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Effects of natural hazards on a sustainable city, design by gamification

Paz Fernández [1*], Matías Ceacero[2]

[1] Department of Civil Engineering, University of Granada, 18071 Granada, Spain.
[2] Department of Civil Engineering, University of Granada, 18071 Granada, Spain.

ABSTRACT

The current settlements present an unsustainable model so that they are currently struggling to achieve sustainability, which is proven by the approval of the Agenda 2030 for sustainable development, constituted by 17 Sustainable Development Goals. One of these SDG tries to make cities inclusive, safe, resilient and sustainable. In this context, this work intends first to study the relationship between Natural Hazards and sustainability. After that, we want to check the potential of gamification as a tool for the Analysis and Management of Natural Hazards. To achieve these objectives Cities: Skylines video game has been used for the design of our city and the verification of its sustainability, as well as for the simulation of different processes, observing the effectiveness of the mitigation measures established in the city. Finally, we have verified that, despite the need for corrections, gamification can be a useful tool in this procedure.

Type of Paper: Empirical

Keywords: Gamification; Natural Hazard; Sustainability; Urban sustainability, Simulation; SDG.

1. Introduction

In order to carry out this work, we part from a previous study of the design and management of the cities, as well as their sustainability, using simulation, with the game Cities: Skylines. This game was thus converted into a serious game (Djaouti, 2008). For this new study we start from the hypothesis that the serious game used, could have potential as a tool in the Analysis and Management of Natural Hazards, applying it to this analysis. To achieve it we have used several variables, being the main one the sustainable city itself that was built in the aforementioned initial study.

To justify this research, we start from the evidence that the current human population settlements present an unsustainable model, to a greater or lesser extent. Due to this, numerous authors have studied the impacts produced by these settlements to the environment, as well as new models that mitigate, as far as possible, these impacts, thus bridging the current path towards unsustainability (Saaty and De Paola, 2017).

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* Corresponding author: Paz Fernández
E-mail: pazferol@ugr.es.
Affiliation: Department of Civil Engineering, University of Granada,

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This is a current issue, which is demonstrated by the approval in 2015 of the Agenda 2030 on sustainable development by the United Nations Organization, which has 17 Sustainable Development Goals (Programa de las Naciones Unidas para el Desarrollo, s.f.). Of these, we have focused on the eleventh because it is more relevant to our work, because it aims to make urban agglomerations inclusive, safe, resilient and sustainable.

In recent decades, we have seen an increase in the study of the effects of human activities on the environment, as a result of the impending environmental crisis we face. In this sense, human settlements are one of the main focuses of this study, since they sometimes generate great impacts on the environment due to poor management of natural resources, excessive waste production, deficient treatment of waste water or erroneous territorial planning, among others. For this reason, recently tools have emerged for the planning and management of cities that incorporate technologies, such as Geographic Information Systems based on 3D models and computer-assisted design (Buyukdermircioglu y Kocaman, 2020), as well as some more specific programs such as CityJSON (Ledoux, et al., 2019). In relation to the sustainability of these settlements, the eleventh Objective for Sustainable Development of the United Nations Organization specifies that one pillar for achieving this is the reduction of damage caused by natural disasters. According to the World Health Organization, these natural hazards cause around 90,000 deaths worldwide each year, affecting approximately 160 million people worldwide (Sangha et al., 2020). In addition to these effects on people, there are also some socioeconomic conditions such as direct losses of property (infrastructure, buildings, agricultural land, etc.), indirect losses in the production of goods and services (interruptions in business and public services such as transportation, health and education), and some intangible losses, such as environmental losses (Sangha et al., 2020). Taking all this into account, the need for actions to avoid, minimize or repair these effects produced by natural hazards is more than notable, as could be the aforementioned techno-informatic tools.

In our case, we used a different type of tool: a video game that has been already used for educational and land planning purposes (Haahtela et al., 2015), but not as a tool for the Analysis and Management of Natural Hazards. In this sense, we have not found references or mentions to this new use, so our research using it for the analysis and management in Natural Hazard is considered novel.

2. Literature Review

Sustainability is a topic of great transcendence. While achieving sustainable development requires the fulfilment of all the United Nations Programme's Sustainable Development Goals (SDG), we will focus on Goal 11, which aims to ensure access for all people to adequate, safe and affordable housing and basic services and to improve slums by 2030 (Programa de las Naciones Unidas para el Desarrollo, s.f.). This entails seven very important achievements, of which we will focus on the fourth:

Providing access to safe, affordable, and sustainable transportation systems for all and improving road safety, in particular by expanding public transportation, with special attention to people in vulnerable situations.

Increase inclusive and sustainable urbanization and capacity for participatory planning and management.

Increase efforts to protect and safeguard the world's cultural and natural heritage.

Significantly reduce the number of deaths and people affected by disasters, including water-related disasters, with special emphasis on protecting people in vulnerable situations.

To reduce the negative per capita environmental impact of cities, with special attention to air quality and waste management.

Provide universal access to safe and inclusive green spaces and public spaces especially for children, the elderly and people with disabilities.

As we can see, one of the goals to be achieved is to make cities resilient and resistant to natural hazards. Walker (2005) defined resilience as "the ability of a system to absorb shocks and reorganize itself while undergoing change, but in a way that still maintains essentially the same function, structure, identity and feedback" (as cited in Bermejo, 2011, p.137). Gomes and Pena (2019) adapted this definition to define urban resilience, understood as the capacity of a city and its urban systems (social, economic, natural, human, technological and physical) to absorb damage and reduce the impacts of a disturbance, as well as to adapt to change. In this sense, urban resilience is based on four pillars, being resistance, recovery, adaptation and transformation; that are divided in five dimensions: natural, economic, social, fiscal and institutional. Finally, these authors concluded that there is a lack of tools and methods to evaluate the resilience of cities, as well as the most effective measures to achieve it, which is a challenge for the future.

