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A study on increasing practical earthquake evacuation knowledge and awareness through serious games

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Abstract
Earthquake evacuation process as a behavioral component of disaster resilience is one of the issues addressed by risk reduction strategies at spatial and urban scales. A well-planned, self-organized evacuation that considers human behavior pattern can reduce the loss of life. In this context, it is possible to establish a civilian-supported evacuation scenario with the behavioral change to be gained at the community scale during and after the earthquake. Geologically, Türkiye is a vulnerable country in terms of earthquakes, and there is a lack of comprehensive earthquake evacuation drills and training in both digital and traditional contexts. Therefore, Türkiye needs to focus on immersive, integrated efforts to increase the knowledge and experience of evacuees during earthquake evacuation. After integrating the necessities identified in the Turkish context and the affordance and potentials of serious games in evacuation, we propose a serious game called EVAC. This proposed model involves a component that enables (1) an increase in the level of knowledge and learning of the evacuation scenario on an individual and collective scale and (2) helps anticipate unforeseen problems, needs, and requirements that may arise during and after the earthquake by enabling the transition to a safe area in case of panic. This model has another potential (3) by integrating indoor and outdoor evacuation, this model can manage the evacuation time of the evacuees from the building, the roles they will gain when they arrive at the emergency assembly area, and the ability to provide civil organization in the area with cooperation.

Keywords
Disaster risk reduction, Earthquake evacuation, Evacuation knowledge, Serious game.

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1. Introduction

In the history of humanity, unpredictable natural disasters have caused significant loss of life. Within the scope of disaster risk reduction strategies, there is a preparation phase related to human behavior both on a structural scale and at the time of emergency. To build a disaster-resilient society, drills, training, and agent-based simulations are applied to improve the evacuation process and to complete the process on time and safely. Simulations are mainly used to measure the operability of exit points and evacuation time in buildings (Daude et al. 2019), while agent-based simulations are combined with various computational tools, such as cellular automata and social force models to describe the human behavior pattern during evacuation (Bernardini et al., 2016; Chapuis et al., 2022; D'Orazio et al., 2014; Iskandar et al., 2021; Serok & Blumenfeld-Lieberthal, 2015; Siyam et al., 2019; Sun et al., 2021; Tsai et al., 2011; Zhong et al., 2023). It would be easier to interpret human behavior during panic when human behavior in real earthquake videos and simulations is considered together. While all these studies are carried out to identify and predict human behavior during evacuation, the aim is to improve the process.

Şahin et al., (2019) demonstrate that improving human behavior through drills and training is possible. However, traditional disaster training, short videos, and earthquake booklets may not be sufficient for a successful evacuation since it will be difficult for individuals to remember and apply the theoretical knowledge, they have acquired about the process due to increasing panic and fear in an emergency. Since the regular experience of the acquired theoretical knowledge will reinforce the previous knowledge, gamification of the process in various scenarios with earthquake simulation that provides sensory and cognitive fidelity parameters in a virtual reality environment will possibly increase the success achieved in the evacuation process. Establishing a well-planned, self-organized, civilian-supported evacuation scenario with the behavioral change to be gained at the community scale during and after the earthquake is conceivable.

Türkiye is situated in a region where a major earthquake fault is named the North Anatolian Fault and has historically been the site of many strong earthquakes (Erdik, 2013). In the face of the expected Great Marmara earthquake and other possible earthquakes, the country needs social awareness and structural resilience. Improving evacuation practices during and after earthquakes and increasing awareness can prevent collective panic and secondary disasters. Therefore, society needs to gain behavioral resistance and receive disaster training in a repeatable way through direct experience. Under these needs, the study proposes a serious game model produced in a fully immersive environment to make the evacuees feel the shocking effect of the earthquake moment in a sensory, cognitive, and narrative way. This training game aims to enable evacuees to use their decision mechanisms effectively in an increasingly panicky environment and to complete the process on time and safely with the increased earthquake knowledge of the evacuees in a mass evacuation. Another objective of this study is to strengthen the civilian organizations, support the division of labor among the evacuees, and create collaborative support with officials after the earthquake.

Within the scope of this study, conceptual and theoretical backgrounds, literature review, and evacuation game examples are discussed in the second section. The method of this study is discussed in the third section, which includes context analysis, literature review, and integration of current serious game design methodologies. In the fourth section, the contextual background of Türkiye concerning disaster training. The game proposal in the fifth chapter includes the game design process as a model proposal and the roles and requirements for the game creation process. The last part, the conclusion, covers the study's contribution to the field, its limitations, and potential for future studies.

2. Earthquake evacuation knowledge and awareness through serious games

Researchers have produced agent-based models for planning and improving the evacuation process and the emergency evacuation route of buildings within the scope of evacuation models. In addition to agent-based models, some studies include models integrated with geographic information systems at the urban scale (Daude et al. 2019) or oppositely, some researchers use cellular automata and social force model to understand human behavior patterns in a micro-scale (Bernardini et al., 2016; Choi & Do, 2019; Quagliarini et al., 2014; Sun et al., 2021; Zhong et al., 2023). Since the evacuation process is complex and multidimensional, improving the behavior of evacuees is essential for the correct functioning of the process. Training and drills to improve human behavior during and after earthquakes are insufficient in directing the experience (Feng et al., 2022; Gwynne et al., 2020; Mitsuhara et al., 2023; Haghani, 2020; Rahouti et al., 2017). Within this perspective, it is crucial to feed by the learning-by-doing approach to improve the behavior of evacuees and thus ensure safe evacuation, which was focused on. This section will examine the conceptual and theoretical background and discuss game examples that aim to raise awareness of the earthquake evacuation process through serious games.

2.1. Conceptual and theoretical background

Natural hazards such as earthquakes, floods, or hurricanes are unavoidable phenomena; however, their transformation into disasters largely depends on the vulnerability and preparedness of societies. While hazards cannot be entirely prevented, they can often be predicted, and it is possible to build societal and structural resilience to reduce their devastating impacts. According to the United Nations General Assembly (2016), vulnerability is defined as "*The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards*" (p. 24). Hyogo Action Framework Plan (2005-2015) draws attention to the vulnerable aspects of individuals who are victims of poverty and injustice caused by income inequality and disadvantaged groups, defines their risks to reduce disaster losses, and argues that vulnerable societies become vulnerable to disasters. Within this perspective, disaster risk management cycles have been universally accepted to prevent this inequality and the devastating effects of disasters. The disaster management cycle has two main parameters, risk management (pre-disaster) and crisis management (post-disaster); while risk management includes preparation and risk and damage reduction strategies, crisis management includes response, recovery, and reconstruction strategies (Kadıoğlu, 2022). *Risk reduction* strategies consist of two categories: structural and non-structural. Structural measures can be summarized as infrastructure, transportation, resettlement, and physical structure reinforcements, while non-structural measures can be summarized as calculation of vulnerability level, risk assessment, identification of hazards, financing preparations, supervision, education, awareness raising, and community participation (United Nations Office for Disaster Risk Reduction, 2005).

Earthquakes are the most frequent disasters and the ones that cause the most loss of life. Similarly, to provide structural and non-structural resilience for earthquake risk management strategies. The evacuation process is a critical component of preparedness and risk reduction strategies. Evacuation plans and drills may not be sufficient in the crisis, and unforeseen problems may arise (Daude et al., 2019). In contrast, a well-planned and self-organized evacuation can reduce casualties (Yao & Zhang, 2021). Therefore, to reduce casualties from earthquakes and damages from secondary disasters, it is critical to anticipate the behavioral responses of evacuees and the structural strength of the buildings, ensure that the emergency exit plan is functioning correctly, and create timely and safe evacuation plans.

Information on the well-known evacuation practice is often delivered through traditional training approaches such as courses, seminars, videos, posters, or drills. Every building has an emergency exit plan, rules, maps, signages, and actions prominently displayed on the walls. There are also traditional drill practices periodically, especially in schools. For training methods, there are new technological proposals for education and gamification of the evacuation process; these games are aimed at experiencing disasters rather than watching videos for children.

Those traditional methods, drills, and warnings are responsible for the earthquake moment, and they should be considered as preparedness strategies for the community. Researchers also need to analyze and evaluate evacuation process and propose well-planned and safe evacuation routes. There are some techniques to evaluate the evacuation process, a standard method is the analysis of *videos* that record the moment of the earthquake, researchers can analyze people one by one and examine the behavior of evacuation in interior and exterior environments. The other method is creating *simulations* as agent-based models in a virtual world that use people as agents and examine the behavioral patterns of emergency evacuation. While the technology developed, earthquake evacuation processes are also modeled on the virtual world, researchers can create simulations by replicating real earthquake moments on building models.

