A VIRTUAL TRAINING GAME FOR POST-EARTHQUAKE DAMAGE INSPECTION

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Abstract

Post-earthquake damage assessment and safety evaluation are urgently required but necessitate proper training to deliver accurate results. Traditional training methods include technical manuals and multimedia films which are passive and time-consuming. Therefore, the contribution of this paper lies in automating the damage inspection training process through game-based learning. More specifically, a serious game was developed that replicates a real-world inspection process and allows players to virtually perform a typical field survey of damages. The gaming tool was tested on several civil engineers who conveyed that inspecting within the virtual world can potentially enhance their performance in a real-world context.

Introduction

Following a major earthquake, the ability to rapidly assess the severity of a built environment damage is crucial to the success of the humanitarian emergency response and repair phases of recovery (Mangalathu 2017). While the vulnerability of the structures mainly depends on the structural system resistance, the safety evaluation of buildings is a challenging task (Harirchian et al., 2020).

In order to determine the usability conditions of buildings after earthquakes, a rapid visual assessment must be done as a quick emergency response (Sucuoğlu et al., 2007, Wallace & Miller, 2008, Jain et al., 2010, Perrone et al., 2015). A quick visual assessment process involves rapid in-situ inspections and tagging each building entrance with posting placards (e.g., green-unrestricted access, yellow-restricted access, or red-no access) according to the observed safety condition of the buildings (ATC 20 2005, NZSEE 2009). A more detailed inspection might be required to identify the type and extent of damage to structural and non–structural components (JBDPA 1991, ATC 20 2005, Baggio et al., 2007).

However, the existing approach adopted to train engineers and structural inspectors on proper evaluation of the structures poses some limitations as most of their decisions are subjective and based on past experiences. To the best of our knowledge, no previous research has investigated appropriate inspection training systems to overcome the limitations of traditional training methods. Previous research has relied on traditional training methods such as technical manuals (TM) and multimedia films (MF) which tend to be passive, but none has adopted serious games to boost traditional damage inspection training and facilitate post-earthquake safety evaluation. In fact, serious games have been applied to a wide spectrum of areas such as training and education (Susi et al., 2007, Laamarti et al., 2014, Gloria et al., 2014), construction safety (Dickinson et al., 2011, Lin & Son, 2011, Guo et al., 2012), evacuation process training (Rüppel & Schatz 2011, Feng et al., 2020) and proved very promising.

Therefore, the objective of this paper is to develop a serious game that replicates real-world inspection scenarios and allows players/inspectors to digitally perform a typical field survey of damages.

Methodology

In this study, the game called “Earthquake Damage Inspector” was designed using the Unity game engine (Haas 2014). First, a typical reinforced concrete building was modeled to use in all scenes to which damaged components pertaining to four different classifications were added. Next, the “Training” and “Assessment” tools were created.

The training part of the game consists of simulating different scenarios of a damaged reinforced concrete moment-resisting frame building. The training tool allows the players to learn about damage types and severities and helps them complete an inspection form for each building to enhance their problem-solving skills. The buildings were classified into 3 categories according to the Applied Technology Council (ATC) forms, namely Inspected, Restricted for Use, or Unsafe. On the other hand, in the assessment part of the game, players are asked to complete inspection forms for 20 buildings presenting different safety conditions.

In order to assess the developed game effectiveness and usability, players are asked to complete a questionnaire at the end.

The following sections delineate the aforementioned game components.

Game Design

Modeling the Environment

A typical reinforced concrete moment-resisting frame building was modeled in Unity. The building is made up of a ground floor, 4 typical floors, and a roof. It includes concrete structural elements (columns, beams, shear walls, slabs) and non-structural components (infill masonry walls, stairs, parapet walls, windows, doors, balconies, and elevator) as shown in Figure 1. Figure 2 shows the building interior.