Therefore, we can affirm that reducing the damage caused by natural risks is a fundamental part of achieving sustainability in cities, with security and social cohesion being priority conditions for this (Ayala - Carcedo and González, 2006).

We understand as a natural hazard, "the physical, chemical and biological ways in which events such as volcanic eruptions, earthquakes, landslides and floods affect the surface of the Earth, or any natural process that poses a threat to human life or property", (Keller and Blodget, 2007, pp.5-6). In addition, all risk factors, such as hazard and vulnerability, must be present for damage to occur (Ayala-Carcedo and Olcina, 2002). The effect of these risks on a society is known as a natural disaster. This term is often used when the effects of a natural process cause society to suffer significant damage to property, injury or loss of life (Keller and Blodget, 2007). In relation to measures to combat natural risks, land use planning has proven to be the most effective, rational and sustainable tool for reducing both vulnerability and exposure to these processes (Olcina, 2006).

As to Cities: Skylines, the video game we have used as a resource in this work, several authors have written about its possibilities in the simulation and visualization of real cities (Pinos, Vozenilek and Pavlis, 20201); Haahtela, Vuorinen, Kontturi, Silfvast, Väisänen and Onali (2015) concluded that this game has advantages and disadvantages over others in its use as a territorial planning tool, for which they carried out a SWOT analysis, shown in Figure 1.

Figure 1 SWOT analysis of the use of Cities: Skylines as a tool in territorial planning. Source: Modified of Haahtela et al. (2015)

Accepting this assessment of the game we have given it as valid as a tool for simulation in this research. Previously, we have also used this game to design sustainable cities, in which all the fundamental variables that define sustainability intervene. We carried out experiments that gave interesting results for the establishment of models of sustainable cities and in which we study the effects of natural risks and their management. This workis an immediate antecedent (Fernández y Ceacero, 2020).

As to the sustainable city itself, which was built through the simulations, it has the configuration of "two twins" (Dembski, Ssner, Yamu, 2019), that is, a city without preventive protection measures and another one that is the same but including preventive measures.

3. Research Methodology

This paper is part of an investigation project that apply the methodological paradigm called design investigations (Confrey, 2006) (Kelly, Baek, Lesh, Bannan-Ritland, 2008) which is characterized among other variables by its systemic character. Within it, diverse research techniques can be chained, concretely in our study the experimentation with simulations constituting a "case study" (Arzaluz, 2005) that we describe below. The project has been carried out in different phases synthesized in

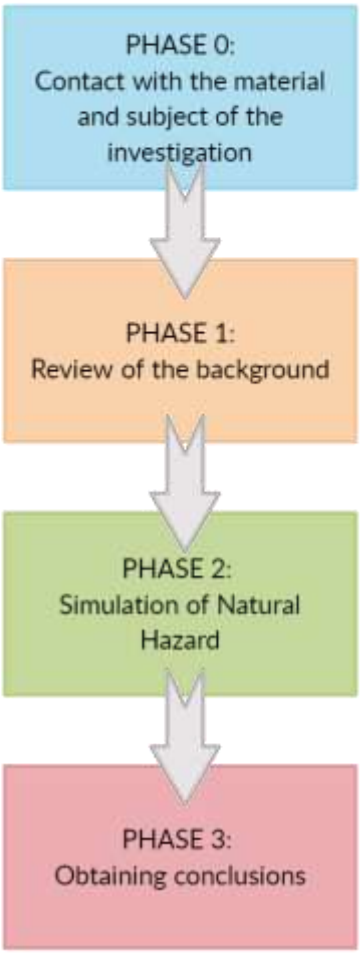


Figure 2 Sequential representation of the project phases.

Phase 1: Literature Review.

During this phase, a search of published works on the subjects: sustainable cities and natural hazards were made using different catalogues. Likewise, a search for publications about gamification and simulation was carried out to evaluate how useful they are, especially in the Analysis and Management of Natural Hazard. Different criteria and catalogues were used to carry out these searches. After these searches, the articles containing the most relevant information were selected for this work. They are the basis of the background review and constitutes the framework of foundations for the analysis of the data obtained in the experimentation.

Phase 2: Simulation of Natural Hazard.

The extension Cities: Skylines - Natural Disasters, allows us to simulate several risks: tornadoes, earthquakes, subsidence, storms, forest fires, landslides, building fires, tsunamis and meteorites. However, not all of them will be simulated since collapses and building fires will not be treated because they are not natural hazards, but could be secondary effects of a natural hazard such as earthquakes, as will be shown later. Tsunamis, although they are natural hazards, will not be simulated due to the city built in phases 2, 3 and 4 on which we will rely is not located on the coast. All these risks will be defined by a single magnitude for all of them, called by the game as severity and between 1 (minimum value) and 10 (maximum value). The game includes a mode in which these risks appear in a fortuitous manner and with a random magnitude, however, we will not use this function because we intend to simulate each process in a particular place and with a certain magnitude.

To simulate the different natural hazards, we followed the same procedure: starting with a simulation with magnitude 10 in the city that has preventive measures. In the same place, with the same magnitude and at the same time, this process is repeated, but this time, in the city without preventive measures. Then we can check the difference between the losses caused in both cities and indeed, the effectiveness of the preventive measures. After this, in the city with preventive measures, two more simulations of the same phenomenon will be carried out, in the same place and at the same time as before, but with different magnitudes. To do this, an intermediate magnitude of 5.5 has been selected, which is the game default value, and the minimum magnitude, 1. This is intended to check the difference in losses at different magnitudes and how the emergency services act in these different situations. In addition, the different natural hazards have been simulated in different areas to check the effectiveness of the emergency services in different places. Below, we present the process followed in each of these phenomena.

Phase 2.1. Earthquake simulation.

First, we proceeded to simulate this process, with a magnitude of 10 in the city for which we had established preventive measures, which for this phenomenon will be: shelters, emergency units and earthquake sensors. For this simulation, a residential area of our city, close to one of the central roads, was selected as the epicentre. After establishing it, we can observe what the game calls it as Disaster Risk, shown in Figure 3.