2.2. Literature review

The literature review on the evacuation process is considered in two different frameworks as: (1) the studies to plan and improve the evacuation process of researchers and the emergency evacuation route of buildings (Bernardini et al., 2016; Chapuis et al., 2022; D'Orazio et al., 2014; Daude, et al., 2019; Iskandar et al., 2021; No et al., 2020; Serok & Blumenfeld-Lieberthal, 2015; Siyam et al., 2019; Sun et al., 2021; Tsai et al., 2011; Tsurushima, 2020; Yamamoto & Li, 2017; Zhong et al., 2023) and (2) the activities addressed within the scope of evacuation training to improve the behavior of evacuees during the evacuation process (Feng et al., 2018; Filomena et al., 2023; Gwynne et al., 2020; Kolen et al., 2011a ; Suwanmolee, 2018). The first framework consists of micro and macro scale simulations, simulations tested by real-time evacuation videos, and simulations considering human behavior patterns. The second framework includes traditional drill approaches and gamification of the evacuation process.

Within the framework of emergency evacuation plans and behavior models, studies in the literature that aim to produce safe evacuation plans and improve the current situation with evacuation simulations on an urban scale. While integrating geographical and social data with a high level of detail, it is possible to simulate a community's evacuation scenario, and the simulations produced are suitable tools for studying how the overall dynamics of an evacuation can be affected by environmental factors (Daude et al., 2019). One of the most widely used models in earthquake evacuation simulations is Agent-Based Model (ABM), pedestrians are represented as agents that can perceive and interact with their environment and other agents (Bernardini et al., 2016; Chapuis et al., 2022; D'Orazio et al., 2014; Iskandar et al., 2021; Serok & Blumenfeld-Lieberthal, 2015; Siyam et al., 2019; Sun et al., 2021; Tsai et al., 2011; Zhong et al., 2023). Researchers use agent-based models by integrating other computational models according to the research area. Some of the researchers use Geographic Information System (GIS) for macro scale evacuation simulations to generate the shortest evacuation distance and evacuation route blockages based on the probability of collapse of buildings and use it to establish the safest evacuation route recommendation (No et al., 2020; Sun et al., 2021; Yamamoto & Li, 2017). However, most agent-based models have focused only on modeling the physical interactions between agents, representing cognitive knowledge, and complex and heterogeneous behavior modeling is a more complex process. Evacuation simulations do not adequately address human behavior at the individual, group, or interpersonal level.

While these simulations calculate evacuation routes, some researchers add computational approaches to assume human behavior patterns and create self-organized evacuation processes. Sun et al. use the Cellular Automata (CA) model to create a crowd reaction rule equation in emergency situations, and they demonstrate that as much as evacuees are familiar with the exit, it increases evacuation efficiency (2021). Zhong et al. also focused on the non-structural components of the evacuation process by modeling the interaction between pedestrians with a Cellular Automata approach (2023). The Social Force (SF) model is also used in some studies to calculate the attractive and repulsive forces a pedestrian feels toward various aspects of the evacuee's environment and to predict the evacuation process (Bernardini et al., 2016; Choi & Do, 2019; Quagliarini et al., 2014). Some of the researchers use simulations and real earthquake moment video analysis together to create correlations between real and virtual evacuations and they try to examine evacuees' behavioral patterns during and immediately after earthquake (Bernardini et al., 2016; Lambie et al., 2016; Quagliarini et al., 2021; Tsai et al., 2011; Tsurushima, 2020; Zhong et al., 2023).

Agent-based simulations can guide decision makers on managerial issues such as emergency exits, evacuation routes, and shelter determination at the macro scale, and information on human and environment, human and human interactions can be obtained in models where simulations and computational models are integrated to include human behavior patterns at the micro-scale. However, it is also necessary to focus on the studies addressed within the scope of evacuation training to improve the behavior of evacuees during evacuation. Hence, simulations and video analysis within the earthquake risk reduction studies' scope need to be more comprehensive to prepare for the evacuation process.

Research on expected human behavior during earthquakes is based on simulations or post-event interviews and surveys, which have limitations such as the participant's willingness and memory to recall the event and the perceived reality of the simulation (Lambie et al., 2016). Evacuation simulations create a virtual environment and virtual behavior for evacuees, people move as ideal agents without thinking about social background, which may affect the decision-making process in case of emergency in these simulations. Creating an effective and well-planned evacuation process could be possible for a single family on a micro scale. However, for public evacuation there are social, demographical, physical, and psychological factors for each agent and their response to earthquakes will be different from each other, as well as interactions between evacuees that can negatively affect the mass evacuation. Evacuees need to experience the process in the best way and prevent instinctive behaviors. According to Şahin et al. (2019), individuals tend to follow their instincts in the decision-making process at the macro level. Instincts are the fastest way to react to an event and do not require consciousness, in the decision-making process, individuals mostly stick to their past experiences and apply learned behavior; experienced individuals act more rationally instead of following their instincts, while inexperienced ones cause more panic and chaos in the crowd (Şahin et al, 2019).

Effective evacuation of individuals is one of the most critical objectives in an emergency such as an earthquake. However, due to the complex nature of dense urban areas, and the substantial lack of public awareness of emergency evacuation, and also unnecessary confusion, injuries, and fatalities have frequently occurred (Sun et al., 2021). Therefore, correct, and effective earthquake evacuation responses of individuals can significantly reduce unnecessary casualties.

For evacuation procedures, every building has the rules, maps, signages, and actions prominently displayed on the walls, but people may not be aware of these procedures, and they may not experience them because they tend to follow previously used and well-known routes that determined by the environmental setting itself (Filomena et al., 2023). Therefore, it is necessary to implement the exercise periodically. Information on the well-known evacuation practice is often delivered through traditional training approaches such as courses, seminars, videos, posters, or drills. However, more than these methods are needed for acquiring and retaining knowledge (Feng et al., 2018). One of the shortcomings of the traditional method is need for more feedback from individuals after the earthquake drill, which evaluates their behavior regarding evacuation processes (Gwynne et al., 2020). Also, these methods could be more impressive and have more sensory capabilities to refer to the earthquake scenarios to educate participants (Feng et al., 2022). As disaster risk reduction method, technology could be the medium; technological tools could have the ability to educate people via improved evacuation behaviors and decision-making mechanisms.

According to Suwanmolee (2018) through gameplay, knowledge of disaster risk reduction increases, and it becomes easier for participants to assess the situation, as well as an attitude of cooperation when communicating and negotiating for resources and behaviors of mutual assistance and sharing under limited resources. Increasing the chances of survival of earthquake victims after the shock of a chaotic situation such as an earthquake can be possible by improving the behavioral responses of building occupants to earthquakes and their evacuation skills, but traditional evacuation training approaches are insufficient to simulate earthquake scenarios (Feng et al., 2022). Filomena et al., (2023), who conducted a board game project designed by psychologists and geologists in contrast to traditional disaster education with passive participation within the scope of the seismic risk perception, stated that the game increased learning motivation as a result of this project with the young age group and emphasized that the game has the potential to develop risk response skills for their own safety and other members of the society beyond the acquisition of an excellent seismic risk perception by young people. The ability to experience the evacuation process through games in the real environment with virtual interfaces makes it possible to improve the immersive evacuation experience by repeating it, providing a “learning by doing” approach. In literature, evacuation games use different game approaches like game-based learning, gamification, and serious games, and there are different tools to create game environments for users named augmented reality, virtual reality, mixed reality.

Serious games have specific objectives and propose to transfer and abstract knowledge, train new skills, and change behaviors by creating awareness for the chosen scope. Concerning the evacuation and gamification process Feng et al., (2018) demonstrate that serious games can be adaptable for emergency education and evacuation and those games propose to educate participants by transmitting the knowledge of the game components even they can offer the possibility of behavioral analysis in case of emergency by monitoring and recording the decision process and behavior patterns during the experience. In short, introducing a new educational approach to earthquake evacuation training through serious gaming in a virtual reality environment participants’ perceptions of the realism of a simulation may alter their behavior and thus provide limited insight into their actions, sequence of actions, and the influence of contextual variables (non-time dependent) that prompt them to respond to earthquake shaking (Kolen et al., 2011a).

2.3. Serious games for earthquake evacuation

A serious game is a game designed primarily for purposes other than entertainment, such as education, training, or behavior change (Damaševičius et al., 2023). In the context of disaster preparedness, they have been increasingly recognized as effective tools to support evacuation training, as they allow individuals to experience decision-making, cooperation, and spatial orientation in simulated yet safe scenarios (Feng et al., 2018; Ribeiro et al., 2012; Yang et al., 2021). Traditional methods such as evacuation drills, written instructions, or seminars remain widely used; however, their effectiveness is often limited by three main factors: lack of realism and engagement, restricted adaptability, and insufficient educational efficiency (Gwynne et al., 2020; Mitsuhara et al., 2023; Haghani, 2020; Rahouti et al., 2017). These limitations can hinder the preparedness of individuals for real emergencies and highlight the need for more dynamic and interactive approaches.

