Exploring the Feasibility of Adopting Virtual Reality as an Alternative Risk Communication Method for Natural Hazards

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ABSTRACT
American communities are now more susceptible to extreme weather events caused by climate change. Increased natural hazards have resulted in annual economic losses of billions of dollars in the United States. Previous research asserts that effective risk communication before natural hazards can enhance preparedness and eliminate the detrimental effect afterward. Existing practices for communicating natural hazards risks, such as tornado watches and warnings, have been implemented to mitigate the impact well ahead of such events. However, existing risk communications of natural hazards, including television, radio, internet, and mobile applications, can only provide generalized and abstract natural disaster information for householders, through which householders cannot comprehend the risk of natural hazards or may misinterpret the risk messages. In this paper, we explored the feasibility of adopting immersive visualization technology, such as virtual reality (VR), as an alternative risk communication tool in the future. We also tried to understand and summarize the willingness and challenges of adopting VR among populations with different socio-economic backgrounds. We conducted a survey with 493 responses in the Dallas/Fort Worth area in Texas. The results revealed that the household had limited experience with VR technologies. There were also polarized results in adopting VR technologies for natural hazards risk communication, in which the younger generations are more willing to use VR for risk communication than older generations. Other socio-economic factors were also assessed concerning the adoption of VR technology. The paper's findings will help researchers develop more effective immersive natural hazards risk communication methods in the future.

Keywords: Risk communication, climate change, virtual reality.

1. INTRODUCTION

American communities are now more susceptible to the risk of extreme weather patterns because of climate change, and these risks have led to incessant natural disasters, causing severe economic losses and human suffering (Irby et al. 2009). According to the statistical data provided by the National Oceanic and Atmospheric Administration (NOAA), there was an average of 20 natural disaster events every year in the United States (US) for the last three years, with a total of 434.6 billion dollars in economic loss and 1460 fatalities (NCEI 2023). Previous studies have found effective risk communications before incoming natural disasters have been identified as one of the best ways to prepare for and mitigate the risks of natural disasters for communities (Höppner et al. 2010; Lindell and Perry 2003). Effective risk communications can increase public awareness and emergency readiness and decrease the impacts of catastrophes. This is because risk communication aims to inform the public about the possibility of a natural disaster, the best strategies to prepare, and any potential consequences.

Existing risk communications of natural disasters such as television broadcasts, radio, internet, text warning messages, mobile applications, and social media have been engaged to deliver risk messages by informing the public on how to take protective action (Haddow and Haddow 2013; Sutton and Kuligowski 2019). However, these existing risk communication practices have been considered generalized, abstract, ineffective, and giving to misinterpretations. For example, Lindell and Perry (2012) attributed the lack of efficiency to factors such as information overload (Sutton et al. 2021), lack of personalization or visualization (Dransch et al. 2010), lack of trust (Engdahl and Lidskog 2014), and limited engagement (Rowel et al. 2012). Therefore, a more effective and immersive risk communication framework is urgently needed to provide households with the necessary disaster information to make informed decisions and take appropriate action to safeguard themselves before incoming natural disasters.

VR has the potential to be developed and implemented as an alternative natural disaster risk communication supplement, which can offer an immersive virtual environment for households to experience incoming natural disasters. Existing studies have found that risk communication can be improved by applying VR technologies (Ogie et al. 2018). For example, Molan et al. (2022) found that virtual wildfire disaster-prone scenarios can improve households' willingness to seek shelter more than other risk communication methods. Sermet and Demir (2019) developed a FloodVR as an educative tool for the general public to visualize incoming flooding disasters, which can be used for emergency training and planning purposes. Mol et al. (2022) designed an experiment in which participants who experienced flood in an immersive VR were found to invest more in flood investment game compared to the control group. Nevertheless, there are very limited studies in the existing literature that investigate households' perceptions of VR technologies and explore the feasibility of adopting VR as an alternative media for future natural disaster risk communications.