Figure 1: Building 3D Model

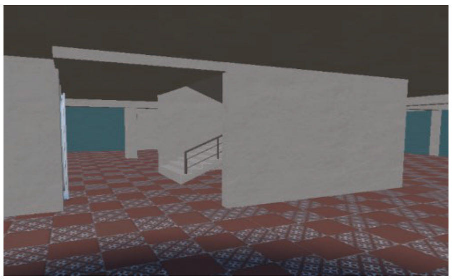

Figure 2: Building Interior

After modeling the building, damage is modeled for each component. Four damage severities (D1-None, D2-Slight, D3-Moderate to Heavy, D4-Severe to Total) were added to every element according to Greek classifications (Anagnostopoulos et al., 2008). More specifically, D1 classification includes fine cracks in few infill walls and in mortar, light spalling of concrete. D2 classification contains small cracks in few infill walls, and cracks and/or spalling of concrete in some structural elements. Moreover, partial sliding or falling of roof tiles and cracking or partial failure of parapets are present. Buildings classified as D3 comprise partition walls with extended large diagonal cracking, partially failed walls, partial disintegration of concrete and larger cracks in several structural elements, partial collapse of parapets, and dislocation of structural elements. Finally, a D4 classified building is partially or totally collapsed. It includes widespread failure of infill walls or severe cracking visible from both sides, substantial number of crushed structural elements and connections, exposure and buckling of reinforcement, and disintegration of concrete. Parapets are also collapsed, structural elements substantially dislocated, a residual drift may be present in any story or the whole building might be dislocated. Figures 3 through 6 depict buildings with damaged components ranging from D1 to D4.

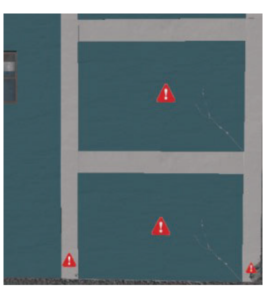

Figure 3: D1 Components

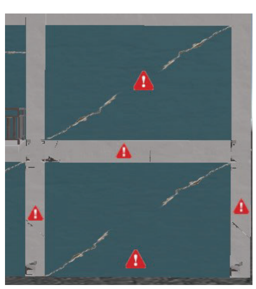

Figure 4: D2 Components

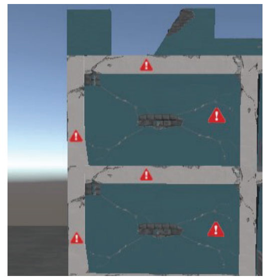

Figure 5: D3 Components

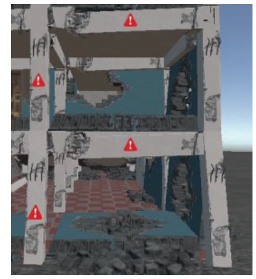

Figure 6: D4 Components

Designing the Training and Assessment Tools

The game starts with a menu in which the player chooses the desired program (i.e. Training or Assessment) as shown in Figure 7. However, it is advised to start with the training tool as it includes sample inspection forms to fill and introduces the player to damage descriptions, severity, and extent of the building components.

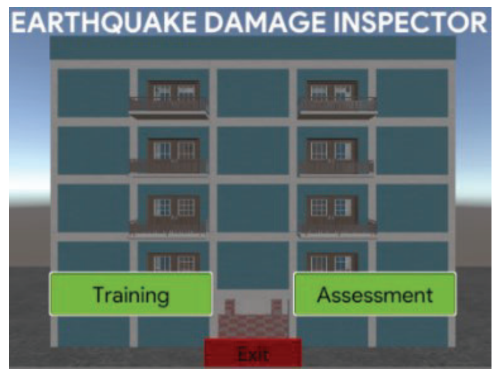

Figure 7: Start Menu

The training tool is made up of multiple scenes. In the first scene, the objective is to explore the building by clicking on all components. When the player clicks on the building element, a small window pops up and shows the name of the component and its type (Figure 8). The player can then click “Next Scene” to move to the next scene.