In this regard, serious games present several advantages for evacuation education: (1) increased engagement and learning, (2) enhanced knowledge retention, (3) development of practical skills through scenario-based simulations, (4) inclusivity and accessibility (e.g., integrating the needs of disadvantaged groups), (5) adaptability and cost efficiency, and (6) cognitive and behavioral benefits that improve self-efficacy and performance during emergencies (Feng et al., 2018; Chittaro, 2023; Carvalho et al., 2022; Capuano et al., 2015). Recent studies further demonstrate that serious games, especially when supported by immersive technologies such as virtual reality (VR), provide participants with realistic and repeatable training experiences that outperform traditional methods in terms of learning outcomes, preparedness, and self-confidence (Mitsuhara et al., 2019; Feng et al., 2020; Rajabi et al., 2022; Ahmadi et al., 2024).

With the serious game proposal called SPOEL, which emphasizes the importance of both simulated and actual testing of mass evacuation planning by the government and the public and aims to prevent problems arising from the lack of real evacuation experience, Kolen et al. (2011) aimed to close the experience gap in emergency planning. SPOEL is a computer game focused on flood evacuation and is known as one of the first digital game examples. Another macro scale game example is an Augmented Reality-based game that focuses on the mass evacuation of a university building (Figure 1). In the study, which emphasizes that community members should be trained with the latest equipment and technology within the scope of experiencing procedures and rules within the scope of evacuation training, which has a vital role in emergencies, *game-based learning* systems, and AR technology were used, various animations were used in training aimed to provide access to the shortest and safest evacuation, and the mobile application tested in the university environment enabled the participants to be trained in a real environment, and positive responses were received from the people who received the training (Catal et al., 2020).

Figure 1. *Evacuation game various scenes (Catal et al., 2020).*

In another study that uses Virtual Reality (VR) technology and proposes the use of innovative digital technologies in the face of traditional drills and training that are insufficient to simulate a life-threatening earthquake scenario, a *serious game* training system was proposed to improve behavioral responses to earthquake and post-earthquake evacuation preparedness involving both employees and patients (Figure 2). an increase in self-efficacy and knowledge was observed after the game and the training was found valuable and instructive by the participants (Feng et al., 2020). The same researchers of this study propose another game after a few years that combines with Immersive Virtual Reality (IVR). In addition to the previous study, in the study aiming to analyze common earthquake behaviors, behavioral sequence analysis (BSA), which is used to understand and model individual behaviors during an earthquake, was adapted to the earthquake drill in a virtual environment, verbal protocol analysis to determine the behavioral sequence of the participants, video analysis obtained from the images of the behaviors exhibited in the IVR environment, and a picture of emergency human behaviors was revealed; it was possible to develop behavior-oriented strategies for earthquake emergencies (Feng et al., 2022).

As an example of a gamification study focusing on the optimization of the plan schemes of buildings and emergency exit routes for indoor evacuation, which is handled within the scope of mass evacuation, the issue addressed in the virtual reality-based game focusing on the evacuation of a hotel building is the analysis of undesirable route selection strategies and the tendency to retreat during evacuation, according to the findings of the researchers, the tendency to retreat is related to spatial configurations and the flatness, visibility, and width of the evacuation corridor led to a decrease in the tendency to retreat (Snopková et al., 2022). Studies focusing on earthquake scenarios at the micro-scale often aim to train evacuees or mitigate damage through spatial adjustments and improvements to avoid secondary disasters and accidents during and immediately after an earthquake. Within

Figure 2. *The storyline of the IVR SG training systems (Feng et al., 2022).*

the scope of indoor evacuation, a virtual reality-based serious game is proposal addressing earthquake scenarios in office environments. Four different methods were applied, and participants were tested: virtual reality-based serious game, video game, manual training, or no training method, compared to conventional exercises, participants were able to avoid physical damage and identify potentially dangerous objects (Li et al., 2017). In Indonesia, traditional evacuation drills with self-rescue practice are used in schools and offices, but Wibisono (2019) proposed a new tool for situations such as lack of seriousness, earthquake shaking sensation, and lack of full involvement of participants in the evacuation. They proposed a virtual reality technology-based model that is experienced individually and creates the feeling of shaking. The experimental group was selected from students who play games for 2-3 hours a day, and most of the students found the designed model more effective than static drills or animations and videos because of the direct interaction with virtual objects and the reality of the earthquake feeling (Wibisono, 2019).

When the studies in the literature on earthquake evacuation through serious play, which is one of the immersive education methods that surpass traditional drills in order to reduce the damage that will occur during and after the earthquake, were examined, most of the existing studies have focused on virtual reality (VR)–based serious games that provide *individual* evacuation experiences within indoor spaces or specific public buildings (e.g., Mitsuhara et al., 2019; Feng et al., 2020; Rajabi et al., 2022; Zhang et al., 2023). In these works, the main emphasis has been on knowledge gain, self-efficacy, and evacuation performance at the individual level, while the role of social influence and multi-user interaction has largely been overlooked. As a matter of fact, when it comes to mass evacuation, there is still no collective game design that enables immersive *multi-user* experiences in public spaces where evacuees move simultaneously and influence each other's decisions (Baraldo & Di Franco, 2024; Liu & Liu, 2025).

When the games and simulations are analyzed, no model has been proposed that provides structured feedback on the adequacy and accessibility of emergency gathering areas, the time required to reach them, or the identification of spatial needs and deficiencies at the final stage of evacuation. Among the studies, there is also a lack of inclusive approaches that incorporate task distribution and division of labor in collective evacuation management, as well as the involvement of vulnerable groups such as the elderly, children, or disabled individuals (Quagliarini et al., 2020; Zhu & Li, 2021). This study, which proposes a new game approach based on the gaps in the literature and existing game proposals, aims to identify and fill the existing gaps.

3. Methodology

This chapter outlines the research methodology adopted in this study, which integrates content analysis, a comprehensive literature review, and the examination of serious game methodologies. While content analysis contains worldwide evacuation practices, earthquake training given within the scope of disaster relief by the Disaster and Emergency Management Presidency (AFAD) in Türkiye, and earthquake evacuation training included in the school curriculum determined by the Ministry of National Education (MEB), the scope and implementation details of which are elaborated in Chapter 4. Within the scope of content analysis, practices regarding evacuation drills, evacuation training, and earthquake training were investigated both around the world and in Türkiye. Widespread and effective methods of public participation have been identified around the world, especially in Japan, Chile, America, and India. This phase, it is examined applications, evacuation and earthquake information booklets, and traning methods worldwide that focus on disaster evacuation education in a collective and participatory way.

A wide scope literature review was conducted on the given keywords between March 2023 and December 2023 by scanning existing literature databases (Web of Science, Scopus, Google

Scholar). The literature review briefly started by examining evacuation models on macro scale and micro scale evacuation simulations, including human behavior. The keywords commonly used at this literature review phase are as follows "Agent-based Models, Mass Evacuation, Behavioral Models, Post-earthquake Evacuation, Pedestrians Behavior Modelling". In the second phase of the literature review, earthquake education methods and the current situation on gamification within the scope of earthquake drills and training were reviewed. The keywords commonly used in the second phase of the literature review are as follows "Earthquake Evacuation Drills, Community-based Drills, Panic Effect, Serious Games, Education for Disaster Prevention".

To trace topic dynamics, we queried Web of Science for five review-structuring keywords—agent-based model, behaviour model, earthquake drill, mass evacuation, and serious game—and exported yearly publication counts for 2010–2023 (Figure 3). For cross-term comparability, we computed a Relative Growth Index by normalizing each series to its 2010 value = 100 (Indext_tt = 100 × Countt_ tt/Count2010_{2010}2010). The resulting trajectories depict timeline trends independent of absolute volume (e.g., an index of 300 indicates a three-fold increase over 2010). Counts are compiled per keyword; a single paper may appear under multiple keywords, so the curves represent trend dynamics rather than a deduplicated corpus total. This benchmarked view supports identifying which concepts accelerated or plateaued over the period and informs priority areas for subsequent studies. Briefly, all five keywords grow relative to 2010; *agent-based model* and *behaviour model* rise steadily, *serious game* accelerates circa 2014–2019 then flattens after 2020, while *earthquake drill* and *mass evacuation* are more volatile—consistent with event-driven attention and low-base effects.

After content analysis and literature review to propose a serious game, another method was an examination of current serious game methodologies, which have comprehensive and multidisciplinary frameworks.