Given the potential of VR to play a supplemental function in the dissemination of natural disaster risk information, it is important for decision makers, and emergency management experts to know the extent to which households are willing to accept the use of VR as a natural disaster risk communication tool. Soden et al. (2022) suggested the need to align the design of risk communication to the specific context and preference of the intended recipients. The potential users of VR for natural disaster risk communication should be drawn towards the technology and are willing to use it for that purpose. The Technology Acceptance Model (TAM) study conducted by Lee et al. (2019) investigated the perceived ease of use and usability of VR – two major components of TAM and found that other related factors such as social networks can drive the acceptance of VR. Therefore, it is important to assess and understand the factors that will act as drivers or barriers to the adoption of VR in the context of natural disasters. To fill this knowledge gap, this study aims to assess households' willingness to adopt VR as a natural disaster risk communication supplement and understand how households' socioeconomic factors could drive the adoption of VR technologies. We conducted a survey with 493 completed responses in Dallas/Fort Worth, Texas to investigate the feasibility of using VR as a supplement to existing risk communication modalities. This study has the potential to inform the design of future VR systems and provide insights into the potential barriers and opportunities for implementing VR in the disaster risk communication process.

2. LITERATURE REVIEW

2.1 The importance of risk communication in disaster management

Risk communication has gained significant attention in recent years as a distinct field, particularly in the late 20th century. This field encompasses various areas, such as the consumer goods (Kim 2017), infectious diseases (Morgan et al. 2002), and natural disasters (McMakin and Lundgren 2018). Research studies have shown that risk communication is essential to disaster management and preparedness as it helps mitigate the impact of natural disasters. However, the effective format that risk communication takes remains a subject of debate, with some studies suggesting that it may include persuasive elements to encourage action or behavior change in recipients (Leiss 2004). The Protective Action Decision Model (PADM) developed by Lindell and Perry (2003) is a well-known theory in risk communication that has been modified over time. PADM identifies three key perceptions: the perception of threats, the perception of protective actions, and the perception of stakeholders. The goal of PADM is to understand the characteristics that influence individuals' decision-making regarding preventive action, which can then be used to design effective risk communication programs, emergency evacuation models, and long-term hazard adjustment plans (Lindell and Perry 2012).

Recent studies have explored risk communication theories in three categories, which are psychological, sociological, and interdisciplinary. Psychological studies focus on cognitive and affective aspects of risk perception, which may influence individuals' behaviors and decision-making. Sociological studies examine how social and environmental cues may impact individuals' perceptions and actions (Kim 2017; Renn and Benighaus 2013). Interdisciplinary studies aim to better define and design risk communication to ensure it covers all risk aspects (Morgan et al. 2002). Media plays an essential role in risk communication by portraying natural disasters and identifying risks to the public. Risk communication can also be used as a decision support tool besides being an informative and educational tool. Communicating complex risks such as climate change-related disasters can largely affect risk perceptions (Spence and Pidgeon 2010). Nevertheless, risk perception remains a critical component of risk mitigation behaviors, and individuals' responses to risk messages can significantly impact the success of risk communication efforts (Arvai and Rivers 2014; Campbell 2014).

2.2 Virtual reality for natural disaster risk communication

VR is a technology that creates pictures of places that look real, and people can feel like they are actually there because they can move around and interact with things using their hands, voice, and body (Burdea and Coiffet 2003). The technological advancements in VR have resulted in the expansion of its potential applications, making it useful in various industries including gaming (Hu et al. 2016), healthcare (Li et al. 2017), and manufacturing (Choi et al. 2015). The immersive virtual environment can enhance users' presence and make them believe that they are in a real-world scenario (Anthes et al. 2016). In recent years, disaster management-related research studies have been exploring the use of VR for immersive disaster visualization. Research shows that VR can improve the users' understanding of natural disasters and decision-making by accurately depicting objects' positions in a 3D dimension (Irby et al. 2009). For example, Sermet and Demir (2019) developed "FloodVR" as an educational tool that used historical meteorological data and immersive 3D visualizations to educate the public about flooding disasters. Oyshi et al. (2022) examined how VR can influence decision-making by supporting the visualization of flood projection data and whether the sense of presence affects the decision-making process in flood risk reduction measures. Participants who viewed the flood impact in VR had a better understanding of the impact of extreme flood events, suggesting that VR can be an asset to visualize weather and climate-related hazard and risk data. Similarly, Molan et al. (2022) used VR to explore participants' evacuation behavior related to wildfire disasters and they found that VR can promote households' decisions regarding protective actions.