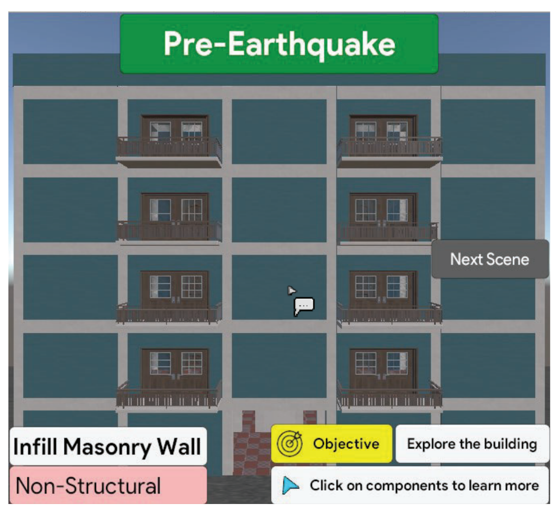

Figure 8: Training Tool Scene 1 Game View

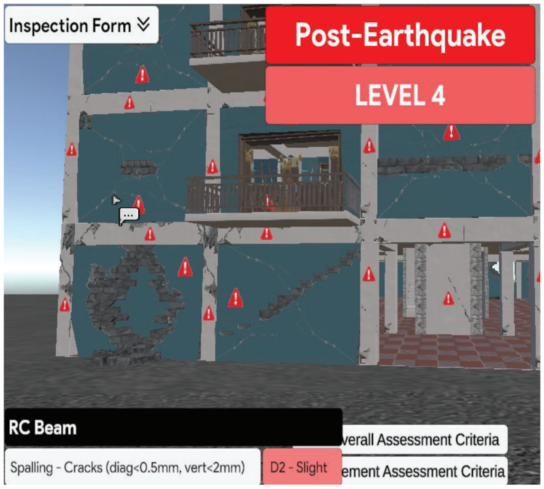

Figure 9: Training Tool Scene 4 Game View

In the remaining scenes, buildings with an increasing damage level are shown consecutively. In each scene, the player must click on damaged components, indicated by the red signs in Figure 9 above, to further learn about each type of damage and its severity. When clicking on the damaged element, a window pops showing the name of the element, its damage description, and severity (D1/D2/D3/D4).

Using given assessment criteria, the player must fill an inspection form for each building (Figure 10).

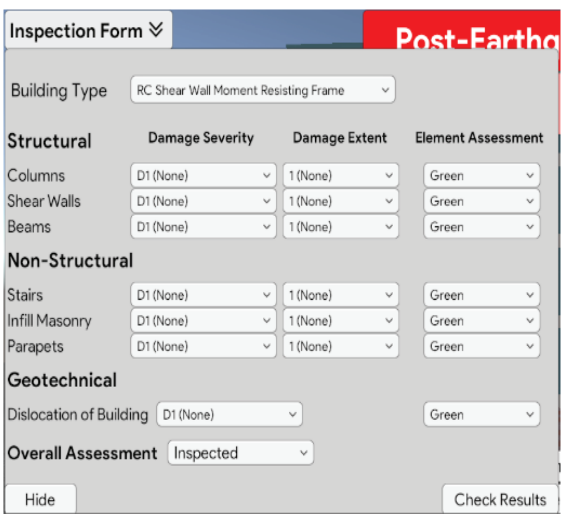

Figure 10: Inspection Form

As seen in Figure 10, the form contains data about every component in the building. The player should select the correct damage severity (D1/D2/D3/D4), damage extent (1-None/2-One to Few/3-Several to Many), element assessment (Green/Yellow/Red), dislocation of building (D1-None/D2-Slight/D3-Severe), and the overall assessment of the building (Inspected/Restricted Use/Unsafe).

The players can then check their results and correct their mistakes (Figure 11).

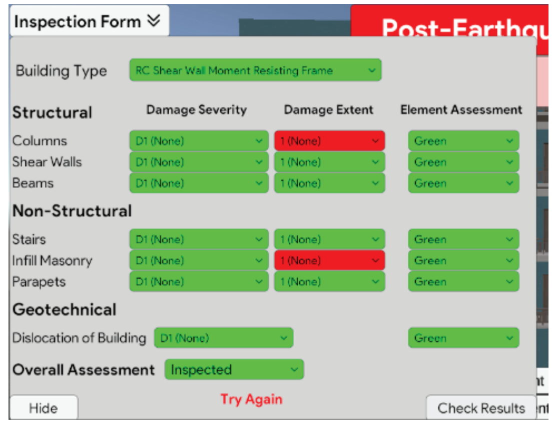

Figure 11: Inspection Form after Checking Results

Following training, the next step consists of accessing the assessment tool so that players can test their knowledge and reinforce their learning. However, the player first needs to fill in some background information (name, age, gender, job position, years of experience, previous inspections (yes/no)) and view the guidelines to learn the procedures prior to starting the assessment as shown in Figure 12.

