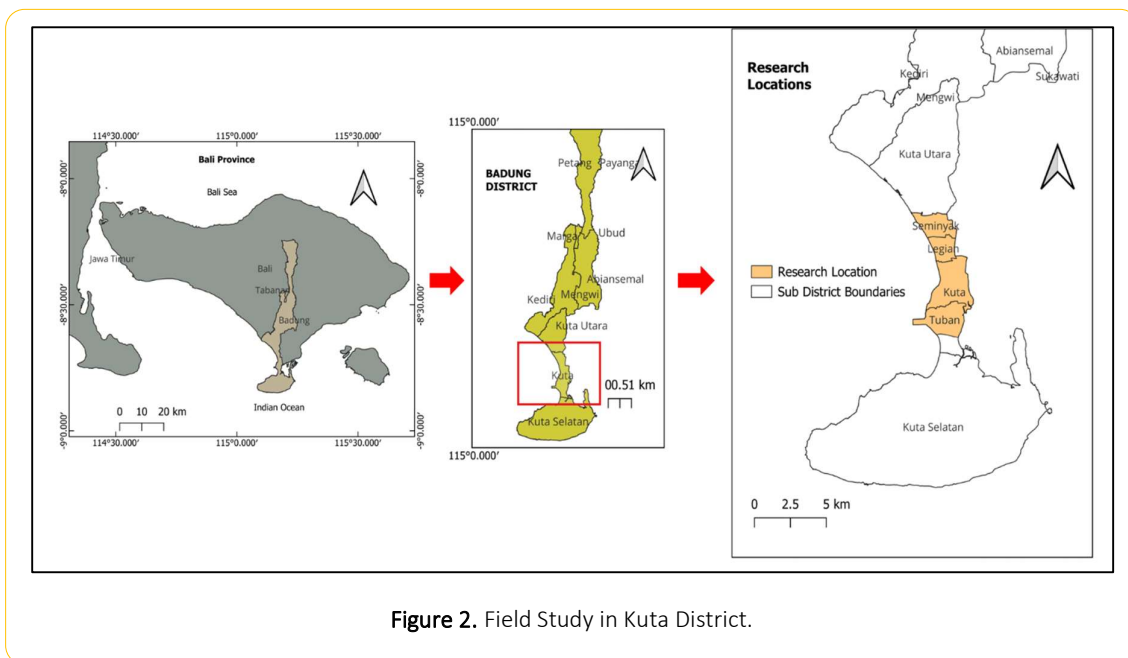


Figure 2. Field Study in Kuta District.

This study surveyed 159 households in Kuta Sub-District during May-June 2023. Respondents were members of four villages within the sub-district: Kuta, Legian, Seminyak, and Tuban (Figure 2). Respondents were selected using non-probability sampling, a combination of purposive and snowball sampling. The study area is designated as a tsunami "red" zone by the National Disaster Risk Reduction Agency (BNPB). A worst-case tsunami scenario for Kuta (Bali) could result in 25,000 casualties with optimal response time and 120,000 deaths with minimal response time (Post et al., 2009). Interviews to fill out the questionnaire took approximately 90 minutes. Due to religious ceremonies, some interviews were conducted twice to ensure the questionnaire was completed. The Survey Monkey platform was used to administer and digitalise survey data. After conducting data pre-processing, a total of 148 households were analysed. These numbers only include households with the complete information on all variables used for analysis in this paper. The participants were members of a household. Most of the respondents were living in Kuta as a household's head or partner. The median age of respondents is 39.5 years. The other socio-demographic characteristics of respondents are presented in Table 1.

Instrument

The research questionnaire was developed in Bahasa Indonesia based on validated items from prior Technology Acceptance Model (TAM) studies. Some minor modifications were made to suit the specific context of our

research focused on the AR/VR (Schwambach et al., 2022). The questionnaire comprised five sections. The initial section gathered demographic information, including gender, age, occupation, and duration of residency in the area. The second section consisted of 16 items to assess disaster knowledge and awareness.

The third section explored participants' perceptions of technology's role in disaster risk reduction. All responses were measured on a Likert scale, ranging from 1 (strongly agree) to 5 (strongly disagree). The fourth section focused on participants' familiarity with VR/AR technology and their intentions to use it. Subsequently, the fifth section gauged the perceived benefits of employing VR/AR technology.

Analysis

Initially, data from the survey questionnaire was digitalised using the SurveyMonkey platform. The dataset from the SurveyMonkey platform was downloaded and conducted data cleaning and recoding. After the dataset was ready, all variables used for this study were generated. This study has two types of variables according to the TAM framework, described in the Framework Research section: exogenous and endogenous variables. Exogenous variable respondents' characteristics including age (in years), sex (female, male), education (primary or below, secondary, higher), migrant status (non-migrant, migrant), Place attachment: the house is close to coast/sea (no, yes), experience to join tsunami drill (no, yes), earthquake experience (no, yes), knowledge on tsunami (no, yes), knowledge on the role of mangrove to protect the coast. Knowledge of tsunamis represented individuals who knew Bali had experienced tsunamis. Other variables were measured using standard items. The summary statistics are shown in Table 1.

Table 1. Respondents' characteristics.

Total (n = 148)	
Village	
Kuta	81 (54.73%)
Legian	17 (11.49%)
Seminyak	29 (19.59%)
Tuban	21 (14.19%)
Respondent relation status in household	
Household's head	43 (29.05%)
Partner	54 (36.49%)
Son/daughter	45 (30.41%)
Others	6 (4.05%)
Age (in years)	
Mean (SD)	38.3 (13.5)
Median (IQR)	39.5 (23.0)
Range	18.0 - 73.0
Sex	
Female	63 (42.57%)
Male	85 (57.43%)
Education	
Primary or bellow	14 (9.46%)
Secondary	114 (77.03%)
Higher	20 (13.51%)
Migrant status	
Non-migrant	84 (56.76%)

Total (n = 148)	
Migrant	64 (43.24%)
Place attachment : house is closed to coast/sea	
No	8 (5.41%)
Yes	140 (94.59%)
Experience to join tsunami drill	
No	133 (89.86%)
Yes	15 (10.14%)
Experience to earthquake	
No	80 (54.05%)
Yes	68 (45.95%)

Perception of the importance of utilisation of technology for evacuation (emergency response), perception of the importance of utilisation of technology for coastal protection, Perception of usefulness, and intention to use VR/AR are endogenous variables measured using a scale of items. These variables were measured using a 5 Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree) and aggregated by the mean score of items (see Table 3 in the Appendix for the details of the measurement items). Therefore, a more excellent value indicates a higher (better) perception or intention. For variables measured using multiple items (item > 1), internal consistency was assessed using Cronbach's alpha (Alpha) values (see Table 2), and the values are above the minimal criteria, 0.6 (Robinson et al., 1991).