Despite evidence that VR has been discovered to support visualization and improve the risk communication of natural disasters, there are no studies that tell whether individuals are willing to use VR technology for that purpose. Our research team proposes a novel VR-based risk communication system designed to simulate natural disaster scenarios. The system delivers individuals an immersive experience of a tornado disaster in a controlled environment without exposing them to actual harm. To deploy this solution, we needed to identify and understand the factors that would affect users' acceptance of this technology before finalizing the design and carting out field tests and human subject experiments. The TAM model has been significantly researched to model the likelihood of acceptance and usage when introducing a new technology (Marangunić and Granić 2015). This informs the need for this present study that asks (1) are survey participants' households willing to embrace VR for natural disaster risk communication? (2) what is the relationship between demographic/socioeconomic factors and the willingness to adopt VR for natural disaster risk communication? (3) which factors can act as drivers for the VR adoption for natural disaster risk communication? Providing answers to these questions can give insight into the factors to consider in VR system development and guide industry experts and risk managers in the visualization designs for the natural disaster risk communication process.

3. METHODOLOGY

In this paper, we explored the feasibility of adopting immersive visualization technology such as VR as an alternative risk communication method in the future. We also tried to understand and summarize the willingness and challenges of adopting VR among populations with different socio-economic backgrounds.

3.1 Survey design

A survey was designed by the research team to understand the existing barriers and challenges of adopting VR to various populations with different socio-economic backgrounds. The survey had three sections, including demographic background, disaster and gaming experience, and willingness to use VR. Section 1 was designed to collect demographic factors as shown in Table 1 to better understand the attributes of the respondents and identify trends and patterns in their responses. Section 2 was designed to ask participants to rate their experiences with disasters, gaming, and VR on a Likert scale from 1 to 7 with 1 representing no experience and 7 representing a lot of experience. Gaming/VR experience was also assessed based on the number of hours spent per week playing the categories investigated as shown in Table 1. Finally, participants were asked about their willingness to use VR as a risk communication method based on the Technology Acceptance Model (TAM). The output of the TAM model is a significant concept that explains people's decision to adopt or reject new technologies (Marangunić and Granić 2015).

3.2 Survey distribution and data collection

The survey was administered by Qualtrics. The survey was targeted toward the residents in the Dallas/Fort Worth area in Texas. The Dallas/Fort Worth area in Texas is an ideal location due to the expanse of the region, history with natural disasters, and its diverse population that offers valuable data on natural disaster risk communication. Data distribution across the U.S highlighted Texas as having been ranked highest in damages and impact on states' GDP (over 100billion dollars) due to climate disasters alongside the state of Florida (NCEI 2023; O'Connor et al. 2021).The study was reviewed and approved by the University IRB before distributing the survey (IRB number: 22-06-5739). The survey was distributed on October 3, 2022, and 536 responses were collected. The survey data were checked for errors, and incomplete and unrealistic records were deleted. The data collected after error-checking resulted in a total of 493 responses. The survey responses were analyzed through descriptive statistics to extract the frequency data along the categories provided. The collected data was then checked for reliability using Cronbach's α to confirm they were in an acceptable range. We analyzed the data using the R statistical analysis package. Demographic data were presented in charts and tables to provide insight into the data distribution of respondents. Further statistical analysis, such as Pearson correlation, linear regression, and structural equation modeling, was done to identify correlations and causal relationships between the variables assessed.

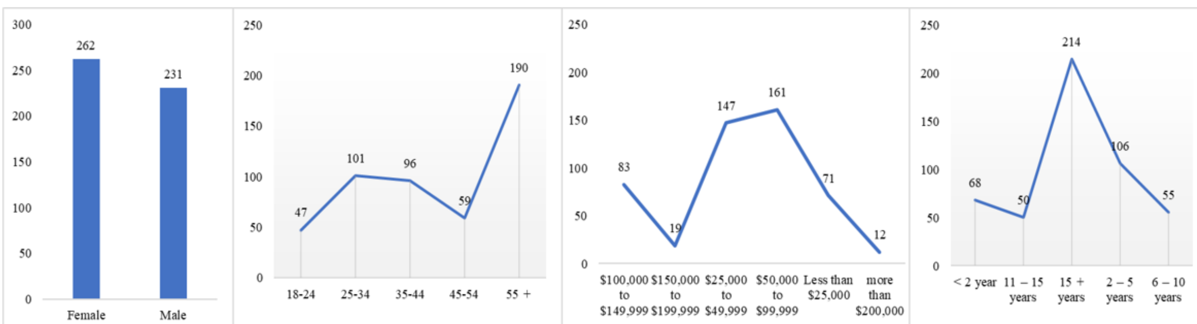
Table 1. Survey questions assessed in the study.