4. Contextual background

Earthquakes impact millions of people around the world and cause loss of life and economic and environmental losses. While structural resilience technology is improving, managing risks by changing behavioral responses before, during, and after the earthquake it is also possible. In this direction, some earthquake education

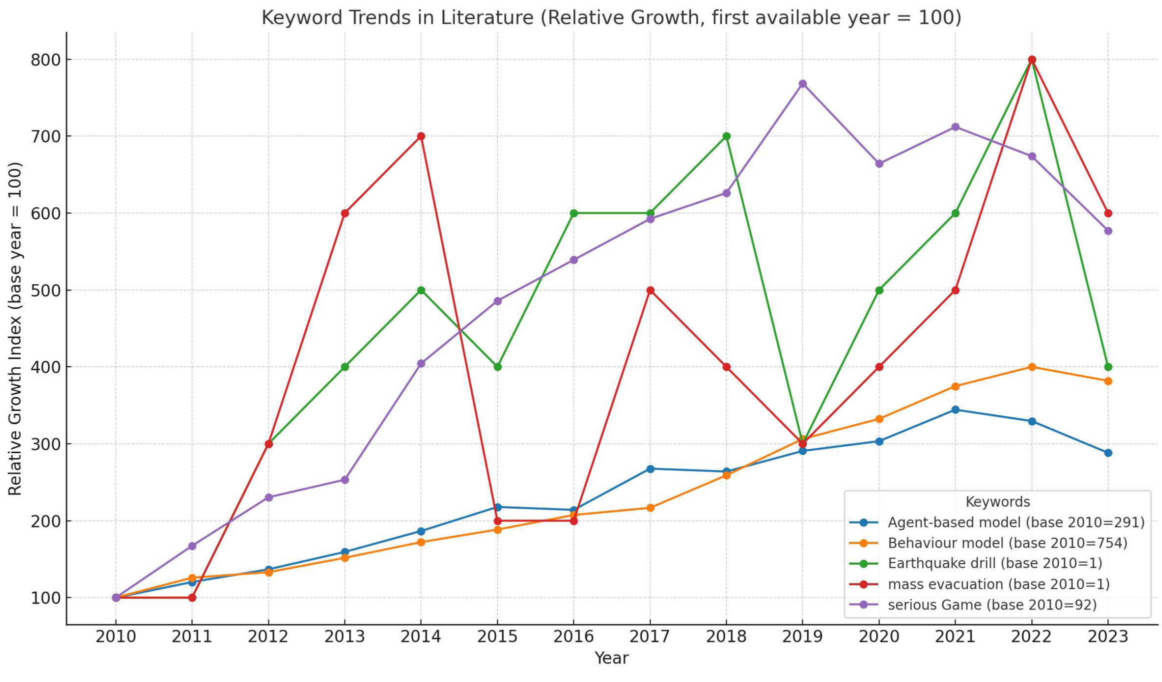


Figure 3. *Keyword trends in the earthquake-evacuation literature (2010–2023, Web of Science).*

systems cover evacuation procedures and civilian-supported systems after the earthquake worldwide. ShakeOut and NETAP training, organized every year in America in cooperation with FEMA, is another disaster training program that combines theoretical and practical training consisting of different modules and stages carried out by the American Red Cross which takes place with the participation of millions of people. These drills enable individuals and communities to learn how to behave during an earthquake (ShakeOut, n.d. ; Federal Emergency Management Agency, n.d.). Japan is known as one of the most prepared countries in terms of earthquake training and disaster preparedness. The training day, called Disaster Prevention Day, is held regularly and collectively on September 1 every year (Shaw et al., 2004). India also developed an earthquake education program called the School Earthquake Laboratory Program (SELP) to increase students' earthquake awareness. SELP has an interactive and participatory learning method, and laboratories have been established, especially in earthquake risk areas (Bansal & Verma, 2013). Chile is another country that has improved evacuation education after Japan, the National Disaster Prevention and Response Service (SENAPRED) has introduced an interactive application called "Visor Chile Prepared"; thanks to this application, anyone who wishes will be able to learn about their exposure to natural disasters based on their location. The aim is for the application to become a tool for the community to develop their planning, as well as provide the user with images of structures, roads, and topography. It allows viewing of education, health, police points, evacuation areas, emergency meeting points, and evacuation routes (Prepared Chile Map Viewer, n.d.).

Türkiye is situated in a border region where Arabian and African lands drift northwards toward Eurasia. In the northern part of the country, a major earthquake fault named the North Anatolian Fault and historically been the site of many strong earthquakes (Erdik, 2013). Between 1900 and 2023, 75 earthquakes bigger than 6.0 magnitudes took place in Türkiye, while 80.876 people died in earthquakes between 1900-2000, this number was 60.317 in the last 23 years, between 1900 and 2023, 141.179 people died, and 17 million people have been directly affected by earthquakes (Emergency Events Database [EM-DAT], 2023). In 1999 the Marmara earthquake affected seven cities with 7.4 magnitudes and caused 17.480 deaths. Lastly, on February 6, 2023, two major earthquakes occurred on the Eastern Anatolian Fault, which had 7.6 and 7.7 magnitudes, and they affected 11 cities and more than 9 million people, 50.783 people died in those earthquakes (United Nations Population Fund, [UNFPA], 2023) (Figure 4). These earthquakes were recorded as the most hazardous in the country's history, generating severe spatial problems such as the suspension of education, difficulties in temporary settlements, and challenges in meeting the needs of disadvantaged groups (Presidency of the Republic of Türkiye, Department of Budget and Strategy, 2023; Gün et al., 2025).

While earthquake risk increases yearly, the Marmara region is expected to experience a major earthquake, as experts have warned for a long time. Therefore, all the official units of Tür-

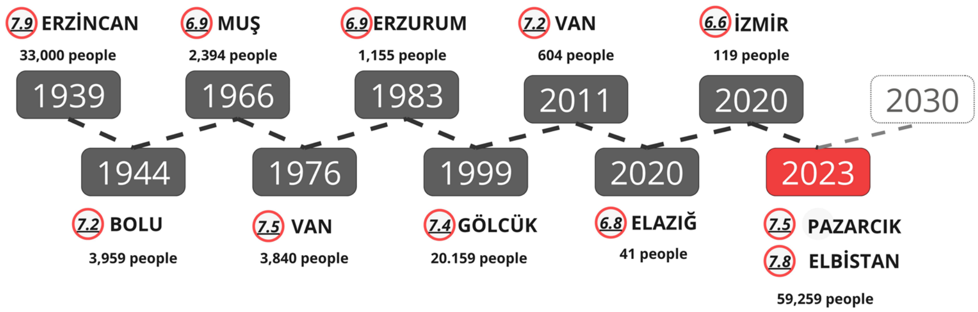


Figure 4. *Earthquakes year, magnitude, and life losses in Türkiye between 1939-2023.*

kiye should focus on disaster risk management and risk reduction strategies. In this regard, increasing knowledge and awareness about the earthquake and evacuation process it is essential to training and educating the evacuees.

The Disaster and Emergency Training Center (AFADEM), which was established in 1960 under the General Directorate of Civil Defense of the Ministry of Interior within the scope of disaster preparedness and raising awareness, has planned to provide effective, efficient, and sustainable services for training services with the mission of "creating a disaster-resilient society", AFADEM aims to improve pre and post-disaster behaviors with training such as "Disaster-ready family, disaster-ready school." Today AFADEM training facility includes classrooms for search and rescue and first aid courses. There are areas such as demolished buildings and wreckage areas for practical training (Afet ve Acil Durum Yönetimi Başkanlığı, n.d.).

Within the scope of earthquake education studies, the Japan International Cooperation Agency (JICA) and Ministry of National Education (MEB) prepared the "School-Based Disaster Education Project" in 2010 covering 80 schools in 10 provinces in order to raise awareness of teachers, students, and parents, the project working group is divided into three, the first group focuses on the implementation and dissemination of the project, the second group compares the education curriculum of Türkiye and Japan, the third group focuses on the school disaster and emergency management plan (Özmen & İnce, 2017). The second phase of the School-Based Disaster Education Project was implemented in 2019, and in this phase, contents such as proactive intervention against disasters for school administrators and teachers were updated. The Disaster Awareness Course Curriculum was developed as an elective course in lower secondary schools for grades 5, 6, and 7, and was approved by the Board of Education and Discipline in 2023. Its primary aim is to enable students to apply life skills in disaster situations, acquire first aid knowledge, understand the impacts of disasters on individuals, society, and the economy, predict possible outcomes, and internalize a culture of disaster awareness (Ministry of National Education [MoNE], 2023). Students take this course in two levels, "Disaster Awareness-1" and "Disaster Awareness-2," each consisting of 72 hours of instruction (Afet ve Acil Durum Yönetimi Başkanlığı, n.d.). In addition, the Disaster and Emergency Management Presidency (AFAD) also supported the development of updated course contents, digital learning materials, and teacher training modules (Özmen, 2023).

In the case of earthquakes, most of the studies focus on post-earthquake mitigation and reconstruction. However, pre-disaster measures have not been given enough importance, and training programs have not gone beyond annual earthquake drills. In İçme and Büyük (2023) study analyzing the curriculum for earthquake education in schools in Türkiye, they stated that there were deficiencies in the program prepared for children to receive earthquake education in schools, that classroom activities were limited to earthquake drills, behaviors that should and should not be done during an earthquake, and earthquake bag preparation, in addition, they stated that technological applications (video, simulation, augmented reality) were not included in school books to be used in earthquake education and that learning areas, learning by living and organizations were not taken into consideration within the scope of out-of-school training.