Figure 3 Representation of the risk of catastrophe for the simulation of the earthquake with magnitude 10 in the city with preventive measures.

When the virtual sensors of the game informed us of the proximity of the earthquake, we proceeded to evacuate the citizens and to observe how our city reacted to this event. Once the earthquake has appeased, the game offers us a statistic of the damages suffered; after that we proceeded to simulate the same earthquake in the without preventive measures. In this occasion, due to the lack of preventive measures, the game does neither offer us the risk of catastrophe, nor allow us to evacuate the population. As in the previous simulation, once this process is over, the game offers a damage statistic.

After this, the simulation was repeated in the city with preventive measures, establishing the epicentre in the same area as before, but in this case at a lower magnitude, 5.5. Finally, a final earthquake simulation was carried out at magnitude 1, the minimum offered by the game. In both cases, once the earthquake is over, the game offers us a statistic of the damages caused, which will be analysed later.

Phase 2.2. Meteorite simulation.

For the simulation of this phenomenon we proceeded in a similar way to the previous one, comparing first the effects in the city with and without preventive measures (in this occasion we would have shelters, emergency units and the deep space radar) for the maximum magnitude. In this case, the place of the meteorite's collision is also a residential area, but different from the one used as the epicentre of the earthquake. As in the previous case, once the space radar of the city informs about the proximity of the meteorite, we proceeded to evacuate the population. Once the impact was produced, we can observe the statistics of the damages provided by the game.

After that, as for earthquakes, this same event was simulated with the same magnitudes as before in order to compare its effects. After this, the data on the damages produced in the city were analysed.

Phase 2.3. Simulation of tornadoes.

In this case, as in the previous risks, firstly, the city was simulated with preventive measures (shelters, emergency units and climate radar), using a magnitude of 10.The origin of it was established in a commercial area of the downtown. Once the tornado had passed, the damage statistics were considered. After this, we proceeded to simulate this same process, with the same magnitude and origin, in the city without preventive measures. Likewise, after the tornado, the statistics of the damages provided by the game were studied.

Following the procedure of the previous risks, the same tornado was simulated with the same magnitudes as before, after which its damage statistics were analyzed.

Phase 2.4. Simulation of subsidence.

As in the previous phenomena, we began by simulating the sinking of the city with preventive measures (shelters, emergency units and earthquake sensors). In this case, the Centre of this phenomenon was established in one of the industrial areas outside, with a magnitude of 10. Once the results of this simulation were obtained, the same procedure was carried out for the city without these measures, subsequently studying the results obtained.

Once again, this simulation was repeated to the previously mentioned magnitudes, and after that its data were analyzed

Phase 6.5. Simulation of forest fires.

Similarly, the simulation began in the city with watchtowers, which act as preventive measures in this occasion. A magnitude of 10 was selected and two focal points were chosen: one in a forest mass far from the city Centre and another one in a forest mass closer to the city. Once these fires were turned off, we obtained the damage statistics and after their study, we proceeded to repeat this event in the city without these towers.

As in the previous risks, this process was repeated with magnitudes 5.5 and 1, obtaining a statistic of the damages that was studied later.

Phase 6.6. Simulation of storms.

Finally, the simulation of the storms was carried out, starting once again with the city with preventive measures that in this case are shelters, emergency units and climate radar. The place selected for the simulation of this process is an intermediate zone between a commercial and a residential strip. Once the storm is over, we can observe once again the statistics of damages caused by this process, and proceeded to simulate the same storm in the city without preventive measures and to analyze the data of the losses caused.

Finally, as in all previous risks, this simulation was repeated in the city with preventive measures with the medium and minimum magnitudes mentioned, and after that the loss statistics were analyzed.

Once all the risks were simulated and the statistics of the losses of each one of them were collected, the analysis of the results obtained in this study was carried out. After this, the discussion about these results and the obtaining of the conclusions was carried out, as we show in the following sections.

4. Results

4.1 Earthquake simulation

First, in the city with preventive measures, after establishing the earthquake the game offers us a representation of the risk of disaster in the area, as shown in Figure 3.

In this city we can evacuate the population so, they are protected at the time of the earthquake. In this simulation we can observe how the earthquake causes the destruction of several roads, as well as the generation of cracks in the ground and some fires. After that we can see the emergency services deploying in this area, putting out this fire. All this is shown in video 1 of Appendix A. On the other hand, for the city without preventive measures, after establishing the earthquake, the evacuation of citizens is not allowed, and the game doesn't offer the representation of the risk of disaster. Once the earthquake has occurred, we can see that, as before, there is destruction of roads, cracks in the ground and fires, which this time are more abundant. We can see that the emergency services are in the area as well again this time. All this is shown in video 2 of Appendix A.

We made the comparative study, in all the risks, from the data on the statistics of the caused losses, in each type of city.

Table 1 Comparative damage statistics of Seismic Risk with magnitude 10

	Earthquake	
	City with preventives measures	City without preventives measures
Deceased citizens	805	3038
Destroyed buildings	170	204
Destroyed roads (meters)	3971	3999
Burned buildings	116	125
Burned trees	72	58

For these simulations (Table 1) we can observe that, in spite of having established the same epicenter for the earthquake, the established cracks differ in direction, as does the abundance of the damage produced. Comparing both simulations, we can see that the time it takes to mitigate the effects of both earthquakes is greater in the city without mitigating measures.

On the other hand, in the case of the simulation with a lower magnitude, 5.5 (shown in video 3 of Appendix A), we can observe the risk of disaster in the area after establishing the epicenter. After that we will evacuate the population again. Once the earthquake finished, the game offers the data on the statistics of the damages, reflected in Table 2.