Section	Item	Cronbach's α
Demographics	Which age group do you belong? What is your gender? How many years have you lived in your community? What was your household income last year before taxes? Which of the following categories best describes your level of education?	
Disaster and gaming experience	Please rate your experiences with the following: Tornadoes; Hurricanes; Earthquakes; Winter Storm; Heatwaves; Flooding; Wildfires; Computer/video games; Virtual reality; First shooter games; Third person games?	0.82
	How many hours per week do you play each of the following: Computer/video games; VR; First shooter games; Third person games?	0.81
Interest to use VR	Are you interested in using VR to visualize incoming natural disasters?	
Perceived ease of use (PEU) and perceived usefulness (PU)	Using VR would enable me to understand the incoming natural disasters more quickly; Using VR would improve my risk perception and protective intent; Using VR would make it easier for me to understand the incoming natural disasters; I would find VR useful for natural disaster risk communications; Learning to operate VR device would be easy for me; I would find it easy to get VR devices to do what I want it to do; It would be easy for me to become skillful at using VR devices; I would find VR devices are easy to use when they are available to me.	0.74

4. RESULTS AND DISCUSSION

4.1 Demographics

The demographic information of the survey participants (n=493) is summarized in Table 2, including age, gender, household income, and the number of years lived in the community. These factors are needed to understand the survey participants' characteristics and their possible effects on survey responses. The result indicated that the gender distribution had more females at 53% and males at 47%, as shown in Figure 1. The highest age range in the distribution is 55 years and above at 39% of the participants, and the lowest age range with 10% was the 18 to 24 years group. The household income distribution has the largest group making between 50,000 dollars and 99,999 dollars with 33%. The years lived in the community revealed about 43% of the respondents have lived in the same community for over 15 years, and only 14% have spent two years or less living in the same community. The household income distribution has the largest group (34%) making between $50,000 and $99,999. This implies that the respondents are relatively middle-income earners, and the years lived in the community are also extended with a large percentage having strong ties to the community.



Gender Age group Household income Years lived in community.

Figure 1: The Demographic distribution of Survey Respondents (n=493)

4.2 Disaster and Gaming Experience

To assess the role of previous disaster experience on the adoption strategies of VR as a risk communication method, we asked the participants about their experiences with eight types of natural disasters. The results showed that most of the participants had more significant and considerable experience with heatwaves and winter storms, with only 9% and 6% choosing "no experience," respectively, followed by tornadoes and flooding, with 37% and 43% choosing "no experience". The findings of disaster experience indicated that most of the participants had considerable experience with heatwaves and winter storms, which are in order, given the recent frequent occurrence of these categories of disasters in the Texas area. A higher percentage of participants reported no experience with tornadoes and flooding, compared to heatwaves and winter storms, but not as high for disasters such as hurricanes, wildfires, and earthquakes, which have not been recorded in the Texas area. The result suggests that the participants had some level of experience with various disaster types, with heatwaves and winter storms being the most experienced, followed by tornadoes and flooding.

The gaming experience has been reported in the existing literature to be strongly correlated with the use of immersive reality technologies with individuals who actively engage in gaming and exhibit enhanced cognitive abilities in virtual environments(Bressler and Bodzin 2013). The level of gaming experience was investigated in this study based on four categories of gaming concepts listed in Table 1. The gaming experience revealed that only 15% had no experience at all playing computer or video games and 41% spent less than one hour each week playing computer or video games. Participants had the least experience with VR from the gaming concepts with 54% having no experience at all and 81% of them choosing less than one VR hour each week. Based on the results of the gaming experience, a significant proportion of the participants had little to no experience with video games, and even fewer had experience with VR as a gaming concept. This could potentially have implications for the adoption of VR as a risk communication method as those with little to no experience with the technology may be less likely to use or understand it as previously researched.