Table 2. Summary for variables constructed using a scale of items

Variables/Statistics	Values
Perception on the importance of utilisation of technology for evacuation (emergency response)	
n items (Alpha)	3 (0.88)
Mean (SD)	4.51 (0.66)
Range	2 – 5
Perception on the importance of utilisation of technology for coastal protection through mangrove conservation	
n items (Alpha)	2 (0.89)
Mean (SD)	4.45 (0.64)
Range	2 – 5
Perception on usefulness	
n items (Alpha)	5 (0.91)
Mean (SD)	4.38 (0.67)
Range	2 – 5
Perception on ease to use	
n items (Alpha)	3 (0.67)
Mean (SD)	3.54 (0.7)
Range	2 – 5
Intention to use	
n items (Alpha)	3 (0.79)
Mean (SD)	4.19 (0.73)
Range	2 – 5

Variables/Statistics	Values
Knowledge on the role of mangrove to protect the coast	
n items (Alpha)	1 (NA) ^a
Mean (SD)	4.59 (0.59)
Range	2 – 5

^aNA: Cronbach's alpha not applicable for single item; n items is number of items.

Univariable ordinary least square (OLS) regression model was performed to assess the relationship between respondents' characteristics and perception of VR/AR and intention to use VR/AR. The univariable means that we estimated a simple OLS model for each pair between the exogenous variable (e.g. respondents' characteristics) and the endogenous variables (e.g., perception of VR/AR, intention to use VR/AR) as model specification. Since the survey for collecting data was a cross-sectional design, the estimated regression coefficient is equivalent to the correlation for the continuous independent variable and the difference in the mean score of endogenous variables for the categorical independent variable (correlation analysis and independent sample t-test). The result of these approaches represents the association between two variables. Therefore, two variables are associated if the estimated regression coefficient is statistically significant. A robust standard error Field (Zeileis, 2004) was employed for hypothesis testing of the estimated regression coefficient to obtain a robust statistical test. All data processing and analyses were conducted using R statistical software (R Core Team, 2023).

Results

The present case study examines the technological acceptance model of individuals who are considered at risk and have yet to be exposed to virtual reality/augmented reality (VR/AR) technology but have extensive exposure to fundamental technologies such as mobile phones and internet connectivity. This section presents the quantitative results, providing the statistical findings and thematic analysis strengthened by data from semi-structured interviews with selected local communities. We divide our results into three parts by highlighting the intention to use VR/AR. It begins with the perception of the role of VR/AR in disaster risk reduction (Section 4.1.), followed by the perceived usefulness and ease of use of VR/AR (Section 4.2.). Section 4.3. examines the intention to use VR/AR.

Perception of VR/AR technology for disaster risk reduction

This study explores the perception of VR/AR technology for disaster prevention, including disaster evacuation and building coastal resilience through mangrove conservation. Mangrove conservation, an existing coastal protection program, was considered in this study to complement perceptions of the role of technology in reducing disaster risk. Our study shows that VR/AR is perceived as an essential tool for emergency response and increasing awareness to protect the coast by conserving mangroves.

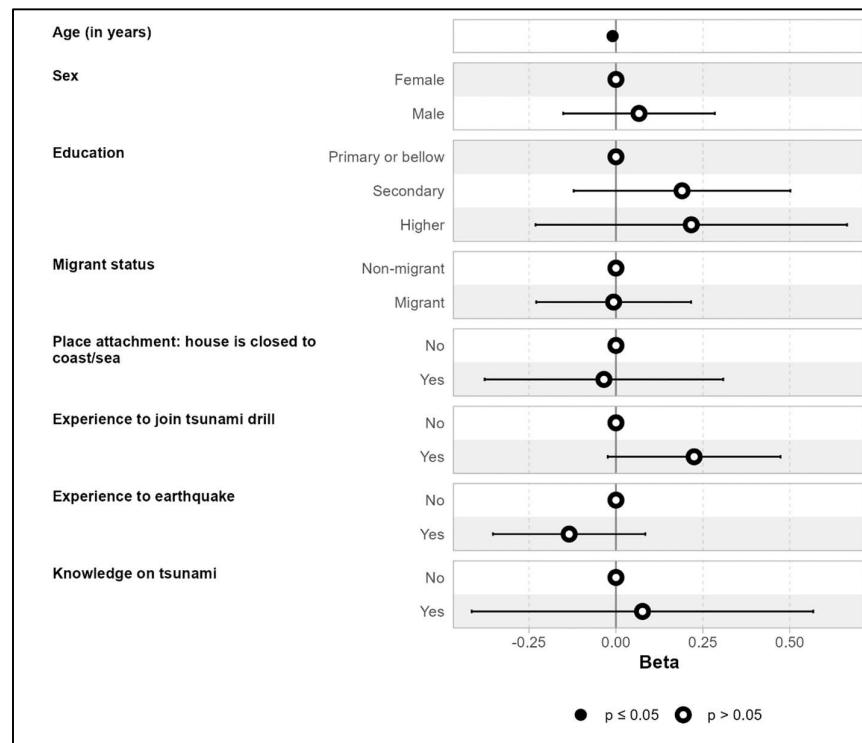


Figure 3. Univariable OLS regression estimation results between respondents' characteristics and perception of the importance of utilisation of technology for evacuation (emergency response) (95% confidence level).

The respondents' perception of the importance of using technology for evacuation (emergency response) was higher (see the mean score in Table 2 and tabulation of items in Table 3 Appendix). There is a notable difference in the perceived significance of VR/AR when analysed through age (see Figure 3). The higher perceived importance of VR/AR technology for disaster evacuation tends to decrease with age. This means that the older age of people they perceive is lower than the younger respondents. Our interviews with local leaders show that less exposure to technology has caused them to keep a conventional approach to reduce risk.