Doğan and Koç (2017), in their study investigating the increasing success rate of education through digital games, formed control and experimental groups of students whose prior knowledge was equivalent to each other, applied the traditional teaching method as in the textbooks to the control group and presented a computer-aided digital game to the experimental group, and it was observed that the academic achievement of the students in the experimental group for earthquake knowledge increased positively compared to the traditional method. In this direction, while digital games and simulations have an essential place in terms of attractiveness and retention of knowledge, their absence in the education programs of schools is a glaring deficiency (İçme & Büyük, 2023).

5. EVAC game model proposal

Contextual background describes another gap in the literature, and it has been determined that disaster trainings are limited to short narratives and videos containing theoretical information, especially at the primary school level. Traditional disaster training and drills are far from direct experience, and in unpredictable and chaotic situations such as earthquakes, it will be difficult to remember the theoretical knowledge with the increasing panic moment. Earthquake evacuation practice, which includes information about the measures to be taken immediately after the earthquake to protect against secondary disasters and about the division of labor that will trigger civilian organization sometime after the earthquake, and which is experienced in a virtual framework with specific repetitions, will both increased awareness on a social scale and facilitate the recall of information. In this direction, creating a game that will increase earthquake awareness by integrating learning objectives is possible; the game can be played in a different scenario in an immersive environment. The learning-by-doing approach can overlap and form the basis of practical and participatory evacuation training. When the games produced within the scope of earthquake studies are examined, the concept of serious games that provide the user with a new skill, education, and learning objectives comes to the fore.

According to Zyda (2005), a serious game is used in non-entertainment fields such as education, health, and communication to achieve a specific purpose. While the use of gamification is becoming widespread in the context of skill acquisition, construction of new knowledge, and interactive learning, according to Anderson, contemporary gaming technology is used to produce virtual worlds for interactive experiences that can include social interactions as well as mixed reality games that blend real and virtual interactions (Anderson et al., 2010). Games created in virtual environments give the player the chance of freedom and repeatability, allowing them to look at and interpret the problem from multiple perspectives (Marne et al., 2012). In this context, a virtual reality-based serious game model is proposed for the earthquake evacuation process, which is the behavioral component of the risk reduction strategies of the disaster management process, offering repeatable and multiplayer drills and training opportunities.

Since the serious game design process also involves knowledge building, learning objectives, and game objectives should be parallel, and the whole game creation process should be completed with the support of various experts. In this context, various methodologies exist within the scope of serious game creation in the literature. One of them, EMERGO methodology, is a study that proposes a holistic creation process including analysis, design, programming, implementation, and evaluation stages to ensure that game and learning objectives are consistent in the serious game development process (Nadolski et al., 2008). Shortly after this study, Marfisi-Schottman et al. (2010) proposed a methodology that includes pedagogical goals, design scenarios, visualization, and presentation and emphasized that cognitive experts, pedagogical experts, game designers, and graphic designer actors should act together. Jaccard et al. (2021) used a categorical approach to propose a methodology that addresses the general goals of the problem, game, and learning-oriented problem-solving those centers on the concept of learning and how to evaluate the solution from both a game and learning perspective. While the Jaccard methodology represents the building blocks and core elements of standard serious game design, it aims to be customizable for each project. The co.LAB framework is an open-access interface created by the Jaccard methodology researchers, adapted to a web platform that any serious game producer and stakeholders can use to control the development of serious game building blocks, work distribution, and project-specific re-organization of categories. Using the Jaccard methodology and the co.LAB web application, serious game building blocks can be constructed and tracked in a collaboratively. Furthermore, Pacheco-Velazquez et al. (2023) proposed a participatory approach to develop actor action schema in the serious game model proposal phase and emphasized the importance of roles and collaborative approaches in the serious game design process. According to Pacheco-Velazquez (2023), the purpose of the serious game is to disseminate knowledge, improve the skills of the players, and make the learning process meaningful for the participants, and the primary responsible actor in this process is the pedagogical expert, and the pedagogical expert should be the team leader at every stage of the process.

The new model, which integrates EMERGO, Jaccard, and Pacheco-Valezquez methodologies, describes the theoretical framework of the serious game creation process, including the context, goals, scenario, functions, and mechanics of the game in categorization, and serves as the basis for the following study with draft game visuals. The integrated model suggests multidisciplinary teamwork using a participatory approach within this perspective. Therefore, software developers, graphic designers, pedagogical experts, cognitive experts, and subject matter experts should collectively share a standard process by considering the game and learning objectives.

The "Context and Goals" category, which includes learning and game goals, combines game developer and pedagogical expert and is the basic building block of the game design process, where an overview of the problem and initial ideas about the solution is established. According to Jaccard (2021), this category is the part that guides the development team and is used for communication with stakeholders. In the "Game Definitions" category, which covers sub-headings such as the game's goals, rules, narrative and scenario, game interfaces, the game universe, and user experience, the game developer, graphic designer, cognitive expert, and pedagogical expert work together.

The "Mechanics" category includes game and learning mechanics, rewards, incentives and interactions, software development experts, game developers, graphic designers, and pedagogical experts working together. The feedback that players receive throughout the game and their actions change the course of the game, making it a meaningful game. The new information learned is linked to previous knowledge, and the player's active participation in the learning process is linked to the meaningful learning process. When meaningful play and meaningful learning are designed to support each other, meaningful serious games emerge (Jaccard et al., 2021).

In the "Pedagogical Objectives" category, which distinguishes serious games from other game types, the pedagogical expert and cognitive expert organize the user profile, pedagogical scenario, learning objectives, and learning basics. In this category, one of the appropriate learning theories should be selected to establish the learning foundations, the content related to the knowledge and skills that the player needs to acquire should be determined or verified by professional experts, and finally, the serious game should remain embedded in the pedagogical scenario with theoretical knowledge and personal work (Jaccard et al., 2021). The "Assessment" category, sub-titled game and learning evaluation, determines how the game and its objectives will be evaluated and includes data processing and visualization processes. At this stage, the software development specialist and graphic designer play a role together (Figure 5).

The proposed game model aims to collectively gain the practice of safe and timely evacuation during and after the earthquake in a multiplayer environment. The game is being played in a university and will be played in a class of 30 students with replacement headsets and controllers given to everyone. Each student will start the game simultaneously and see the earthquake shaking start in their classrooms in a VR environment, what to do during the earthquake shaking will be presented to the player by the game, and the students will wait safely until the shaking is over (Figure 6).

After the shaking, the evacuation process from the university building will begin, and the player will be given instructed by the game to ensure safe and timely access to the nearest emergency gathering area. At the end of the game, the player will be able to receive feedback from the game and have the chance to give feedback to the game (Figure 7).

The game aims to raise earthquake risk awareness and improve participants' evacuation knowledge and skills, in the context of earthquake evacuation, students will learn how to wait in a safe area, in an appropriate position during an earthquake, and how to evacuate from classrooms and school in a safe and timely manner immediately after the earthquake, and when they reach the emergency gathering areas, they will be able to divide the work in the gathering area according to the role distribution given by the game according to the player profile (Figure 8). The secondary objective of the game is to determine the adequacy and accessibility of the assembly area according to the current situation after evacuation.

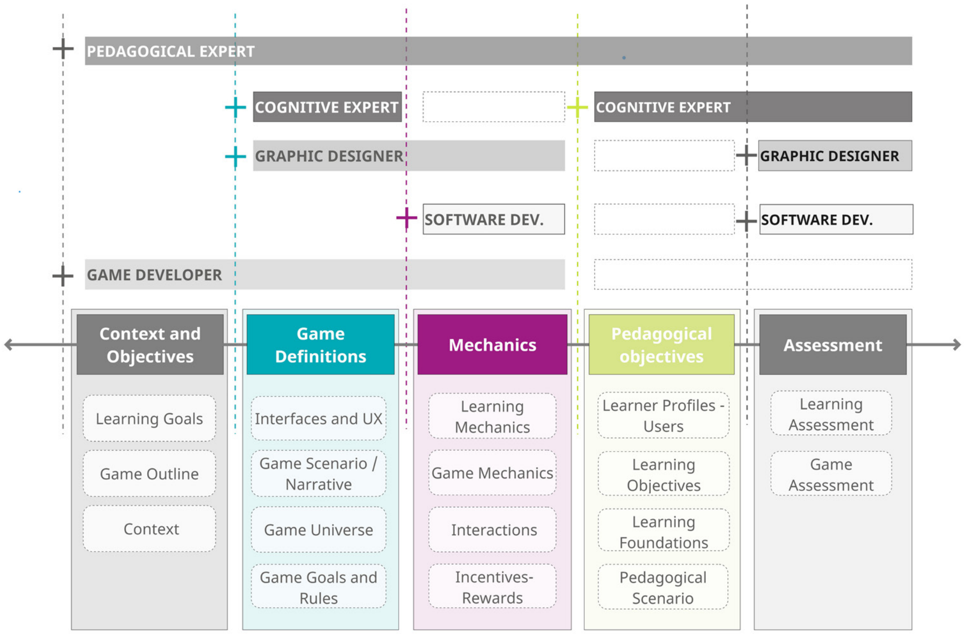
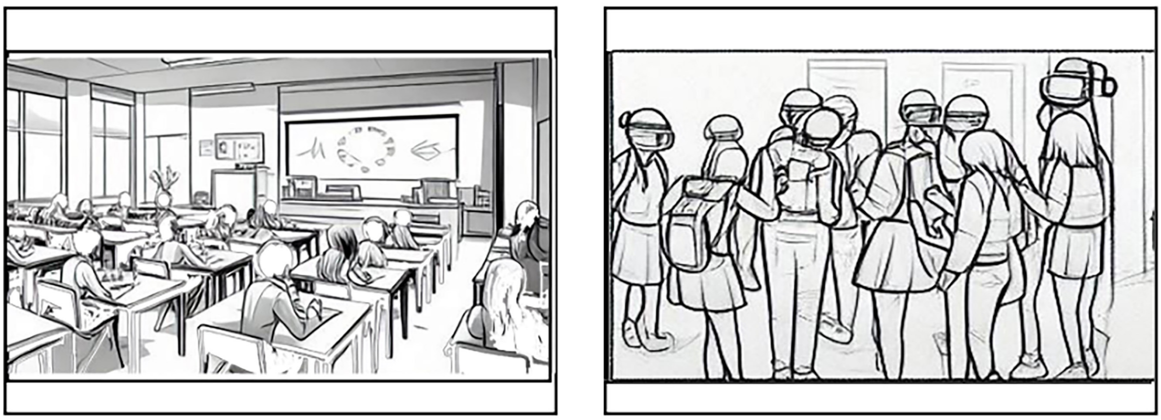