Table 2 Seismic Risk damage statistics with magnitude 5.5

	Earthquake
	City with preventives measures
Deceased citizens	691
Destroyed buildings	131
Destroyed roads (meters)	2949
Burned buildings	105
Burned trees	69

Comparing the results of both magnitudes, we can appreciate first of all that, for a greater magnitude, the risk of catastrophe covers a larger surface, reaching the limits of our city (for example, covering the dam), while, for a lower magnitude, it expands a little beyond the outskirts of the city, without reaching its limits. Comparing both simulations, we see that the duration of this process is the same despite the difference in magnitude. We also see how the primary effects of the earthquake seem to be the same, since the same crack has been generated, apparently of the same depth, although for magnitude 5.5 it seems to be a little smaller. In the simulation with a lower magnitude, we observe a smaller number of burned buildings, so there is less abundance of emergency services.

Finally, for the simulation with magnitude 1 (shown in video 4 of Appendix A), as in the previous cases, we observe the representation of the disaster risk and we can evacuate the population. The results obtained in this case are shown in Table 3.

Table 3 Damage statistics of Seismic Risk with magnitude 1

	Earthquake
	City with preventives measures
Deceased citizens	691
Destroyed buildings	131
Destroyed roads (meters)	2949
Burned buildings	105
Burned trees	69

In this case, we can appreciate that the risk of catastrophe is lower, not reaching the outskirts of the city. We also appreciate a lower number of burnt buildings, which means a lower abundance of emergency services. As for the effects produced in the city, we can observe how, despite being the smallest possible magnitude, cracks also occur in the terrain, although of a smaller size. In this last simulation we can see that sometimes vehicle traffic (which continues even after the population has been evacuated) slows down in areas close to the event, making difficult for emergency services to arrive.

4.2 Meteorite simulation results.

Video 5 of Annex I correspond to the simulation of the meteorite in the city with preventive measures. We can see how after establishing the place of collision, the first thing the game offers us is a representation of the risk of catastrophe for this simulation. In addition, it allows us to evacuate the population, indicating with a chromatic scale which buildings are evacuated. In this way, before the moment of the meteorite's collision we can check that the city has been evacuated in its entirety. Due to the impact we can see that some roads have been destroyed, some trees have been charred and some buildings are on fire, after which the emergency services (fire trucks and helicopters) begin to arrive to extinguish these fires.

On the other hand, in video 6 of Appendix A (corresponding to the simulation of this phenomenon in the city without preventive measures) we can see that, after selecting the collision site, it is not possible to evacuate the population. Similarly, it does not offer us the representation of the risk of catastrophe that it provided in the previous case. As before, we can see that the meteorite has caused the destruction of roads, as well as the burning of trees and buildings. In this case we also observe the emergency services extinguishing these effects. Next, in Table 4, we can compare the losses produced in both situations.

Table 4 Comparative statistics of meteorite damage with magnitude 10

	Meteorite	
	City with preventives measures	City without preventives measures

Deceased citizens	3282	3792
Destroyed buildings	158	158
Destroyed roads (meters)	6155	6153
Burned buildings	53	54
Burned trees	99	99

Comparing the simulations for this risk we can see that, despite having established the same collision point for the meteorite, it comes from different places. We can also see that, in the city with preventive measures, the time invested in extinguishing the effects of the risk is less than for the city without them.

On the other hand, in the case of the simulation of this process at a magnitude of 5.5, shown in video 7 of Appendix A, we can also observe the risk of catastrophe after establishing the collision zone, which seems to have a lower expansion than for magnitude 10. As before, we will proceed to evacuate the population after the collision of this meteorite causing the losses shown in Table 5.

Table 5 Meteorite damage statistics with magnitude 5.5

	Meteorite
	City with preventives measures
Deceased citizens	1956
Destroyed buildings	75
Destroyed roads (meters)	2019
Burned buildings	26
Burned trees	24

Comparing the simulations of magnitude 10 and 5.5, we can see that despite having a lower impact on the area, which is corroborated by the comparison of damage statistics, visually its effects seem to be the same.

Finally, in video 8 of Appendix A, we can visualize the simulation of this phenomenon at the minimum magnitude. Once again, after establishing the place of impact, the game offers us the representation of the disaster risk, which is lower than in the previous cases. In this occasion we also proceeded to evacuate the population, observing how this process occurs. Again, the collision also produces fires and the destruction of roads, which causes the presence of emergency services in the area, especially helicopters. The damage statistics from this event are shown in Table 6.

Table 6 Meteorite damage statistics with magnitude 1

	Meteorite
	City with preventives measures
Deceased citizens	308
Destroyed buildings	17
Destroyed roads (meters)	823
Burned buildings	4
Burned trees	2

4.3 Results of the tornado simulation

In the city with preventive measures, after establishing the Centre of this process, the game offers us the representation of the risk of catastrophe in this area. In the same way, after evacuating the population we can observe the evacuation process by means of a chromatic scale and check that when the tornado happens, all citizens have been evacuated. Once the tornado has passed, we can see how some houses and roads have been destroyed. However, unlike the risks simulated above, we neither find any fires, .nor can observe the emergency services in the area of tornado advance (video 9 of Appendix A). Once the previous simulation was finish, the same process was carried out for the city without any preventive measures. In this occasion, as in previous cases for this city, we cannot observe the representation of the risk of catastrophe, and the population evacuation is not allowed. After the tornado passed we can observe that some buildings and roads have been destroyed, but we do not observe the emergency services in this area either (video 10 of Appendix A). Next, in Table 7 we can compare the damages produced in both simulations.

Table 7 Comparative statistics of tornado damage with magnitude 10

	Tornado	
	City with preventives measures	City without preventives measures
Deceased citizens	4554	10423
Destroyed buildings	356	516
Destroyed roads (meters)	9965	11896

On the other hand, in the video 11 of Appendix A we can visualize this process with a magnitude of 5.5. As before, we establish the place of origin of the tornado, we observe the risk of catastrophe (which this time has a smaller extension) and we evacuate the population. The effects produced by this event coincide with those produced in the previous case: buildings and roads destroyed and loss of citizens. As in the previous case, we cannot observe the emergency services in the area either. The damage statistics produced in this case are shown in Table 8.