The results contradict studies in psychology, which mainly show that the elderly population has a positive perception of VR technology that causes them to be willing to adopt new technology (Syed-Abdul et al., 2019). Similarly, the perception of VR is also high in the study of well-being and connectedness among older adults (Milnamow et al., 2022). The elderly show a high preference for technology that helps them with everyday necessities and supports limited capacities to do physical activities.

On the other hand, the other variables (Sex, Education, Migrant status, Place attachment, Experience of joining tsunami drill, Experience of earthquakes, and Knowledge of tsunamis) do not have statistical differences in perception of the importance of technology for evacuation. The results are consistent with Charness & Boot (2009) and Basak et al. (2008). Although the differences are not statistically significant, we find a difference in scores. The perception of the importance of males is higher than that of females. The perception is better, along with the higher level of education. These patterns are also shown for respondents who have experienced joining tsunami drills and have knowledge of tsunamis.

Regarding the perceived importance of technology for coastal protection through mangrove conservation, perception did not significantly correlate with age (see Figure 4). On the contrary, knowledge of mangroves' role in protecting the coast was statistically correlated with the perceived importance of technology for coastal protection. This result is strengthened by our semi-structured interviews with local NGOs who work on mangrove conservation, who mention that awareness among the residents still needs to improve. However, they understand that mangroves could protect them from the risk of coastal-related disasters. Acknowledging the current limited information, they are motivated to use VR to access integrated knowledge about mangroves.

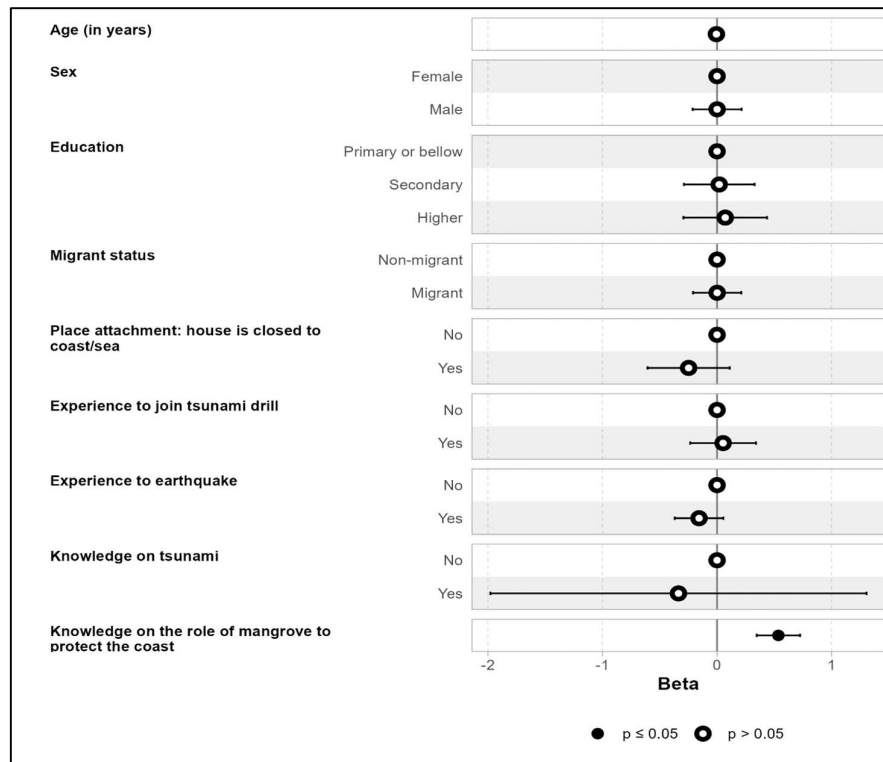


Figure 4. Univariable OLS regression estimation results between respondents' characteristics and perception of the importance of utilisation of technology for coastal protection through mangrove conservation (95% confidence level).

Similar to the results of the importance of utilisation of technology for evacuation, the variables of Sex, Education, Migrant status, Place attachment, Experience of joining tsunami drill, Experience of earthquake, and Knowledge of tsunamis do not have a statistically significant correlation with the perception on the importance of technology for coastal protection. Our semi-structured interviews show that tsunami drills have been conducted among the residents but are mainly focused on tourism business actors. Therefore, they need comprehensive information about the urgency of using VR/AR technology during an emergency.

In contrast to the perception of VR/AR technology, the analysis above suggests that the degree of involvement and understanding of the significance of VR/AR technology in efforts to protect coastal areas is not significantly influenced by gender. The semi-structured interviews show that both male and female groups contribute equally and have access to mangrove forests. For instance, both males and females could be involved in local associations to take economic benefit from the mangrove forests. Gender roles in mangrove conservation tend to be equal, but they are more likely to be involved in different types of activities (Moudingo et al., 2015). For instance, males participate more in the nursery and out-planting stages, while women focus on the harvesting and processing stages (Moudingo et al., 2015).

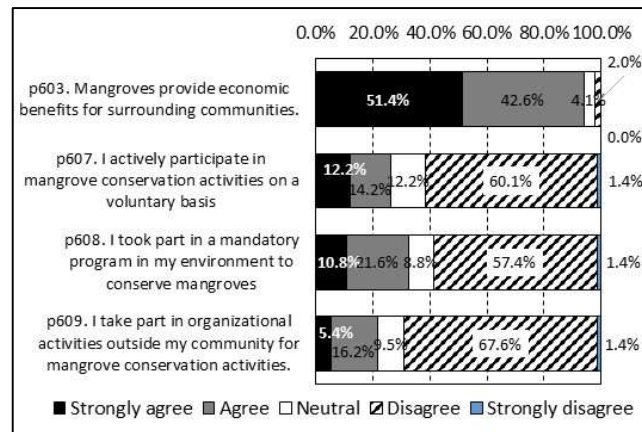


Figure 5. Mangrove conservation and financial benefits from mangroves.

Perception of the usefulness and ease of use of VR/AR

Figure 6 presents the association between respondents' characteristics and perception of usefulness and ease of use of VR/AR use. Respondents' age is a characteristic of a negative association with the perception of usefulness and ease of use of VR/AR. The regression coefficient is statistically significant at the 10% level. For the age characteristic, the pattern remains the same with the perception of VR/AR utilisation for DRR. The perception of usefulness and ease of use decreases with old age.