Figure 5. *New integrated model for the EVAC game development process in a structured approach.*



Information phase

In this phase instructors will give theoretical knowledge about earthquake, evacuation process and emergency assembly areas.

Preparation phase

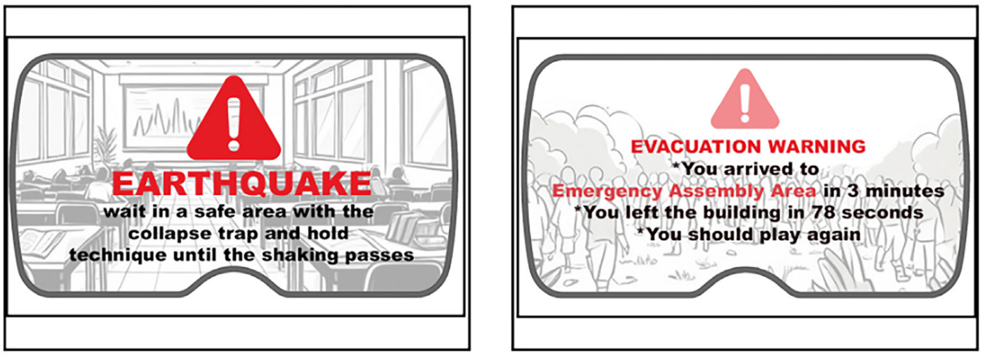
30 university students will start to play with replacement headset and hand controller to move in game; game will start the simultaneously .

Figure 6. *Information and preparation phase of the EVAC game.*

Constructivist and socio-constructivist learning theories are used within the scope of the proposed game. Those approaches make evacuees collectively experience earthquake evacuation in a real environment, learning is considered a process, and the importance of experience in the learning process is accepted. The game universe, defined as the world in which the game will be played, is a simulation of the earthquake moment, and players should follow a role-playing "pretend" scenario. The most critical building block of the game definitions category is the "player decisions" section, as the reality to be represented and the type of fidelity will determine the reflexes and decisions players should make in the simulation. Depending on the reality being simulated, one or more of the sensory (visual, auditory, and physical), narrative (story and narratives), and cognitive (reflexes) fidelity types can be used (Figure 9).

6. Conclusion

The evacuation process is one of the non-structural measures addressed within the scope of earthquake risk reduction strategies. Despite the panic experienced during an earthquake, a self-organized and collectively executed evacuation process can reduce the destructive impact of earthquakes and save lives. The post-earthquake evacuation process is complex and multidimensional. However, allowing evacuees to experience earthquake shaking and evacuation practices through a "learning-by-doing" approach can ensure a safer process.



Game phase

They will see the earthquake shaking start in their classrooms in VR environment. Students will wait safely until the tremor is over in a proper situation by orientation of the game.

Feedback phase

At the end of the game, the player will be able to receive feedback from the game and will also have the chance to give feedback to the game.

Figure 7. *Game and feedback phase of the EVAC game.*

Civilian supported process

it is possible to establish a well-planned, self-organized, civilian-supported evacuation scenario with the behavioral change to be gained at the community scale during and after the earthquake.

Role sharing

Within the scope of civil-based support there will be a role distribution phase given by the game according to the player profile.

Figure 8. *The EVAC game aims to create a civilian-supported system with a role-sharing approach.*

sensory and cognitive fidelity

The simulation of a dramatic and immersive natural event such as an earthquake should be realistic to simulate the moment of panic.

sensory and cognitive fidelity

To improve the player's ability to make decisions from the moment of the earthquake the simulation should aim to resemble reality sensually, narratively and cognitively as a fidelity criterion.

Figure 9. *Fidelity components of the EVAC game.*

In this context, we propose a serious game called EVAC. This game model aims to increase the level of knowledge and learning about evacuation scenarios on both individual and collective scales and to anticipate unforeseen problems by facilitating a safe transition to a secure area during panic. This study is designed as the first step in future research, with certain limitations. Within the scope of the EVAC game proposal, the scenario, development team, and theoretical framework of the game have been established. Since the game development phase has not yet begun, fieldwork has not been conducted, and the game has not been tested. As an immediate next step, we will run a small-sample pilot with volunteer participants once institutional ethics approval is granted and Law on the Protection of Personal Data (KVKK) -compliant procedures are in place (explicit consent, data minimization, de-identification, opt-out). The pilot will focus on pre–post evacuation knowledge, self-efficacy, route-choice accuracy, time-to-assembly, and cooperation metrics using interaction logs and questionnaires (no psychophysiological sensors at this stage).

In the long term, the aim is for a broader audience to play the game, expanding the dataset to gather more information about the evacuation process. To clarify intended use and evaluation logic, we outline representative scenarios and expected results: (i) multi-storey school building with/without a designated leader—expected shorter decision latency and fewer wrong turns with leadership; (ii) blocked exits and dynamic hazards (aftershock, alarm)—expected faster re-routing and reduced bottleneck dwell time after training; (iii) inclusive evacuation with a mobility-restricted peer—expected higher help rates and clearer task allocation with minimal penalty to time-to-assembly; (iv) building-to-assembly-area leg—expected more accurate assembly-area selection, fewer backtracks, and improved role distribution (guide/scout/helper) under time pressure. These pilotable scenarios are designed to yield actionable, quantitative signals that inform iteration on core mechanics and feedback design.

In the upcoming stages, students' evacuation knowledge and skills will be measured through various practices, particularly interviews with authorities, to collect data for the game development process. These two preliminary studies will provide different data to the development team, and the game creation process is planned to start after these stages. This study contributes to the field by proposing a comprehensive, participatory, and multidisciplinary game development approach, based on the analysis of the current situation and content, as well as identifying gaps in the literature. The EVAC game aims to improve earthquake evacuation practices, increase awareness, and establish a civil support system with a mutual aid approach in the immediate aftermath of an earthquake. The EVAC game universe is designed to simulate the moments during and after an earthquake in the real world. With this proposed model, the foundations of the EVAC game have been laid, particularly the general framework for actor action distribution during the game production process. The VR-based evacuation game is expected to allow students to experience the earthquake and its aftermath, control the panic moment, and fulfill their duties by coping with the shock immediately after the earthquake. In the future, it is planned to obtain implicit behavioral data, such as eye movements, EEG, and other health metrics, through VR technology during panic, which will help inform decision-making mechanisms. This data will enable us to achieve results that can influence decision-makers, such as evacuation times at structural and urban scales and accessibility to emergency gathering points. In sum, the staged plan—pilot first, then extended evaluation—addresses the current limitation (no test yet) and derisks later deployment by producing early evidence on knowledge gains and behavioral outcomes under socially realistic conditions.

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References

Ahmadi, M., Yousefi, S., & Ahmadi, A. (2024). Exploring the Most Effective Feedback System for Training People in Earthquake Emergency Preparedness Using Immersive Virtual Reality Serious Games. *International Journal of Disaster Risk Reduction*, 104630. https://doi.org/10.1016/j.ijdrr.2024.104630

Afet ve Acil Durum Yönetimi Başkanlığı. (n.d.). *Eğitimler*. Retrieved August 20, 2024, from https://www.afad.gov.tr/egitimler.

Anderson, E.F., McLoughlin, L., Liarokapis, F. *et al.* Developing serious games for cultural heritage: a state-of-the-art review. *Virtual Reality* 14, 255–275 (2010). https://doi.org/10.1007/s10055-010-0177-3

Bansal, B. K., & Verma, M. (2013). Science and technology based earthquake risk reduction strategies: The Indian scenario. *Acta Geophysica*, *61*(4), 808–821. https://doi.org/10.2478/s11600-013-0105-5

Baraldo, M., & Di Franco, P. D. G. (2024). Place-centred emerging technologies for disaster management: A scoping review. *International Journal of Disaster Risk Reduction*, 104782. https://doi.org/10.1016/j.ijdrr.2024.104782.

