Constructions of earthquake scenarios based on virtual simulations

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Abstract. The earthquake is an emergency with low probability and high risk. Constructing a real earthquake disaster scene can be used for earthquake emergency exercises, and timely inspection of escape, self-rescue and mutual rescue, and government decision-making deficiencies. Conducting the earthquake exercises under realistic conditions is not easily realized. Compared to the previous methods, the method based on virtual simulations is considered as one of the best effective ways. In this study, we employ the virtual simulations to construct earthquake disaster scenarios. The disaster scenarios immerse people in a virtual environment, where they learn to respond to earthquakes. We demonstrated the system architecture and its components, adopted 3dMAX and virtual simulations to reconstruct the modeling and reproduction of the regional topography, the city and the roads, bridges, hospitals, and building collapses in disaster areas. Virtual reality technology is used to realize the construction of the virtual city. Tests show that the system has good stability and effect, and reached the target set by the system.

1. Introduction

A risk society theory proposed by German sociologist Becker pointed out that there are three causes of the hazards brought by modernization in the post-industrial modern society, including unpredictable modern risks in the field of physical chemistry, industrial overproduction, and unpredictable technological developments. As a consequence, the root of modern risk is humanity [1]. After decades of reform and opening up, Chinese social economy has developed rapidly, its industrialization is getting higher and higher, and it has gradually realized the interconnection of all things to the intelligence of all things. The concentration of population and social wealth is also getting higher and higher, and it has the characteristics of a risk society [2].

The social and economic costs of earthquakes to the China and throughout the world have grown significantly over the last several decades, especially for the last ten years. The causes of earthquakes are numerous and complex, such as increased developments to the earth, pressures of the earth releasing, the migration of populations to coastal areas, global warming and others. In 2008, Wenchuan earthquakes exceeded $100 billion in costs, claimed over 69 thousand lives and caused significant economic losses where they impacted [3]. Once another catastrophic earthquake occurs, it
will cause tremendous damages to the social functions, threaten the sustainable development of the society, and pose an increasing threat to the public’s life, ecological security, and public’s safety. Human is also keenly aware of the necessity to mitigate losses from the natural disasters.

China is located at the junction of the Asia-Europe plate, the Pacific plate and the Indian Ocean plate and is a region prone to earthquakes. According to statistics, terrestrial earthquakes in China account for about one-third of the global terrestrial earthquakes. The number of deaths due to the earthquakes in China is more than one-half of the global earthquake deaths. About 95% of casualties and property losses in the earthquake are caused by building collapses caused by destruction [4].

Traditional disaster construction methods have disadvantages such as long construction time, high cost, and many difficulties in flexible use. As the technologies of computer and integrated circuit have evolved dramatically, virtual simulations technology is an innovative tool to provide a relatively realistic virtual environment that enables participants to quickly immerse themselves in the earthquake disaster scene and make them to acquire knowledge and develop specific skills in a computer-generated virtual environment [5]. Compared with the traditional construction methods, virtual simulations do not have strict requirements on the site, and have some advantages, such as fast constructions, reusability, simplicity, and fast switching. Due to its advantages, virtual simulations have been successfully applied to different scenarios.

2. Literature
According to their implement methods, earthquake disaster scene construction mainly includes real scene constructions and virtual simulations constructions.

2.1. Real scenes constructions
In China, National Earthquake Emergency Rescue Training Base of China used three-layer structure of the slab-column structures to form seismic ruins with slab-pillar structures through explosions. In the design process, the structural design of the building was carried out. According to the training course designs, building structure and ruin type design, the explosion plan was prepared. In order to improve the success rate of ruin morphology, designers carried out a large number of finite element numerical simulations. Through the finite element numerical simulation, the explosive forming design can be continuously optimized and adjusted to achieve the expected collapse pattern [6]. Another type of an important earthquake disaster scene is the Wenchuan earthquake site. It forms an earthquake disaster scene by protecting the original destruction site at the place where the earthquake disaster occurs [7].