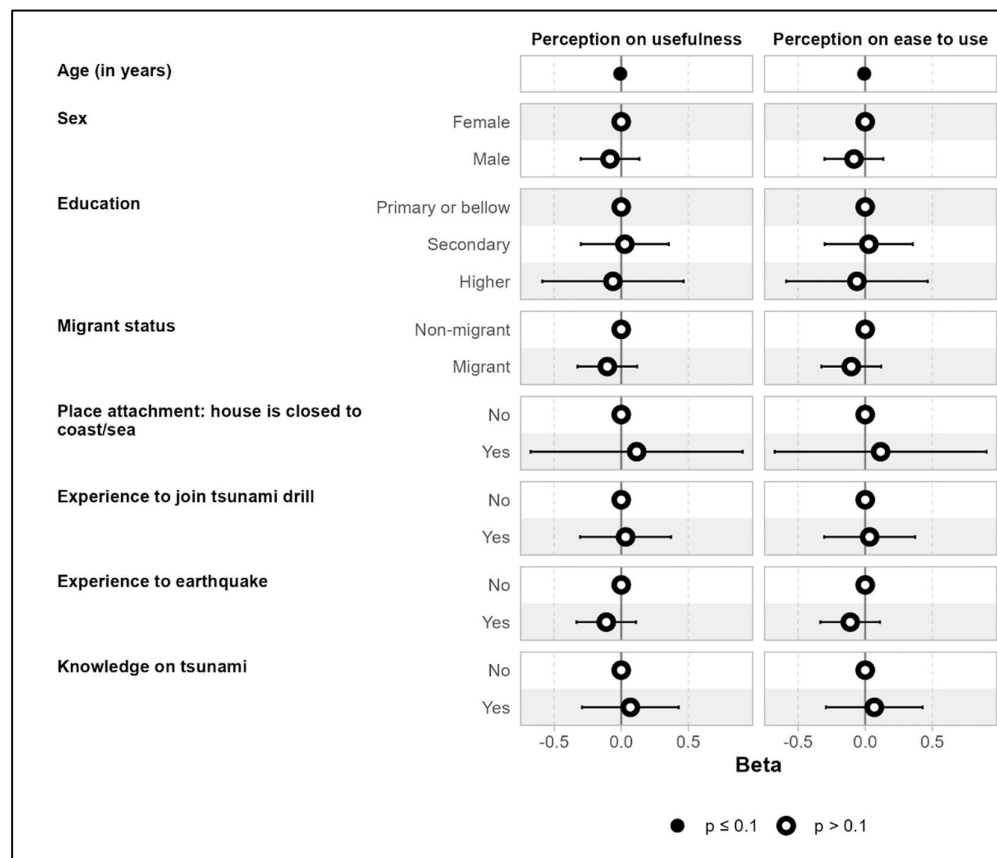


Figure 6. Univariable OLS regression estimation results between respondents' characteristics and perception of the usefulness and ease of use of VR/AR (95% confidence level).

However, it is essential to note that participants who had yet to gain prior experience with the technology still expressed confidence in its ability to provide valuable information on natural disasters such as tsunamis and earthquakes (see Figure 7: $\chi^2 (3, n = 148) = 3.403, n.s.$).

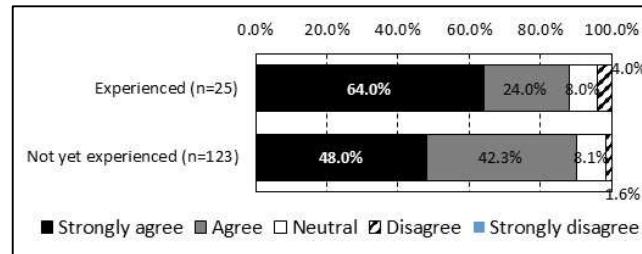


Figure 7. Relationship between prior experiences of VR/AR use and perception of usefulness.

They believed that VR/AR technology could simulate the intensity and impact of a tsunami, allowing them to experience and comprehend the devastation it can cause (see Figure 8: $\chi^2 (3, n = 148) = 3.655, n.s.$).

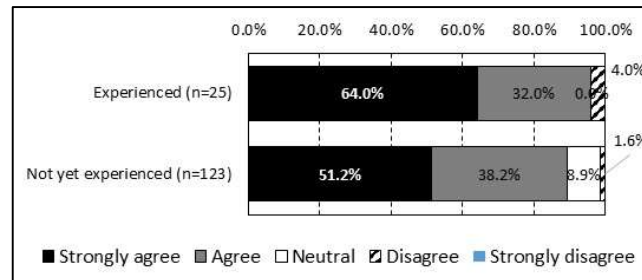


Figure 8. Relationship between prior experiences of VR/AR use and perception of simulation of the intensity and impact of tsunami.

Furthermore, they expressed interest in using VR/AR to educate themselves about the warning signs and safety measures during a tsunami and better understand the potential aftermath and recovery efforts (see Figure 9: $\chi^2 (3, n = 148) = 1.397, n.s.$).

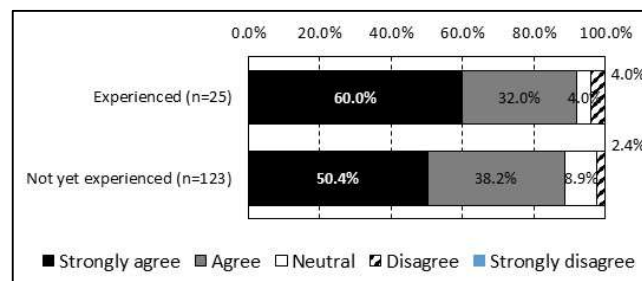


Figure 9. Relationship between prior experiences of VR/AR use and opinion that VR/AR can be used to find out how to deal with disasters.

This study shows that about 95.3% of the respondents supported the notion that VR/AR technology could enhance their understanding of the complex ecological functions of mangroves and how they contribute to mitigating the impacts of tsunamis. By immersing individuals in a virtual or augmented reality environment, 87.8% of the respondents acknowledged that VR/AR can effectively educate and raise awareness about tsunamis' potential dangers and effects. This can empower communities to make informed decisions and take necessary precautions to mitigate risks.

These findings indicate that many respondents recognise the potential benefits of using VR/AR technology for disaster preparedness and safety. Figure 8 illustrates to what extent the respondents perceived that tools like VR can provide transparent information about earthquakes and tsunamis. They perceived that the VR tool was straightforward (see Figure 10).