Table 8 Tornado damage statistics with magnitude 5.5

	Tornado
	City with preventives measures
Deceased citizens	2216
Destroyed buildings	181
Destroyed roads (meters)	5416

If we compare the simulations with magnitudes 10 and 5.5 we can verify that in spite of establishing the same origin of the tornado, it comes from different places, covering similar distances, although with different directions. It is also observed that the tornado with a smaller magnitude has a smaller size than the one with a larger magnitude.

Finally, in the video 12 of Appendix A, we can visualize this same phenomenon with the minimum magnitude. In this case we also observe the risk of catastrophe, with a smaller extension, and the evacuation of the population. As in the three previous cases, we also cannot observe the emergency services in the area through which the tornado has advanced. Table 9 below shows the statistics of losses in this case.

Table 9 Tornado damage statistics with magnitude 1

	Tornado
	City with preventives measures
Deceased citizens	400
Destroyed buildings	25
Destroyed roads (meters)	1366

This time too, we observe that despite having the same origin, the tornado emerges from a different place and has another path. Similarly, for a smaller magnitude, we observe a smaller size of the tornado.

4.4 Results of the sinking simulation

In the video 13 of Appendix A we can observe once again how in the city with preventive measures, once the sinking zone has been chosen, the game shows us the representation of the risk of catastrophe. We can also observe in this case the evacuation of the city. Once this process has occurred, we can see that the emergency services are not in the area this time either. In the case of the city without preventive measures, shown in video 14 of Appendix A, we can see once again that this city does not offer us the risk of catastrophe for this phenomenon. On this occasion, once the sinking has occurred, we cannot observe the emergency services either. In both cases, the effects produced by this phenomenon are the destruction of buildings and roads and the loss of human lives. Table 10 below shows the damage caused in each case.

Table 10 Comparative statistics of sinking damage with magnitude 10

	Sinking	
	City with preventives measures	City without preventives measures
Deceased citizens	2	6
Destroyed buildings	4	5
Destroyed roads (meters)	303	303

In the video 15 of Appendix A we can observe the same process with a magnitude of 5.5. Once again, after selecting the area where the sinking will take place, the game performs the representation of the disaster risk (which, as in previous risks, also has a smaller extension) and we observe the evacuation of the population. As it happened before, the sinking produces the destruction of buildings and roads, to which is associated the loss of some citizens. However, we did not observe the emergency services this time either. The loss statistics in this case are shown in Table 11.

Table 11 Sinking damage statistics with magnitude 5.5

	Sinking
	City with preventives measures
Deceased citizens	1
Destroyed buildings	2
Destroyed roads (meters)	252

Comparing both simulations, we observe that the fracturing produced in the ground is less in the case of subsidence with a lower magnitude.

Finally, video 16 of Appendix A shows this event for the minimum magnitude. As in the previous cases, once the area to be sunk has been selected, we can observe the risk of catastrophe (with a smaller extension in this case) and the evacuation of the population. The effects produced by the sinking are the same as in the previous cases, the loss statistics being those shown in Table 12.

Table 12 Sinking damage statistics with magnitude 1

	Sinking
	City with preventives measures
Deceased citizens	0
Destroyed buildings	1
Destroyed roads (meters)	211

In this case we also found that, for a smaller magnitude, the fragmentation of the terrain is smaller.

4.5 Results of the forest fire simulation

In the first place, for the city with preventive measures, after establishing the focus of the forest fire, the detection services inform us of the risk of catastrophe in the area and then the population was evacuated. Of the two established focuses we can observe that the one that is closer to the population reaches the industrial zone, being able to see by this zone the emergency services (helicopters and fire trucks), that extinguish this fire. For the other focus, the farthest from the city, as there are no roads that reach it, we can only observe the arrival of the helicopters. This event is shown in video 17 of Appendix A. On the other hand, in the city without preventive measures, shown in video 18 of Appendix A, the game provides the representation of the risk of catastrophe, but only of the focus closer to the city. The focus near the city reaches the industrial zone, being shut down again by trucks and helicopters, while the focus far from the city is extinguished alone, without the intervention of the emergency services. The statistics of damages caused by these events are shown in Table 13.

Table 13 Comparative statistics of forest fire damage with magnitude 10

	Forest fire	
	City with preventives measures	City without preventives measures
Deceased citizens	0	0
Burned buildings	15	7
Burned trees	4932	1422

Comparing both simulations, we can see that the fire in the city without preventive measures remains active longer than in the case of the city with them.

In video 19 of Appendix A we find the simulation of this phenomenon at a magnitude of 5.5. Again, we can observe the risk of catastrophe and the evacuation of the population. Once again, we appreciate the emergency services in the areas where the fire occurs, causing the losses reflected in Table 14.

Table 14 Forest fire damage statistics with magnitude 5.5

	Forest fire
	City with preventives measures
Deceased citizens	0
Burned buildings	1
Burned trees	2599

Comparing the simulations with magnitudes 10 and 5.5 we can see that the fires produced in both cases have a similar extension, taking longer to extinguish the one with a lower magnitude.

Finally, in the video 20 of Appendix A the previous procedure is repeated, observing a smaller extension of the disaster risk and assisting again to the evacuation. As in the previous cases, the emergency services extinguish both sources. The losses caused in this case are shown in Table 15.

Table 15 Forest fire damage statistics with magnitude 1

	Forest fire
	City with preventives measures
Deceased citizens	0
Burned buildings	0
Burned trees	84

In this occasion the extension of the focus is smaller than for larger magnitudes, becoming extinct in less time.