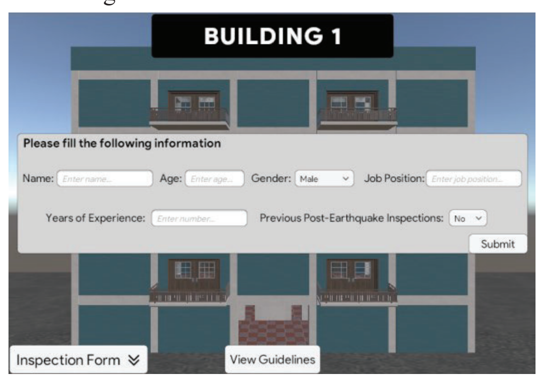

Figure 12: Background Information Panel

In the assessment program, 20 buildings of different safety conditions are created. The main objective is to fill in the inspection form for each building to test the player's knowledge. Once the player submits the answers, he/she must click "Next Building" to view the next building (Figure 13).

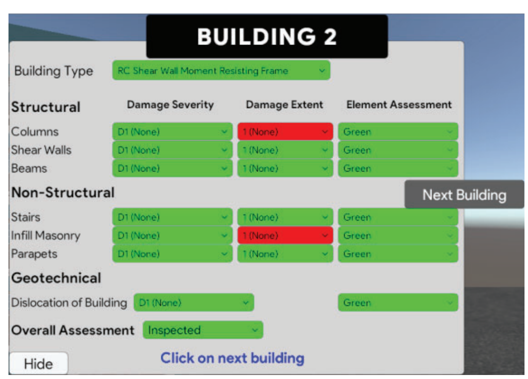

Figure 13: Inspection Form in Assessment Tool

In-Game Survey

After finishing the assessment program, the player is asked to fill in a survey for future analysis. The survey contains statements directly related to the game and some others about serious games in general. The players must state their opinion about each statement as follows: Completely Agree, Agree, Neutral, Disagree, or Completely Disagree). They also have the option to share their comment and feedback about the game. The statements used were:

1. I learned about the types of earthquakes structural and non-structural damage.
2. I learned about the damage severity of structural and non-structural components after earthquakes.
3. I was able to correctly classify buildings into different safety conditions.
4. I increased my overall knowledge in post-earthquake damage inspection.
5. I enjoyed this game.
6. The game is easy to use.
7. The UI is clear and straightforward.
8. I advise other civil engineers to try this game to provide them with necessary training before starting their inspection
9. Game-based learning is better than traditional methods for training purposes.
10. I would be more interested in using a game than reading a textbook.
11. I think that educational games would be good for revising or consolidating existing knowledge.

Results and Discussion

The gaming tool was tested on 30 civil engineers of different age groups, gender, job positions and years of experience, as shown in Figure 14.