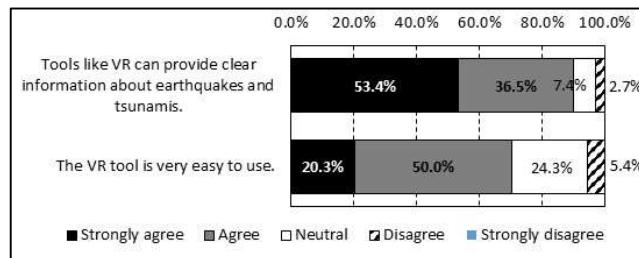


Figure 10. Potential benefits of using VR/AR technology for disaster preparedness and safety.

The high agreement rates suggest that people believe VR/AR can play a crucial role in providing accurate and accessible information during natural disasters, ultimately aiding in saving lives and protecting families. 52.0% of the respondents indicated that VR tools can be used anytime and anywhere. This result implies that it is also influenced by the user-friendly interface and intuitive controls, making it accessible to many individuals, including those with limited technological expertise. Moreover, the vulnerability of the tool refers to its ability to withstand harsh environmental conditions and potential technical glitches, ensuring its reliability in emergencies (see Figure 11).

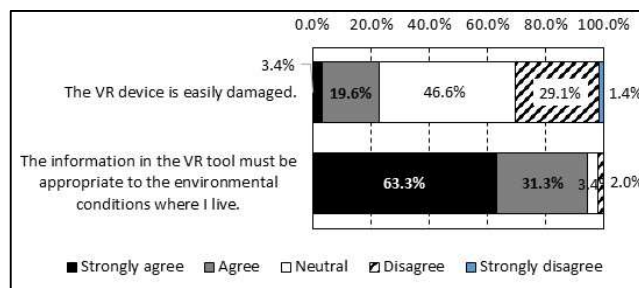


Figure 11. Vulnerability of the tool and toughness in environmental conditions.

The result shows that the lack of direct experience with VR/AR may contribute to uncertainty and disagreement among respondents. Once individuals try these technologies, their opinions may shift and become more favourable.

These statistics indicate that a significant portion of respondents find VR/AR to be user-friendly and easy to use. However, it is essential to note that opinions on the ease of using these technologies may vary among individuals. Further research and exploration are needed to understand the factors influencing these differing perceptions and address potential challenges to enhance user experience.

Intention to use VR/AR

Figure 12 presents univariable OLS estimation results for factors associated with intention to use VR/AR. The intention to use VR/AR among at-risk people is mainly influenced by age. The older groups have less intention to use while the younger groups have more intention to use it. Perception of usefulness and ease of use are other significant factors influencing the intention to use VR/AR. These factors positively affect the intention to use VR/AR. Respondents with a better perception of the usefulness or ease of using VR/AR have more intention to use VR/AR.

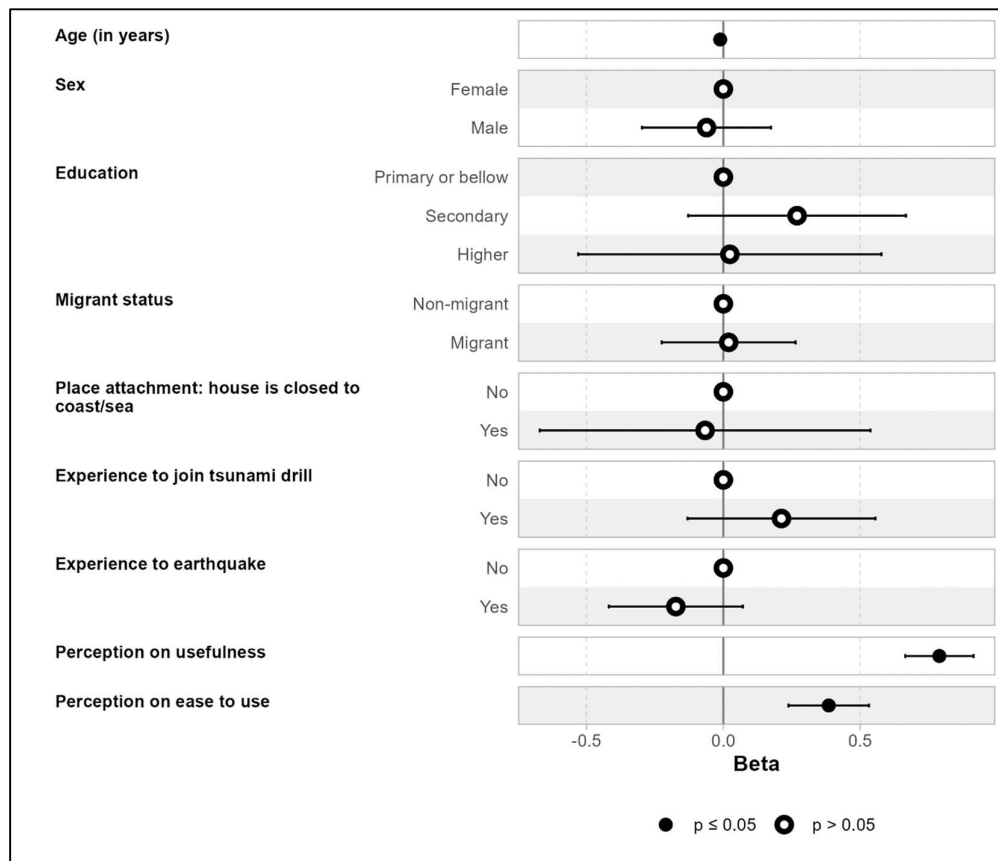


Figure 12. Univariable OLS regression estimation result for factor correlates with intention to use VR/AR (95% confidence level).

Moreover, respondents also stated that VR/AR must be able to help them improve the current initiative to conserve mangroves. Most respondents (97.3%) have a similar understanding of the benefit of mangroves in building coastal. The analysis also counts correlations with related variables such as education, migrant status, place attachment, the experience of joining tsunami drills, earthquake experience, and age. The intention to use the new technology is mandatory and voluntary. Almost 50 % of respondents said they would use the tools voluntarily (see Table 3 in Appendix). Intention to use also follows the decision of the majority in the neighbourhood.