In foreign countries, Germany, Singapore, Japan and other countries have built some earthquake disaster scenes through design and construction methods.

2.2. Virtual simulations constructions
Simulation refers to the process of creation of a virtual environment which simulates the operation of a real-world process to explore certain rules or laws between things. When the actual system is not available or the cost of conducting a test in the real environment is high, the simulation technique is often used to study a process or search the fundamental laws of matter under the situations [8].

Virtual simulations can mimic the emergency events for humans. With the development of information and simulation technology, virtual simulations have been used to provide participants with the opportunity to experience any emergency event at almost any scale or environment, regardless of whatever the emergency event is highly risky and complicated in the real world. The technology is employed to investigate how users behave during different emergency situations and to enhance the capability of approaches to handle the disaster [9, 10].

Regarding these benefits, the method have been applied to help users to navigate in the virtual environment, learned the observation and self-protection skills to survive the earthquake [9]. Lovreglio investigated the behavior of building residents during an earthquake evacuation [10]. Takabatake
developed an agent-based tsunami evacuation model considering the type of people and analyzed in detail the impact of tourists on evacuation through several sets of cases [11].

![Figure 1. System architecture.](image1)

![Figure 2. Scenes editor structure.](image2)

3. Virtual simulations scenario system
The virtual simulations scenario system in Figure 1 includes the concept editing subsystem, simulation editing subsystem, 3D scenario databases, operation management subsystem, and the interface subsystem [12].

Concept editing subsystem is responsible for transforming scenarios into certain abstract objects, space, time and other logical constraints. Generally, the imaginary things are transformed into a collection of some data and relations. The subsystem is also an important basis for the simulation scenario editing subsystem.

Simulation editing subsystem is responsible for realizing the simulation operation, management and reconstruction, and mapping the models, parameters, relationships and data in the scenario. After importing the scenario conceptual models into the simulation scenario editing subsystem, the system will added the necessary information to construct the models to run. Users can also modify the scenario model according to different needs.

3D scenario database includes scenario database and three-dimensional model database. The databases store the three-dimensional environmental text descriptions, basic assumptions, templates and parameters, functions, behaviors, and sounds needed to generate the scene.

Operation management subsystem is responsible for the scenario operation. It tracks and changes the imagined data and parameters in time, and generates an imagined three-dimensional virtual environment in real time. At the same time, the files in the database are modified in time through parameters to ensure the continuity and integrity of the scene data.

The interface subsystem is an interactive interface between the earthquake disaster scene, the user and the simulation system [12].

4. Scenes constructions
Catastrophic earthquakes generally cause the destruction of buildings, roads and bridges, and other facilities, as well as secondary disasters such as fires, explosions, dust, landslides, and mudslides. Due to the current study in mechanism and process of earthquake occurrence, there is no mature theoretical research or deterministic conclusions. Also the propagation and attenuation of seismic waves will vary greatly with the structure and geological structure of buildings. All of these make it very difficult to create disaster prototypes. According to the distribution of earthquake damage impacts on the surface, based on the attenuation of earthquake intensity and the characteristics of earthquake damages, the group earthquake damage estimation method is used to construct the damage situation of earthquake disasters [13]. Based on the plug-in programming method of the virtual reality builder, we have developed the construction methods of template insertions showed in Figure 2 for a topography, urban
architectures, traffic roads, etc. The system has the editing function of the terrains and the surface vegetation, and realizes the addition of mountains, hills, rivers, reservoirs, seas, trees, etc. Using 3dMAX's global light renderer (including Scanline, Radiosity and VRay) to generate light maps, makes the scene realistic and shadowing. The real-time material editing function of the virtual reality platform is used to adjust the color and highlight of the material.

4.1. Macro scene constructions
The scope of earthquake disaster scenarios depends on the magnitude, epicenter distance, depth of earthquake occurrence, geology and other conditions. Different geologies and depths affect the disaster ranges of the earthquake. We use the ellipse model to fit the attenuation relationship of the earthquake intensity, as shown in the following formula.

\[ I = C_1 + C_2 M_s + C_3 \lg\left(\frac{a}{2 + a_0}\right) \]  

(1)

In the formula, \( C_1, C_2, C_3, a_0 \) are regression coefficients. \( I, a \) and \( M_s \) respectively represent the intensity, the length of the major axis or the minor axis of the isoseismal line of intensity \( I \), and the magnitude of the surface wave. The above parameters use empirical values in the literature [13].