4.6 Results of the storm simulation

In the video 21 of Appendix A we can see the simulation of the storm in the city with preventive measures. After selecting the origin of this storm, we can observethe risk of catastrophe, as well as the evacuation of the population. Once the storm is over, we can see that the main effects produced by this phenomenon are the fires of trees and buildingsand we can also see the presence of the emergency services in the area. In video 22 of Appendix A, we can observe this same process, but in the city that lacks preventive measures. Now we cannot observe the risk of catastrophe nor evacuate the population. The effects produced are the same as in the previous case: buildings and trees set on fire, so once again we see the emergency services in the area. Despite having selected the same origin, we see that, in both cases, the fire sources differ, remaining active in the city for longer without preventive measures. Table 16 shows the comparison of damages suffered in both cases.

Table 16 Comparative statistics of storm damage with magnitude 10

	Storm	
	City with preventives measures	City without preventives measures
Deceased citizens	0	0
Burned buildings	46	33
Burned trees	299	365

On the other hand, in the video 23 of Appendix A we can see the simulation with a magnitude of 5.5. We can also observe the representation of the risk of catastrophe, with a smaller extension, and the evacuation of the population. In this occasion the effects caused are the same: building and tree fires, so the emergency services can also be seen. The damage caused by this event is reflected in Table 17.

Table 17 Storm damage statistics with magnitude 5.5

	Storm
	City with preventives measures
Deceased citizens	0
Burned buildings	76
Burned trees	377

If we compare this simulation with the previous ones, we can see that despite having a lower magnitude, the time to extinguish its effects is greater than in the case of the city without preventive measures.

Finally, video 24 of Appendix A shows the same simulation of a storm with a magnitude 1. Similarly, we observe the risk of disaster (which is also lower in this case), the evacuation of the population and emergency services after the fire of buildings and trees. The damage statistics are shown in Table 18.

Table 18 Storm damage statistics with magnitude 1

	Storm
	City with preventives measures
Deceased citizens	0
Burned buildings	26
Burned trees	63

In this case we observe that for a minor magnitude the effects produced are minor, as well as the time of its extinction.

5. Discussion

In the statistics of damages of the seismic risk, for the simulations of magnitude 10, we can observe that the losses caused in relation to deceased citizens, destroyed buildings and highways and burned buildings would make sense, because they are greater in the city without preventive measures than in the city that has them. However, this is not the case with burned trees, which turn out to be more in the case of the city with measures. In addition, the number of burned trees in this last item is even less than for the 5.5 magnitude earthquake, when the predictable damage would be that, for a smaller magnitude, the damages caused would be less. In terms of citizens killed, buildings and roads destroyed and buildings burned, there are a decrease for magnitude 5.5 compared to magnitude 10. Finally, the magnitude 1 earthquake does fulfill this prediction since the losses are lower than for the higher magnitude simulations. With these results we can conclude that the sensors of earthquakes, installed like preventive measure for this risk are effective because they reduce in great measure the produced damages, as it is reflected in Table 1. On the other hand, we can also affirm that the game makes a correct interpretation of the different magnitudes since before an earthquake of smaller magnitude, we obtain a representation of the risk of smaller catastrophe and generally also smaller losses are obtained, which can be corroborated with the comparison of Tables 1, 2 and 3.

For the damages produced in the city by the meteorite, as reflected in Table 4, the destroyed buildings and roads and the burned buildings and trees we see that they do not present great differences in the simulation with magnitude 10 in the city with preventive measures and without them, except in the number of lost citizens that is greater in the case of the second one. In this case this result is logical because when evacuating the population, the number of victims expected is lower than in the case of not evacuating, while the damage to buildings, roads and trees should be the same in both cases because the same place of collision was selected, at the same time and with the same magnitude. Furthermore, comparing both simulations, it can be seen that the effects produced by the meteorite in the city that lacks preventive measures are greater than in the case that it has them, and the same occurs in the simulations carried out with all the magnitudes. Similarly, the risk of catastrophe and the time invested in mitigating the effects produced are also reduced in the event of a decrease in the magnitude of the process, which would make sense. Then the game makes a correct interpretation.

In the case of tornadoes, for a magnitude 10, we observe that the losses caused in the city with preventive measures are less than those caused in the city without preventive measures so we can affirm that the measures are effective. In this case, after this event, the emergency services do not appear in the area. In the simulations mentioned above, earthquakes and meteorites, we could observe fire trucks and helicopters in the area. Although, in this occasion these services are not necessary because there is no fire, the presence of some kind of emergency service was expected, due to the construction of an emergency unit building during the design of the city and whose function according to the game is: "send helicopters and trucks loaded with personnel to clear debris and rescue survivors", which did not happen. With this we can assume that the game only sends emergency units in case of a fire. For the simulation of this same phenomenon at smaller magnitudes such as 5.5 and 1, we can see both a lower risk of catastrophe and lower losses, this being the predictable. However, on these occasions we cannot observe the emergency services either.

In the simulation of sinking, as in the case of tornadoes, since there are no fires, the emergency services are not seen in the area. In the case of the simulation at magnitude 10, we observe that the predictions are fulfilled since the number of citizens lost is lower in the case of the city with preventive measures due to the possibility of evacuation, while the buildings and roads destroyed are practically the same in both cases. The interpretation of the game for this phenomenon of magnitudes is also correct, because when it decreases, the size of the land fracturing is smaller, which is consistent with the reduction of the risk of disaster and damage in the area.

With regard to losses caused by forest fires, as shown in Table 13, none of the magnitude 10 simulations produce any loss of citizens. However, in this same table we can see that both the trees and buildings burned are greater in the city with preventive measures, contrary to what is expected. In addition, the time invested in extinguishing the fires is also higher for this city, and this is not what is expected either. This time the game does represent in a similar way this event for the same magnitude after establishing the same focuses. A particularity of this simulation is that the city without preventive measures does not offer a representation of the risk of catastrophe for this phenomenon, which could be due to the presence of fire stations in the city. For a magnitude of 5.5 there is also no loss of citizens. For this magnitude, the buildings and trees set on fire are smaller than in the case of this same phenomenon for a magnitude 10 in the city with preventive measures. However, in the case of the city without preventive measures, for a magnitude 10 the burned trees are smaller compared to the simulation at magnitude 5.5. Finally, in the case of the minimum magnitude, there is a decrease in the damages produced compared to the rest of the simulations, causing only the burning of trees on this occasion.