Robustness test

We use the univariable OLS regression model to assess the association between respondents' characteristics, perception, and intention to use VR/AR. The model is equivalent to Pearson correlation analysis and two sample-independent t-tests. We also checked using non-parameters which alternative of these tests, five of these tests, namely Spearman's rank correlation and Mann Whitney-U test, respectively. The results of the non-parametric test are consistent with the results of univariable OLS regression—the non-parametric test results presented in Tables 4 and 5 (Appendix).

Conclusions

This study has attempted to understand the acceptance of VR/AR technology among people at risk of tsunamis. We present the results and findings based on the perception of the technology. As our study is the pre-condition towards implementing technology, perception is based on their knowledge of the technology and current

experience in managing risk, including existing conventional initiatives to build resilience, particularly by generating benefits from ecosystem services.

By exploring the importance of using technology for disaster prevention and coastal resilience, we dig deeper into understanding the perceived usefulness and ease of use of VR/AR technology to assess their intention to use the technology.

We concluded that the need to use advanced technology such as VR/AR is significant among those at risk. However, it needs to consider the characteristics of the population to accept and intend to use. As Davis (1989) highlights, the intention to use depends on perceived usefulness and ease of use.

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Appendix

Table 3. Summary of items for perception on the utilisation of technology for DRR, perception on usefulness, ease to use, intention to use VR/AR, and knowledge on the role of mangroves to protect the coast.

Variables/Items	Per cent (%)					Mean
	1	2	3	4	5	
Perception on the importance of utilization of technology for evacuation (emergency response)						
There is a need to have a tool/technology to provide directions for evacuation routes	0.00	4.05	1.35	29.73	64.86	4.55
There is a need to have a tool /technology to show refugee locations	0.00	4.05	1.35	31.76	62.84	4.53
There is a need to have a mobile phone to provide directions to the evacuation route	0.00	4.73	1.35	39.19	54.73	4.44
Perception on the importance of utilization of technology for coastal protection through mangrove conservation						
Technology is needed to provide knowledge and information about the benefits of mangroves	0.00	2.70	2.03	42.57	52.7	4.45
Technology is needed to provide knowledge of the role of mangroves in reducing tsunami risk	0.00	2.70	2.03	42.57	52.7	4.45
Perception on usefulness						
VR tools can provide very clear information about earthquake and tsunami events	0.00	2.03	8.11	39.19	50.68	4.39
I can use VR tools like the one above to get information about how to save myself during an earthquake and tsunami	0.00	2.03	7.43	37.16	53.38	4.42

Variables/Items	Per cent (%)					Mean
	1	2	3	4	5	
I can use VR tools like the one above to find out how to deal with disasters	0.00	2.70	8.11	37.16	52.03	4.39
I want to know about earthquakes and tsunamis clearly through VR tools	0.00	8.78	3.38	34.46	53.38	4.32
Tools like VR above can provide clear information about earthquakes and tsunamis	0.00	2.70	7.43	36.49	53.38	4.41
Perception on ease to use						
The VR tool is very easy to use	0.00	5.41	24.32	50	20.27	3.85
This VR tool can be used anytime and anywhere	1.35	22.97	23.65	39.19	12.84	3.39
The VR tool is difficult to use ^a	2.70	50.68	30.41	13.51	2.7	3.37
Intention to use						
If there is a VR tool, I will use it to get knowledge and information related to earthquakes and tsunamis	0.00	8.78	5.41	41.22	44.59	4.22
I would use VR tools like the ones above if required/programmed in this environment	0.68	3.38	2.03	48.65	45.27	4.34
I will use VR tools voluntarily	0.68	10.81	10.14	44.59	33.78	4.00
Knowledge on the role of mangrove to protect the coast						
Mangroves are useful in protecting homes and the environment here from abrasion and tsunamis	0.00	1.35	1.35	33.78	63.51	4.59

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

^aReversed score

Table 4. Non-parametric test of perception on the importance of technology for DRR.

Variables	Perception on the importance of utilization of technology for evacuation (emergency response)	Perception on the importance of utilization of technology for coastal protection through mangrove conservation
Spearman's rank correlation		
Age (in years)	-0.255**	-0.111 ^{n.s.}
Knowledge on the role of mangrove to protect the coast		0.509**
Mann Whitney-U test		
Sex		
Female ^a		
Male	2473.5 ^{n.s.}	2706.5 ^{n.s.}
Education		

Variables	Perception on the importance of utilization of technology for evacuation (emergency response)	Perception on the importance of utilization of technology for coastal protection through mangrove conservation
Primary or bellow ^a		
Secondary	603.5 ^{n.s.}	742 ^{n.s.}
Higher	95 ^{n.s.}	130 ^{n.s.}
Migrant status		
Non-migrant ^a		
Migrant	2649.5 ^{n.s.}	2720 ^{n.s.}
Place attachment : house is closed to coast/sea		
No ^a		
Yes	533 ^{n.s.}	670 ^{n.s.}
Experience to join tsunami drill		
No ^a		
Yes	821 ^{n.s.}	993.5 ^{n.s.}
Experience to earthquake		
No ^a		
Yes	2935 ^{n.s.}	3052 ^{n.s.}

^aReference group ; "n.s." stands for statistically non significant, ** p < 0.01.

Table 5. Non-parametric test or perception on usefulness, ease of use, and intention to use VR/AR,

Variables	Perception on usefulness	Perception on ease to use	Intention to use
Spearman's rank correlation			
Age (in years)	-0.166*	-0.137 ^{n.s.}	-0.166*
Perception on usefulness			0.743**
Perception on ease to use			0.354**
Mann Whitney-U test			
Sex			
Female ^a			
Male	2868 ^{n.s.}	2355 ^{n.s.}	2677.5 ^{n.s.}
Education			
Primary or bellow ^a			
Secondary	731.5 ^{n.s.}	677.5 ^{n.s.}	606.5 ^{n.s.}
Higher	120 ^{n.s.}	119 ^{n.s.}	134 ^{n.s.}
Migrant status			
Non-migrant ^a			
Migrant	2947 ^{n.s.}	2593 ^{n.s.}	2639 ^{n.s.}
Place attachment : house is closed to coast/sea			
No ^a			
Yes	598.5 ^{n.s.}	643 ^{n.s.}	591 ^{n.s.}
Experience to join tsunami drill			
No ^a			
Yes	1000 ^{n.s.}	1054 ^{n.s.}	863 ^{n.s.}
Experience to earthquake			
No ^a			
Yes	2892.5 ^{n.s.}	2130.5 ^{n.s.}	2964 ^{n.s.}

^aReference group ; "n.s." stands for statistically non significant, ** p < 0.01, * p < 0.05.