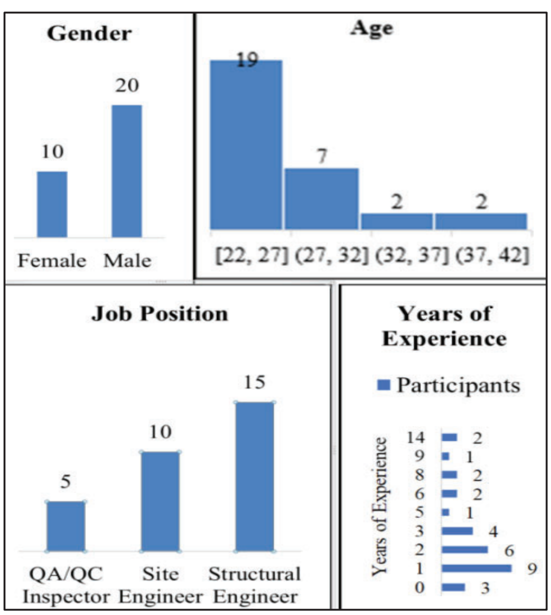

Figure 14: Participants Background Information

Results of the survey revealed that all participants either agreed or completely agreed that they learned about damage types and severities of structural and non-structural components after earthquakes. On the other hand, 33% of the players said they fully agreed that they were able to classify buildings into different safety conditions. The majority of the players agreed on that statement as well, while others (14 %) either held a neutral opinion or disagreed because they felt that the assessment criteria is quite complicated. Furthermore, the majority stated that they increased their overall knowledge about post-earthquake damage inspection, enjoyed the game, and mentioned that the user interface was clear and straightforward. When asked about the game's difficulty, the majority said it was easy while only 7% of the participants felt it was hard.

The positive feedback obtained provides key insights of the potential use of the developed "Earthquake Damage Inspector". The game is found instrumental in grasping earthquake damage knowledge and mastering robust inspection skills by performing virtual inspections.

The participants were also asked to state their opinion vis-à-vis using gaming technology for training purposes. Survey findings show that 93% of the participants don't mind advising other civil engineers to try the "Earthquake Damage Inspector" game to provide them with necessary inspection training. They also stated that game-based learning is better than traditional methods for training purposes. In addition, the majority either agreed or completely agreed that they would be more interested in using a game rather than reading textbooks or manuals and think that educational games would be good for revising or consolidating existing knowledge. In fact, only players above 30 years old held a neutral position on these statements. Figure 15 summarizes the survey results.

The aforementioned results further reinforce the importance of gaming technology for training and educational purposes. As a matter of fact, past findings revealed that serious games can contextualize user's experience in simulated challenging and realistic environments to support situated cognition (De Gloria et al., 2014).

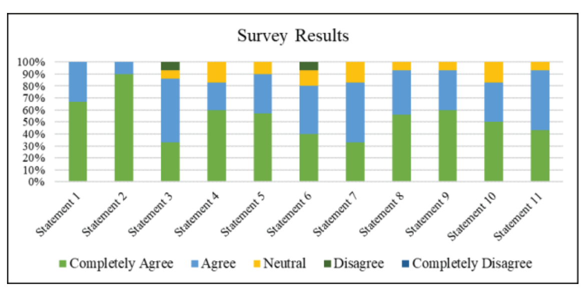

Figure 15: Survey Results

Summary, Conclusion, and Future Work

After earthquakes, it is urgent for structural engineers and building inspectors to assess the safety of buildings and determine their usability conditions. This can be done by performing rapid in-situ inspections and tagging buildings with green, yellow, or red placards according to their safety condition.

Previous research has relied on traditional training methods such as technical manuals and multimedia films which tend to be passive. Recently, game-based learning is emerging as a new approach that offers opportunities to apply knowledge in a virtual world, facilitating the learning process, and improving training performance. Nonetheless, no research has still adopted serious games to boost traditional damage inspection training and facilitate post-earthquake safety evaluation. Therefore, the aim of this research is to facilitate post-earthquake safety evaluation training of reinforced concrete buildings using gaming technology by allowing players to walk within the virtual environment and perform a typical field survey of damages.

The developed game is made of a training program that introduces the player to damage types and severities of structural and non-structural components of buildings. It also includes an assessment tool that contains a set of 20 buildings with different safety conditions whereby the player is asked to fill an inspection form for every building. The players must then complete an in-game survey where they state their opinion vis-à-vis the game and serious games in general.

Thirty civil engineers were chosen to test the game. Each player was asked to complete both the training and assessment programs and fill the questionnaire survey at the end. Results revealed that most of the participants stated that they enhanced their knowledge, enjoyed the learning process, and can potentially improve their performance in a real-world context. They also supported the potential of using game-based learning for training purposes.

From these results, it can be concluded that serious games provide a promising avenue towards better training and learning performances. However, the study comes with certain limitations. A larger sample size would make the results more representative and help gain more insight into the perception of inspectors towards the adoption of serious games for post-earthquake evaluation training. Future work aims to include as well other building types such as wood and steel and other structures (e.g. bridges, infrastructure systems, etc.).

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