4.3 Willingness to use VR technology for natural disaster risk communication

The willingness to adopt VR technology for natural disaster risk communication was investigated in the final section. The TAM framework answers the question of adoption of the VR technology to communicate about incoming natural disasters and the survey participants were asked directly what their instant decision was, with yes or no responses. Overall, the results showed that 41% of households were willing to use VR for natural disaster risk communication. Further analysis of the willingness to use VR for natural disaster risk communication revealed that pertaining to gender, 57% of those not willing to use VR for risk communication were female while 52% of those willing to use VR for risk communication were male. Age demographics revealed that 53% of those not willing to accept VR were above 55 years old as against only 18% of those willing to accept VR being above 55 years and above. The income level of the participants was not different following the breakdown of the willingness to accept VR for risk communication with a percentage revolving around the same range as the total sample as shown in figure 2.

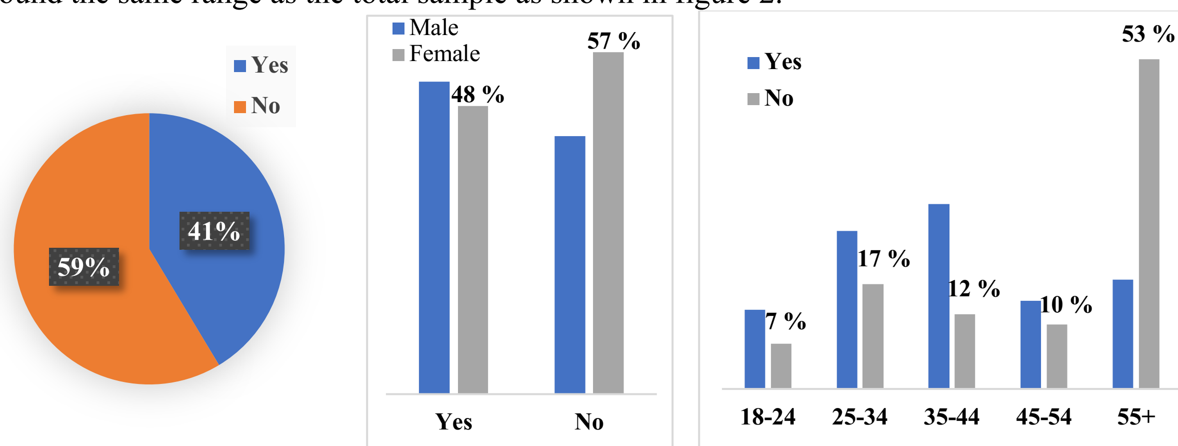


Figure 2: Demographic distribution of VR interest for risk communication

The findings imply that most participants were not willing to use VR for natural disaster risk communication which could be traced from their insignificant experiences with natural disasters generally. However, it is important to note that 41% of participants were still open to the idea, indicating that VR could still be a viable tool for some individuals. Further analysis suggests that gender and age may be important factors in determining the willingness of individuals to adopt VR as a communication tool for natural disaster risks. The breakdown by gender and age highlights potential areas for targeted outreach and education. For example, the higher percentage of females not willing to use VR for risk communication could suggest a need for more targeted messaging and outreach to address potential concerns or reservations that women may have regarding VR technology. Similarly, the high percentage of older individuals declining to accept VR could indicate a need for targeted outreach and education to inform them of the potential benefits of using VR as a risk communication tool. Overall, these findings can inform the development of more effective risk communication strategies using VR, tailored to specific demographic groups. These findings also indicate that income level may not play a significant role in the decision to accept or reject VR as a method of risk communication for natural disasters.

4.4 Drivers for VR Adoption for Natural Disaster Risk Communication

The final objective of this study had to do with identifying factors that could act as drivers or predictors for the adoption of VR for use in natural disaster risk communication. statistical analysis was carried out in RStudio. Pearson correlation coefficient results between the variables being considered – VR/gaming experience, VR/gaming hours per week, perceived ease of use, perceived usability, and intention to use VR are shown in Table 3. All these variables (0.33 to 0.74) were positively correlated.

Table 2: Pearson correlation coefficients of TAM constructs .