Bernardini, G., Quagliarini, E., & D'Orazio, M. (2016). Towards creating a combined database for earthquake pedestrians' evacuation models. *Safety Science*, *82*, 77–94. https://doi.org/10.1016/j.ssci.2015.09.001

Catal, C., Akbulut, A., Tunali, B., Ulug, E., & Ozturk, E. (2020). Evaluation of augmented reality technology for the design of an evacuation training game. *Virtual Reality*, *24*(3), 359–368. https://doi.org/10.1007/s10055-019-00410-z

Capuano, N., & King, R. (2015). *Adaptive serious games for emergency evacuation training*. In *2015 International Conference on Intelligent Networking and Collaborative Systems* (pp. 308–313). IEEE. https://doi.org/10.1109/INCoS.2015.32

Carvalho, P. V. R., Santos, I. L. C., & Gomes, J. O. (2022). Using serious game in public schools for training fire evacuation procedures. *International Journal of Serious Games, 9*(3), 23-39. https://doi.org/10.17083/ijsg.v9i3.476

Chapuis, K., Minh-Duc, P., Brugière, A., Zucker, J.-D., Drogoul, A., Tranouez, P., Daudé, É., & Taillandier, P. (2022). Exploring multi-modal evacuation strategies for a landlocked population using large-scale agent-based simulations. *International Journal of Geographical Information Science*, *36*(9), 1741–1783. https://doi.org/10.1080/13658816.2022.2069774

Chittaro, L. (2023). *Improving knowledge retention and perceived control through serious games: A study about assisted emergency evacuation*. *IEEE Transactions on Visualization and Computer Graphics, 30*(8), 5339–5349. https://doi.org/10.1109/TVCG.2023.329473 Choi, S., & Do, M. (2019). Effect of Evacuation Information and Evacuation Behaviors on High-Rise Apartment Residents. *KSCE Journal of Civil Engineering*, *23*(11), 4886–4897.

Damaševičius, R., Maskeliūnas, R., & Blažauskas, T. (2023). *Serious games and gamification in healthcare: A meta-review*. *Information, 14*(2), 105. https://doi.org/10.3390/info14020105

Daudé, E., Chapuis, K., Taillandier, P., Tranouez, P., Caron, C., Drogoul, A., Gaudou, B., Rey-Coyrehourcq, S., Saval, A., & Zucker, J.-D. (2019). *ESCAPE: Exploring by simulation cities awareness on population evacuation*. In *Proceedings of the 16th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2019)* (pp. 76–93). https://shs.hal.science/halshs-02144058

D'Orazio, M., Spalazzi, L., Quagliarini, E., & Bernardini, G. (2014). Agent-based model for earthquake pedestrians' evacuation in urban outdoor scenarios: Behavioural patterns definition and evacuation paths choice. *Safety Science*, *62*, 450–465.

Dogan, E., & Koc, H. (2017). The Impact of Instruction Through Digital Games on Students Academic Achievement in Teaching Earthquakes in a Social Science Class. İnternational Journal of Turkısh Education Science. 5 (8), 90-100.

Emergency Events Database (EM-DAT). (2023). *Disaster profile of Turkey (1900–2023)*. Retrieved July 15, 2023, from https://www.emdat.be

Erdik, M. (2013). Earthquake Risk in Turkey. *Science*, *341*(6147), 724–725. https://doi.org/10.1126/science.1238945

Federal Emergency Management Agency. (n.d.). *Earthquake training courses*. U.S. Department of Homeland Security. Retrieved August 18, 2024, from https://www.fema.gov/emergency-managers/risk-management/earthquake/training/courses

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers & Education*, *127*, 252–266. https://doi.org/10.1016/j.compedu.2018.09.002

Feng, Z., González, V. A., Amor, R., Spearpoint, M., Thomas, J., Sacks, R., Lovreglio, R., & Cabrera-Guerrero, G. (2020). An immersive virtual reality serious game to enhance earthquake behavioral responses and post-earthquake evacuation preparedness in buildings. *Advanced Engineering Informatics*, *45*, 101118. https://doi.org/10.1016/j.aei.2020.101118

Feng, Z., González, V. A., Spearpoint, M., Thomas, J., Trotter, M., Cabrera-Guerrero, G., & Paes, D. (2022). A sequence analysis of behaviors in immersive virtual reality for indoor earthquake and post-earthquake evacuation. *International Journal of Disaster Risk Reduction*, *75*, 102978. https://doi.org/10.1016/j.ijdrr.2022.102978

Filomena, M. G., Pace, B., De Acetis, M., Aquino, A., Crescimbene, M., Pace, M., & Alparone, F. R. (2023). Play to Learn: A Game to Improve Seismic-Risk Perception. *Sustainability*, *15*(5), 4639. https://doi.org/10.3390/su15054639

Gün, A., Pak, B., & Bakan, K. (2025). Empowering communities through social design practices: Lessons learned from post-disaster practices in Türkiye. *A|Z ITU Journal of the Faculty of Architecture 21,* (1), 233-259. https://doi.org/10.58278/0.2025.73

Gwynne, S., Amos, M., Kinateder, M., Benichou, N., Boyce, K., van Der Wal, C. N., & Ronchi, E. (2020). The future of evacuation drills: Assessing and enhancing evacuee performance. *Safety Science*, *129*, 104767. https://doi.org/10.1016/j.ssci.2020.104767

Haghani, M. (2020). Optimising crowd evacuations: Mathematical, architectural and behavioural approaches. *Safety Science, 129*, 104743. https://doi.org/10.1016/j.ssci.2020.104743

Iskandar, R., Dugdale, J., Beck, E., & Cornou, C. (2021). *PEERS: An integrated agent-based framework for simulating pedestrians' earthquake evacuation*. In *Proceedings of the 18th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2021)* (pp. 86–93). https://hal.science/hal-04196478

İçme, T., & Büyük, U. (2023). Türkiye'de deprem eğitimi: Fen bilimleri ders kitaplarının deprem eğitimine yönelik analizi. *MANAS Sosyal Araştırmalar Dergisi*, *12*(3), 944–958.

Jaccard, D., Suppan, L., Sanchez, E., Huguenin, A., & Laurent, M. (2021). The co. LAB generic framework for collaborative design of serious games: development study. *JMIR serious games*, *9*(3), e28674. doi: 10.2196/28674

Kadıoğlu, M. (2022). *Afet yönetimi: Beklenilmeyeni beklemek, en kötüsünü yönetmek*. Marmara Belediyeler Birliği.

Kolen, B., Thonus, B., Zuilekom, K. M., & de Romph, E. (2011). *Evacuation: A serious game for preparation*. In *Proceedings of the 2011 International Conference on Networking, Sensing and Control* (pp. 317–322). IEEE. https://doi.org/10.1109/ICNSC.2011.5874896

Lambie, E., Wilson, T. M., Johnston, D. M., Jensen, S., Brogt, E., Doyle, E. E., Lindell, M. K., & Helton, W. S. (2016). Human behaviour during and immediately following earthquake shaking: Developing a methodological approach for analysing video footage. *Natural Hazards*, *80*, 249–283. 10.1007/s11069-015-1967-4

Li, C., Liang, W., Quigley, C., Zhao, Y., & Yu, L.-F. (2017). Earthquake safety training through virtual drills. *IEEE Transactions on Visualization and Computer Graphics*, *23*(4), 1275–1284. 10.1109/TVCG.2017.2656958

Liu, Q., & Liu, R. (2025). Virtual reality for indoor emergency evacuation studies: Design, development, and implementation review. *Safety Science*, *181*, 106678. https://doi.org/10.1016/j.ssci.2024.106678

Marfisi-Schottman, I., George, S., & Tarpin-Bernard, F. (2010). *Tools and methods for efficiently designing serious games*. In *Proceedings of the 4th European Conference on Games Based Learning (ECGBL 2010)* (pp. 226–234)

Marne, B., Wisdom, J., Huynh-Kim-Bang, B., & Labat, J.-M. (2012). *The six facets of serious game design: A methodology enhanced by our design pattern library*. In A. Ravenscroft, S. Lindstaedt, C. D. Kloos, & D. Hernández-Leo (Eds.), *Proceedings of the 21st Century Learning for 21st Century Skills Conference (EC-TEL 2012)* (pp. 208–221). Springer. https://doi.org/10.1007/978-3-642-33263-0_17

Ministry of National Education [MoNE] (n.d.). *Ortaokullarda afet bilinci dersinin müfredatı hazırlandı*. Retrieved August 20, 2025, from https://www.meb.gov.tr/ortaokullarda-afet-bilinci-dersinin-mufredati-hazirlandi/haber/31787/tr

Ministry of National Education [MoNE], (2023). Afet Bilinci Dersi Öğretim Programı (I-II) (The Disaster Awareness Course Curriculum). Board of Education and Discipline, Ankara.