In the case of simulating storms at maximum magnitude, we can see in Table 16 that there are no losses of citizens. In relation to the number of trees that are burned, we can see that this is less in the city with preventive measures than in the city without them, which was to be expected. On the contrary, the number of burned buildings is higher for the city with preventive measures, which contradicts our predictions. This could be justified by the fact of despite establishing the same origin of the storm in both simulations, the storms come from different places, and the fires produced move in different directions. For a magnitude of 5.5, in spite of obtaining a lower risk of catastrophe, the losses caused are greater than both simulations of magnitude 10, taking longer to alleviate their effects, which does not agree with the hypothesis that the lesser the magnitude, the lesser the damages produced, which are also reduced with the presence of preventive measures (Table 17). Finally, for the minimum magnitude, the data obtained agree with the previous hypothesis, since the losses suffered are less than in the previous simulations.

So far, all the observations about the system of simulations carried out have been favourable, however there are aspects that require criticism and search for improvements in future actions, we detail the most representative below.

There are some simulations in which there are big differences between the expected and the observed, to find out what caused this difference between major losses in city with prevention measures and minor losses in city without prevention measures, these simulations were repeated once again, establishing in these cases the phenomenon (forest fire and storms) in the outskirts of the city, and we observe that the game does not give the statistics of damages, we believe that because these are almost out of the city, or because the game makes the representation of some phenomena in a random way, so it is not reliable in these cases, that it would be necessary to study how to avoid them.

In general, it is considered that evacuation in the face of an imminent natural hazard is not correctly interpreted by the game, since in all the simulations we observe that despite having evacuated the population in its totality, which can be verified with the chromatic scale provided by the game, vehicles continue to circulate even in the area where this phenomenon has occurred. In the simulations of the storms we can even observe that once the storm has passed, some vehicles continue to arrive at the shelters.

On the other hand, taking as an example the risk of catastrophe at the maximum magnitude of all the simulated phenomena, we can see that even though in some occasions the evacuation of the whole population is necessary as in the case of earthquakes, tornadoes and storms, since they spread all over the city, In other cases, such as meteorites and sinking, in the representation of the risk of catastrophe we can observe that the event will occur in a small portion of it, or in the case of forest fires it is even outside of it, so it would not be necessary a total evacuation of the population, but only of that area reflected in this representation.

This could also be extrapolated to smaller magnitudes with which we have been able to verify that the risk of catastrophe is reduced. Evacuating the entire population means a great loss of money, which can be seen in the reduction of our city's budget in any of the simulations. As far as evacuations are concerned, as we can see in all the risk simulations, the game allows us to free the evacuated citizens when the effects of the event are still present in the area. Being still present these effects in the territory, the game offers us the statistics of the losses caused, so we can assume that the damages produced can be a bit higher than those offered, because, during the time dedicated to its extinction, these can increase.

On the other hand, in relation to the magnitude of the different risks, a criticism can be made. Firstly, the game establishes the same magnitude, which it calls gravity, for all the risks. It is considered that it would be more correct that when it was possible, each phenomenon could be established with the scale that corresponds to it. Examples of this could be the earthquakes that could be established according to their magnitude with the Richter scale for example or according to their intensity with the European Macroseismic Scale (EMS-98); and the tornadoes that could be defined using the Fujita - Pearson scale. This can also be justified by looking at the damage statistics of all phenomena at the same magnitude, in this case 10, shown in Table 20.

Table 20 Comparison of damage statistics for different phenomena at magnitude 10.

	Earthquake	Meteorite	Tornado	Land subsidence	Forest fire	Storm
Deceased citizens	805	3282	**4554**	2	-	-
Destroyed buildings	170	158	**356**	4	-	-
Destroyed roads (meters)	3971	6155	**9965**	303	-	-
Burned buildings	**116**	53	-	-	15	46
Burned trees	72	99	-	-	**4932**	299

As we can see, despite the fact that they are all of the same magnitude, the damages produced by them differ greatly. It can be seen that these events produce different types of damage, and this may be justified by the differences in the selection of the place of production. However, for the same type of damage a smaller difference was expected between the data obtained. This fact makes us consider that using the same scale for all risks is not sufficiently representative to know the severity of them. We propose to use the scales for each risk in order to make a more real approach.

Generally, with some exceptions mentioned, we have been able to verify that the risks simulated in the city with preventive measures have suffered lower losses, so we can affirm the effectiveness of these measures. In addition, in this city the time invested to mitigate the effects produced is generally lower. So, we can corroborate the importance of preventive measures since they can make the difference between a disaster and a catastrophe.

As we mention in the background, (Gomes and Pena, 2019) concluded that there was a lack of tools to measure the resilience of cities. In the simulation of the different risks we have been able to check how the city reacted to the phenomenon, avoiding and fighting against its effects, so we can say that simulation could be a good tool to check the resilience, recovery, adaptation and transformation of the city after this process.

6. Conclusion

In this work about natural hazards management, we elaborated the case of Cities: Skylines, with a process to turn it into a serious game, in which the definition of the objective would be its use as a tool for the design of cities and for the simulation of different natural hazards. On the other hand, regarding the delineation of objective behaviours, with this gamified system it is intended that users can use this material for the management of natural hazards. These users could be the current risk and land planning managers and university students of the Environmental Science Degree.

Regarding the activity cycles, we can say that the game Cities: Skylines, is based on the ladder of progression, since it structures its action in the overcoming of several levels. As we saw, one of the most important points was the system's potential for fun. While this is subjective, in our opinion the game presents a fun and attractive mechanics that makes it enjoyable to use. Finally, as far as the tools are concerned, we found the game's own instruments for the design of cities, including the preventive measures of natural hazards, as well as the tool for the simulation of these phenomena.