4.2. Exercises scene constructions

4.2.1. Templates.
According to the setting needs of the earthquake scene, templates for land, rocks, mountains, trees, roads, tunnels, a variety of residential, commercial and damaged building types were established. In order to maintain a better proportional relationship, certain sizes, shapes, and colors are set for different types of templates. For the buildings in the earthquake disaster scene, a random construction method is adopted to increase the diversity of earthquake disasters. In order to improve the surface diversity of earthquake disaster scenes, the vegetation is added in a random manner within the region.

4.2.2. City constructions.
In the construction of urban areas, the system realizes the rapid addition of large regional modules such as residential buildings, downtown areas, hospitals, industrial facilities, damaged buildings. The system adds different styles of building types, and also realizes road intelligent joints and vehicle implantation functions. Users can select different styles from the template library to quickly add them in the virtual city.

4.2.3. Generations of secondary disasters.
In order to increase the reality of the exercises and provide a better sense of immersion, the system simulated the secondary disasters caused by the earthquake. Three-dimensional scene simulation of fires in earthquakes is to deduce the simulation display and data description of the fire scene through qualitative models by processing simulation links such as information input, modeling, behavior analysis and result output. In the simulation process, the system will render and simulate the fire scene of the building fire according to the structure type of the building and the fire situation of the facility. By calling script parameters from the scene library, the building are fired and rendered, and superimposed on the city scene to generate a simulation of a certain fire scene in the city.

5. Scenes constructions
A three-dimensional city model is based on a Chinese city in north. We refer to the city’s geographic locations, terrains, commercial area distributions, traffic roads, population and other information. A 3D virtual city model was built using the virtual reality development system, which increased the reality of scenes. It adopts design methods such as visual analysis, height adjustment, layered display, and sunshine analysis to achieve the right. The simulations of earthquake disaster scenarios such as the city’s disaster scale, damaged buildings, and road interruptions are shown in Figure 3. At the same time, the system provides some triggering effects, such as fires, poison gases, dusts, explosions and others. These increase the authenticity and practicality of the scenes.
Users can construct mountains, hills, rivers, and seas through the lifting and descending functions of the terrain as shown in Figure 4. Users can also set the soil quality of the selected area through the soil color tools. They can also select a certain area and use tools to randomly plant different trees demonstrated in Figure 5. Users can select a certain area, determine the type of constructions, and realize the rapid implantation of a certain area through the import function of the buildings. They can also select different building types from the templates’ library, such as residential buildings, downtown areas, hospitals, industrial facilities, damaged buildings. The system adopts a simple interactive way to realize road paving and interfaces, and vehicle layouts. The user only needs to select the location where the road is laid, and then click the button in the editor to map the road. At the same time, the system also realized the layout of road intersections and random implantation of vehicles shown in Figure 6, which improved the authenticity and immersion of the scenes. In the same way, the layout of tunnels and bridges can be deployed.

6. Conclusions
Virtual simulations are adopted to realize the constructions of earthquake disaster scenes. The proposed tools can construct landform through terrain elevation editing, which increases the diversity of disaster scenarios. The tools have the functions to construct different building types, quickly deploy mass buildings, and realize the modeling and reproduction of the city. In order to demonstrate the secondary disasters of earthquakes, we added renderings of fires, dusts, explosions and poisonous gases in the scenes. We also developed some convenient functions such as fast paving and bridge erections.

However, the proposed method has some problems.
The building templates need to be added to increase the diversity of buildings in disaster scenes.

The dynamic changes of the scene are not strong enough to fully show the dynamic development of the event.

In terms of compatibility with GIS, the system needs to be strengthened. These are the directions for our future research.

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