References

- Al-Gahtani, S. S., & King, M. (1999). Attitudes, satisfaction and usage: Factors contributing to each in the acceptance of information technology. *Behaviour & Information Technology*, 18(4), 277–297. <https://doi.org/10.1080/014492999119020>
- Alimamy, S., Deans, K., & Gnoth, J. (2018). An Empirical Investigation of Augmented Reality to Reduce Customer Perceived Risk. In P. Rossi & N. Krey (Eds.), *Marketing Transformation: Marketing Practice in an Ever Changing World* (pp. 127–135). Springer International Publishing. https://doi.org/10.1007/978-3-319-68750-6_42
- Anderson, R., Booth, A., Eastwood, A., Rodgers, M., Shaw, L., Thompson Coon, J., Briscoe, S., Cantrell, A., Chambers, D., Goyder, E., Nunns, M., Preston, L., Raine, G., & Thomas, S. (2021). *Synthesis for health services and policy: Case studies in the scoping of reviews*. NIHR Journals Library. <http://www.ncbi.nlm.nih.gov/books/NBK573412/>
- Angus, L., Snyder, I., & Sutherland-Smith, W. (2004). ICT and educational (dis)advantage: Families, computers and contemporary social and educational inequalities. *British Journal of Sociology of Education*, 25(1), 3–18. <https://doi.org/10.1080/0142569032000155908>
- Azuma, R., Bailiot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, 21(6), 34–47. <https://doi.org/10.1109/38.963459>
- Baaren, E., van de Wijngaert, L., & Huizer, E. (2011). Understanding Technology Adoption Through Individual and Context Characteristics: The Case of HDTV. *Journal of Broadcasting & Electronic Media*, 55(1), 72–89. <https://doi.org/10.1080/08838151.2011.546257>
- Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging*, 23(4), 765–777. <https://doi.org/10.1037/a0013494>
- Benssam, A., Nouali-Taboudjemmat, N., & Nouali, O. (2016). An e-readiness assessment model for disaster management. *International Journal of Information Technology and Management*, 15(2), 118–143. <https://doi.org/10.1504/IJITM.2016.076412>
- Bhattacharjee, A., & Premkumar, G. (2004). Understanding changes in belief and attitude toward information technology usage: A theoretical model and longitudinal test. *MIS Quarterly*, 28(2), 229–254.
- Brown, N., Margus, C., Hart, A., Sarin, R., Hertelendy, A., & Ciottone, G. (2023). Virtual Reality Training in Disaster Medicine: A Systematic Review of the Literature. *Simulation in Healthcare*, 18(4), 255. <https://doi.org/10.1097/SIH.0000000000000675>
- Carby, B. (2018). Integrating disaster risk reduction in national development planning: Experience and challenges of Jamaica. *Environmental Hazards*, 17(3), 219–233. <https://doi.org/10.1080/17477891.2017.1415864>
- Charness, N., & Boot, W. R. (2009). Aging and Information Technology Use: Potential and Barriers. *Current Directions in Psychological Science*, 18(5), 253–258. <https://doi.org/10.1111/j.1467-8721.2009.01647.x>
- Chau, P. Y. K. (1996). An Empirical Assessment of a Modified Technology Acceptance Model. *Journal of Management Information Systems*, 13(2), 185–204. <https://doi.org/10.1080/07421222.1996.11518128>
- Chen, P.-H., & Truc, N. T. L. (2008). Computer-Aided Visual Communication for Way-Finding in Emergency in Indoor Environment. *ISARC Proceedings*, 440–446.
- Cipresso, P., Giglioli, I. A. C., Raya, M. A., & Riva, G. (2018). The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. *Frontiers in Psychology*, 9. <https://www.frontiersin.org/articles/10.3389/fpsyg.2018.02086>

- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. <https://doi.org/10.2307/249008>
- Fong, H., & Harris, E. (2015). Technology, innovation and health equity. *Bulletin of the World Health Organization*, 93(7), 438–438A. <https://doi.org/10.2471/BLT.15.155952>
- Franchi, J. (1994). Virtual reality: An overview. *TechTrends*, 39(1), 23–26. <https://doi.org/10.1007/BF02763870>
- García, S., Trejo, P., García, A., García, S., Trejo, P., & García, A. (2021). Intelligent VR-AR for Natural Disasters Management. In *Augmented Reality and Its Application*. IntechOpen. <https://doi.org/10.5772/intechopen.99337>
- Khanal, S., Medasetti, U. S., Mashal, M., Savage, B., & Khadka, R. (2022). Virtual and Augmented Reality in the Disaster Management Technology: A Literature Review of the Past 11 years. *Frontiers in Virtual Reality*, 3. <https://www.frontiersin.org/articles/10.3389/frvir.2022.843195>
- Klopfer, E., & Squire, K. (2008). Environmental Detectives—The development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, 56(2), 203–228. <https://doi.org/10.1007/s11423-007-9037-6>
- Lai, Y.-A., Ou, Y.-Z., Su, J., Tsai, S.-H., Yu, C.-W., & Cheng, D. (2012). Virtual disaster management information repository and applications based on linked open data. *2012 Fifth IEEE International Conference on Service-Oriented Computing and Applications (SOCA)*, 1–5. <https://doi.org/10.1109/SOCA.2012.6449431>
- Mathieson, K., Peacock, E., & Chin, W. W. (2001). Extending the technology acceptance model: The influence of perceived user resources. *ACM SIGMIS Database: The DATABASE for Advances in Information Systems*, 32(3), 86–112. <https://doi.org/10.1145/506724.506730>
- Mehrabi, Z., McDowell, M. J., Ricciardi, V., Levers, C., Martinez, J. D., Mehrabi, N., Wittman, H., Ramankutty, N., & Jarvis, A. (2021). The global divide in data-driven farming. *Nature Sustainability*, 4(2), Article 2. <https://doi.org/10.1038/s41893-020-00631-0>
- Mol, J. M., Botzen, W. J. W., & Blasch, J. E. (2022). After the virtual flood: Risk perceptions and flood preparedness after virtual reality risk communication. *Judgment and Decision Making*, 17(1), 189–214. <https://doi.org/10.1017/S1930297500009074>
- Moudingo, J.-H., Ajonina, G., & Diyouke, E. M. (2015). Mangrove Social and Ecological resilience geared in the Cameroon Estuary. *Journal of Ecology and the Natural Environment*. <https://www.semanticscholar.org/paper/Mangrove-Social-and-Ecological-resilience-geared-in-Moudingo-Ajonina/90f3eb11fd9c966f7a4c583e1905b4b6a26e1fdc>
- Ordaz, N., Romero, D., Gorecky, D., & Siller, H. R. (2015). Serious Games and Virtual Simulator for Automotive Manufacturing Education & Training. *Procedia Computer Science*, 75, 267–274. <https://doi.org/10.1016/j.procs.2015.12.247>
- Post, J., Wegscheider, S., Mück, M., Zosseder, K., Kiefl, R., Steinmetz, T., & Strunz, G. (2009). Assessment of human immediate response capability related to tsunami threats in Indonesia at a sub-national scale. *Natural Hazards and Earth System Sciences*, 9(4), 1075–1086. <https://doi.org/10.5194/nhess-9-1075-2009>
- R Core Team. (2023). *R: A Language and Environment for Statistical Computing* [Computer software]. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Rialti, R., Filieri, R., Zollo, L., Bazi, S., & Ciappei, C. (2022). Assessing the relationship between gamified advertising and in-app purchases: A consumers' benefits-based perspective. *International Journal of Advertising*, 41(5), 868–891. <https://doi.org/10.1080/02650487.2022.2025735>