Mitsuhara, H., Nakamura, H., & Kondo, Y. (2023). Location-based game for thought-provoking evacuation training. *Multimodal Technologies and Interaction, 7*(1), 12. https://doi.org/10.3390/mti7010012

No, W., Choi, J., Park, S., & Lee, D. (2020). Balancing Hazard Exposure and Walking Distance in Evacuation Route Planning during Earthquake Disasters. *ISPRS International Journal of Geo-Information*, *9*(7), 432. https://doi.org/10.3390/ijgi9070432

Özmen, B., & İnce, Z. D. (2017). Okul tabanlı afet eğitimi. *Resilience*, *1*(1), 21–29.

Özmen, B. (2023). Eğitim kurumları için afet ve acil durum yönetimi planlama rehberi. İstanbul Sismik Riskin Azaltılması ve Acil Durum Hazırlık Projesi (İSMEP), İstanbul Proje Koordinasyon Birimi & AFAD İstanbul. https://www.ipkb.gov.tr/wp-content/uploads/2023/03/EGITIM-KURUMLARI-ICIN-AFET-VE-ACIL-DURUM-YONETIMI-PLANLAMA-REHBERI-BROSUR.pdf

Pacheco-Velazquez, E., Bester, A., Mayer, L. R., & Rodes-Paragarino, V. (2023). *Proposal for a participa-*

tory methodology for the creation of serious games. In *Proceedings of the 17th European Conference on Games Based Learning (ECGBL 2023)* (pp. 475–481). Academic Conferences International. https://doi.org/10.34190/ecgbl.17.1.1626

Presidency of the Republic of Türkiye, Department of Budget and Strategy. (2023). *Türkiye earthquakes recovery and reconstruction assessment*. https://www.sbb.gov.tr/turkiyeearthquakes-recovery-and-reconstruction-assessment/

Quagliarini, E., Bernardini, G., & Spalazzi, L. (2014). EPES–Earthquake pedestrians' evacuation simulator: A tool for predicting earthquake pedestrians' evacuation in urban outdoor scenarios. *International Journal of Disaster Risk Reduction*, *10*, 153–177. https://doi.org/10.1016/j.ijdrr.2014.08.002

Quagliarini, E., Lucesoli, M., & Bernardini, G. (2021). Understanding Human Behaviors in Earthquakes to Improve Safety in Built Environment: A State of the Art on Sustainable and Validated Investigation Tools. In J. Littlewood, R. J. Howlett, & L. C. Jain (Eds.), *Sustainability in Energy and Buildings 2020* (Vol. 203, pp. 297–307). Springer Singapore. https://doi.org/10.1007/978-981-15-8783-2_25

Rahouti, A., El Arass, S., & El Asri, B. (2017). An immersive serious game for firefighting and evacuation training in healthcare facilities. *World Academy of Science, Engineering and Technology, International Journal of Computer, Electrical, Automation, Control and Information Engineering, 11*(6), 743-749. https://doi.org/10.5281/zenodo.1134567

Rajabi, M. S., Taghaddos, H., & Zahrai, S. M. (2022). Improving emergency training for earthquakes through immersive virtual environments and anxiety tests: A case study. *Buildings*, *12*(11), 1850. https://doi.org/10.3390/buildings12111850.

Ribeiro, J., Rodrigues, J. M., & Cardoso, P. (2012). *Using serious games to train evacuation behaviour*. In *Proceedings of the 7th Iberian Conference on Information Systems and Technologies (CISTI 2012)* (pp. 1–6). https://doi.org/10.1109/CISTI.2012.6317254

Serok, N., & Blumenfeld-Lieberthal, E. (2015). A simulation model for intra-urban movements. *PloS One*, *10*(7), e0132576. https://doi.org/10.1371/journal.pone.0132576

Servicio Nacional de Prevención y Respuesta ante Desastres (SENAPRED). (n.d.). *Visor Chile Preparado* [Web application]. Retrieved August 12, 2024, from https://web.senapred.cl/visor-chile-preparado-2/

ShakeOut. (n.d.). *Great ShakeOut earthquake drills*. Retrieved August 18, 2024, from https://www.shakeout.org

Shaw, R., Shiwaku Hirohide Kobayashi, K., & Kobayashi, M. (2004). Linking experience, education, perception and earthquake preparedness. *Disaster Prevention and Management: An International Journal*, *13*(1), 39–49. https://doi.org/10.1108/09653560410521689

Siyam, N., Alqaryouti, O., & Abdallah, S. (2019). Research issues in agent-based simulation for pedestrians evacuation. *IEEE Access*, *8*, 134435–134455. 10.1109/ACCESS.2019.2956880

Snopková, D., Ugwitz, P., Stachoň, Z., Hladík, J., Juřík, V., Kvarda, O., & Kubíček, P. (2022). Retracing evacuation strategy: A virtual reality game-based investigation into the influence of building's spatial configuration in an emergency. *Spatial Cognition & Computation*, *22*(1–2), 30–50. https://doi.org/10.1080/13875868.2021.1913497

Sun, H., Hu, L., Shou, W., & Wang, J. (2021). Self-organized crowd dynamics: Research on earthquake emergency response patterns of drill-trained individuals based on GIS and multi-agent systems methodology. *Sensors*, *21*(4), 1353. https://doi.org/10.3390/s21041353

Suwanmolee, S. (2018). *Gamified Chaingrai earthquake lesson learned for disaster education*. In *Proceedings of the Disaster Risk Governance Academic Seminar*. https://www.researchgate.net/publication/331627551

Şahin, C., Rokne, J., & Alhajj, R. (2019). Human behavior modeling for simulating evacuation of buildings during emergencies. *Physica A: Statistical Mechanics and Its Applications*, *528*, 121432. https://doi.org/10.1016/j.physa.2019.121432

Tsai, J., Fridman, N., Bowring, E., Brown, M., Epstein, S., Kaminka, G.

A., Marsella, S., Ogden, A., Rika, I., & Sheel, A. (2011). *ESCAPES: Evacuation simulation with children, authorities, parents, emotions, and social comparison*. In *Proceedings of the 10th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2011)* (pp. 457–464). https://u.cs.biu.ac.il/~kaminkg/publications/papers/aamas11jason.pdf

Tsurushima, A. (2020). *Validation of evacuation decision model: An attempt to reproduce human evacuation behaviors during the Great East Japan Earthquake*. In *Proceedings of the 12th International Conference on Agents and Artificial Intelligence (ICAART 2020)* (pp. 17–27). https://www.scitepress.org/Papers/2020/88743/88743.pdf

United Nations Population Fund (UNFPA). (2023). *Türkiye earthquake situation report No. 5 (19 June 2023)*. https://reliefweb.int/report/turkiye/unfpa-turkiye-earthquake-situation-report-5-19-june-2023

United Nations General Assembly (2016). Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction. Accessed at < https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf?startDownload=true>.

United Nations Office for Disaster Risk Reduction. (2005). Hyogo Framework for Action 2005–2015: Building the resilience of nations and communities to disasters. Retrieved from https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf

Wibisono, R. A. (2019). Self-evacuation drills by mobile virtual reality application to enhance earthquake preparedness. *Procedia Computer Science*, *157*, 247–254. https://doi.org/10.1016/j.procs.2019.08.164.

Yang, Y., Lin, C., & Chen, S. (2021). Virtual fire evacuation drills through a web-based serious game. *Applied Sciences, 11*(5), 2194. https://doi.org/10.3390/app11052194.

Yao, Y.; Zhang, Y.; Yao, T.; Wong, K.; Tsou, J.Y.; Zhang, Y. A GIS-Based System for Spatial-Temporal Availability Evaluation of the Open Spaces Used as Emergency Shelters: The Case of Victoria, British Columbia, Canada. ISPRS Int. J. Geo-Inf. 2021, 10, 63. https://doi.org/10.3390/ijgi10020063

Yamamoto, K., & Li, X. (2017). Safety evaluation of evacuation routes in Central Tokyo assuming a large-scale evacuation in case of earthquake disasters. *Journal of Risk and Financial Management*, *10*(3), 14. https://doi.org/10.3390/jrfm10030014

Zhang, M., Xu, R., Siu, M. F. F., & Luo, X. (2023). Human decision change in crowd evacuation: A virtual reality-based study. *Journal of Building Engineering*, *68*, 106041. https://doi.org/10.1016/j.jobe.2023.106041

Zhong, G., Zhai, G., & Chen, W. (2023). Evacuation simulation of multi-story buildings during earthquakes based on improved cellular automata model. *Journal of Asian Architecture and Building Engineering*, *22*(2), 1007–1027. https://doi.org/10.1080/13467581.2022.2070491.

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

Zyda, M. (2005). From visual simulation to virtual reality to games. *Computer*, *38*(9), 25-32. https://doi.org/10.1109/MC.2005.297