	VR/gaming experience	VR/gaming hour/week	Perceived usability	Perceived ease of use	Interest/Intention to use
VR/gaming experience	1	0.57	0.36	0.5	0.42
VR/gaming hour/week		1	0.33	0.35	0.33
Perceived usability			1	0.58	0.74
Perceived ease of use				1	0.52
Interest/Intention to use					1

The result of the structural equation modeling (SEM) analysis explains the relationships between latent variables, particularly perceived usefulness (PU) and perceived ease of use (PEU), and their impact on the intention to use (IU). The standardized regression coefficient for PU revealed a weaker influence on IU (0.237) than PEU which showed a stronger association (0.760). These findings suggest that, within the model, PU contributes modestly whereas PEU plays a more influential role in driving user acceptance of VR for natural disaster risk communication.

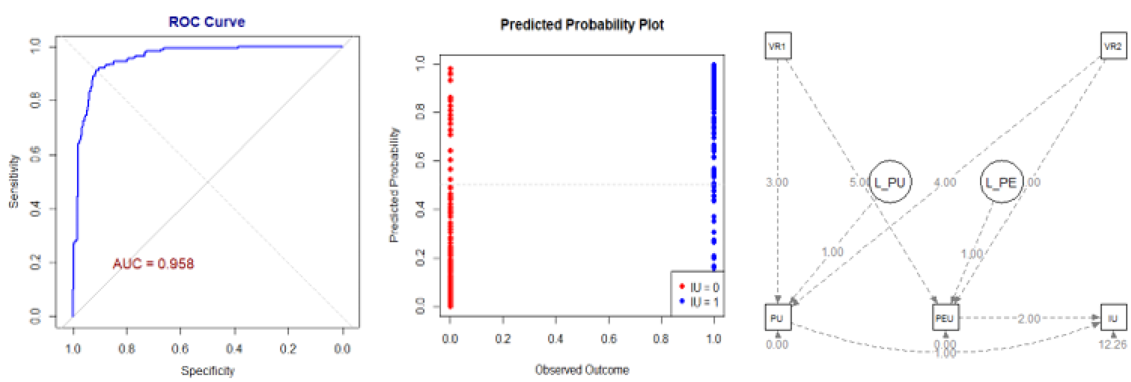


Figure 3: Path modeling for VR interest for risk communication

5. CONCLUSION

In this paper, we sought to explore the feasibility of adopting immersive visualization technology such as virtual reality (VR) as an alternative risk communication supplementary tool. Furthermore, we tried to understand and summarize the existing barriers and challenges of adopting VR to various householder populations with different socio-economic backgrounds. The findings revealed that disaster experience is a significant indicator of how people perceive incoming natural disasters. We also reviewed existing literature and found that VR aids visualization of natural disasters without causing the harm that real experiences come with and propose a comprehensive system to communicate natural disaster risks. The study results found that a higher proportion of male genders and younger populations were very willing to accept VR technology as an alternative risk communication method. Further findings suggested that the demographics of age and gender are significant and could be exploited through education and sensitization to support the adoption of VR for communicating incoming natural disasters. The demographics of household income did not show a significant difference in relation to VR willingness for disaster communication.

As proposed by previous TAM studies, analysis of constructs of VR and gaming experience, perceived usability and perceived ease of use showed that people who had considerable experience with computer video games, VR, first shooter, and third-person role-playing games perceived the VR technology to be useful and usable and will in turn be more willing to adopt the technology for natural disaster risk communication. The number of hours per week spent on gaming and VR was also slightly significant but not as significant as experience. Overall, we found that those who perceive that VR is easy to use have the highest adoption tendencies. This provides insight that developing training programs that encourage the viewing or gaming with simulated natural disaster events can drive the interest and adoption of VR technology for natural disaster risk communication. However, several research limitations still need to be addressed in the future as the current study is directed to a sample of residents in Texas and will need to be confirmed with a nationally represented sample. The high proportion of respondents aged 55 and above is a limitation that can lead to the generalizability of the study's findings to younger populations. Similarly, the low proportion of respondents aged 18-24 years may mean that the experiences of younger individuals are not well-represented in the sample. Since this paper is a preliminary study to a larger study that elaborate other unique demograhic constructs, future studies are in progress to explore these factors further using these other identified TAM constructs, mediating factors and devise strategies to address the barriers to VR adoption.

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