- Robinson, J. P., Shaver, P. R., & Wrightsman, L. S. (1991). Criteria for Scale Selection and Evaluation. In J. P. Robinson, P. R. Shaver, & L. S. Wrightsman (Eds.), *Measures of Personality and Social Psychological Attitudes* (pp. 1–16). Academic Press.
- Ruggiero, L. (2018). *A Review of Augmented Reality Applications for Building Evacuation* (arXiv:1804.04186). arXiv. <https://doi.org/10.48550/arXiv.1804.04186>
- Sagnier, C., Loup-Escande, E., Lourdeaux, D., Thouvenin, I., & Valléry, G. (2020). User Acceptance of Virtual Reality: An Extended Technology Acceptance Model. *International Journal of Human–Computer Interaction*, 36(11), 993–1007. <https://doi.org/10.1080/10447318.2019.1708612>
- Schwambach, G. C. S., López, Ó. H., Sott, M. K., Carvalho Tedesco, L. P., & Molz, R. F. (2022). Acceptance and perception of wearable technologies: A survey on Brazilian and European companies. *Technology in Society*, 68, 101840. <https://doi.org/10.1016/j.techsoc.2021.101840>
- Sharma, S., Jerripothula, S., Mackey, S., & Soumare, O. (2014). Immersive virtual reality environment of a subway evacuation on a cloud for disaster preparedness and response training. *2014 IEEE Symposium on Computational Intelligence for Human-like Intelligence (CIHLI)*, 1–6. <https://doi.org/10.1109/CIHLI.2014.7013380>
- Spahn, H., Hoppe, M., Kodijat, A., Rafliana, I., Usdianto, B., & Vidiarina, H. D. (2014). Walking the Last Mile: Contributions to the Development of an End-to-End Tsunami Early Warning System in Indonesia. In F. Wenzel & J. Zschau (Eds.), *Early Warning for Geological Disasters: Scientific Methods and Current Practice* (pp. 179–206). Springer. https://doi.org/10.1007/978-3-642-12233-0_10
- Sunarta, I. N., Nugroho, S., & Adikampana, I. M. (2021). Spatial Transformation of Subak in Northern Kuta Tourism Area, Bali: From Agricultural to Cultural-Service. *South Asian Journal of Social Studies and Economics*, 26–38. <https://doi.org/10.9734/sajsse/2021/v9i130229>
- Syed-Abdul, S., Malwade, S., Nursetyo, A. A., Sood, M., Bhatia, M., Barsasella, D., Liu, M. F., Chang, C.-C., Srinivasan, K., M., R., & Li, Y.-C. J. (2019). Virtual reality among the elderly: A usefulness and acceptance study from Taiwan. *BMC Geriatrics*, 19(1), 223. <https://doi.org/10.1186/s12877-019-1218-8>
- Tüzün, H., & Özding, F. (2016). The effects of 3D multi-user virtual environments on freshmen university students' conceptual and spatial learning and presence in departmental orientation. *Computers & Education*, 94, 228–240. <https://doi.org/10.1016/j.compedu.2015.12.005>
- Velev, D., Zlateva, P., Steshina, L., & Petukhov, I. (2019). Challenges of Using Drones And Virtual/Augmented Reality for Disaster Risk Management. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-3-W8, 437–440. <https://doi.org/10.5194/isprs-archives-XLII-3-W8-437-2019>
- Wegscheider, S., Post, J., Zosseder, K., Mück, M., Strunz, G., Riedlinger, T., Muhari, A., & Anwar, H. Z. (2011). Generating tsunami risk knowledge at community level as a base for planning and implementation of risk reduction strategies. *Natural Hazards and Earth System Sciences*, 11(2), 249–258. <https://doi.org/10.5194/nhess-11-249-2011>
- Wu, P.-H., Hwang, G.-J., Yang, M.-L., & Chen, C.-H. (2018). Impacts of integrating the repertory grid into an augmented reality-based learning design on students' learning achievements, cognitive load and degree of satisfaction. *Interactive Learning Environments*, 26(2), 221–234. <https://doi.org/10.1080/10494820.2017.1294608>
- Zeileis, A. (2004). Econometric Computing with HC and HAC Covariance Matrix Estimators. *Journal of Statistical Software*, 11(10), 1–17. <https://doi.org/10.18637/jss.v011.i10>

Zhu, Y., & Li, N. (2021). Virtual and augmented reality technologies for emergency management in the built environments: A state-of-the-art review. *Journal of Safety Science and Resilience*, 2(1), 1–10. <https://doi.org/10.1016/j.jnlssr.2020.11.004>