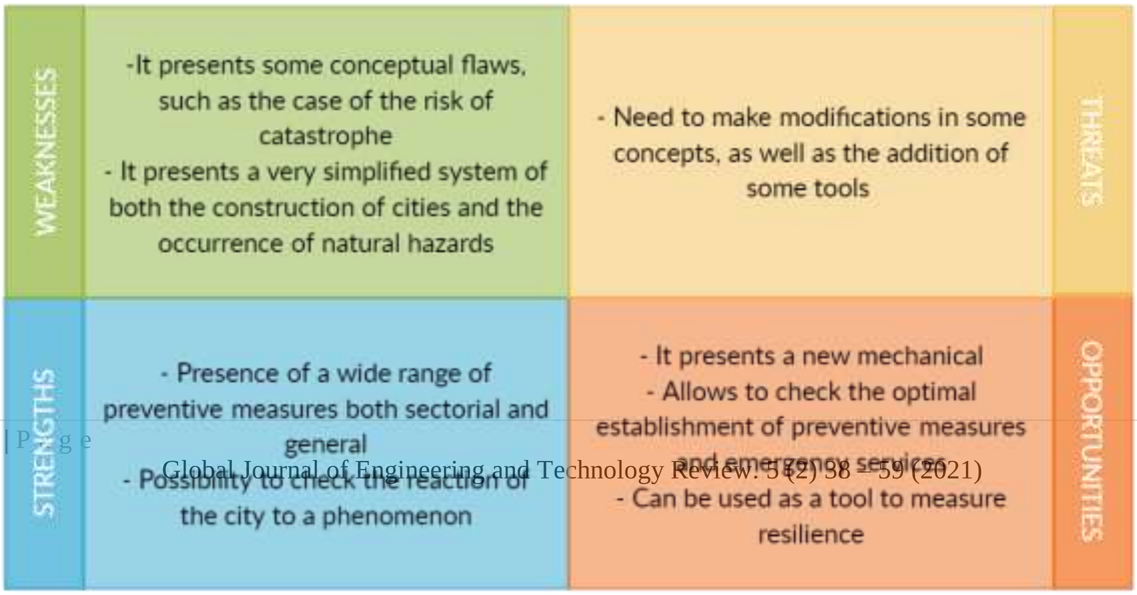
On the other hand, we have been able to verify that the game could have a place in the damage statistics since, after a phenomenon occurs, we can observe the statistics of the losses caused. We have also found that it can be used as a tool to inventory the mitigation measures for an event, as well as to check its efficiency. Therefore, we can affirm that gamification combined with simulation, can be a good resource for the analysis, evaluation and management of risk.

Finally, it has been proven that the game could improve a series of elements in relation to the simulation of natural hazards. First, the game has a simplified mechanics in the production of different risks because it does not take into account key elements of their generation such as the type of soil material of the ground for the production of earthquakes and subsidence, wind speed for the generation of tornadoes or density and biodiversity of species for the generation of fires, which could be improved to make these simulations more real. On the other hand, measures to combat natural hazards should be improved. Although, as we have seen, preventive measures work efficiently, reconstruction measures work poorly, since they only act against fires, as we have seen in several simulations.

In addition, palliative measures could be added by incorporating the role of civil protection. We have also seen that most of these measures were management measures since they were based on the early detection of this event to avoid risk. That is why some structural measures could be added, such as the seismic-resistant design of buildings (for that the inclusion of the type of soil material of the terrain, mentioned above, would be very useful) or the construction of wind resistant structures, since we only find the installation of lightning rods in buildings as a structural measure. Similarly, in the informative panel, explained during the methodology of this work, we could see that one of the sections is the detection of disasters, however, this only informed us about earthquakes, so a modification would have to be made to include the rest of natural hazards.

Finally, it should improve the types of natural hazards that the game allows to simulate, since it considers part of them to the collapses and fires of buildings, being these an effect produced by some natural hazards, and it does not include volcanoes, landslides, soil liquefaction or droughts, among others.

After the realization of this study we have been able to verify, as other authors had described, that the gamification and simulation together can be a useful tool for the territorial planning since it allows to verify the optimal zoning of the different sectors, the design of cities and the prediction of the traffic, among others. Similarly, after carrying out the different simulations, once the results obtained



have been studied and the effectiveness of the risk mitigation measures corroborated, we can conclude that this tool could also be used in the Analysis and Management of Natural Hazards. To synthesize all the conclusions and based on the results of this work, we have carried out the SWOT analysis shown in Figure 5.

Figure 4: SWOT analysis of the simulation carried out for the Analysis and Management of Natural Hazards.Source. Own elaborated.

Finally, we could conclude saying that achieving sustainability in cities is a challenge for the future, since as we have seen no city meets this objective today. A sustainable city must guarantee economic and social development and environmental protection. Furthermore, an indispensable goal of these cities is resilience to natural disasters through the presence of preventive measures (which mitigate, as much as possible, the effects caused and the time invested in repairing the damage), territorial planning and services such as civil protection. We have been able to verify that gamification can be a good tool for the construction of these cities and the corroboration of their sustainability by means of the simulation, as much of the natural hazards and their consequences, as of the effects of the city itself on the environment, knowing in addition its influence on the socio - economic system.

Acknowledgements (If Any)

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Appendix A.

1. Simulation of a 10 magnitude earthquake in the city with preventive measures:
https://youtu.be/2zH7bQlm9xU
2. Simulation of a 10 magnitude earthquake in the city without preventive measures:
https://youtu.be/25lr1Vx_pu0
3. Simulation of a 5.5 magnitude earthquake in the city with preventive measures:
https://youtu.be/GEdJCc62fyI
4. Simulation of a magnitude 1 earthquake in the city with preventive measures:
https://youtu.be/x8rXdgHJt6o
5. Meteorite simulation with magnitude 10 in the city with preventive measures:
https://youtu.be/zQKKjBcWuaY
6. Meteorite simulation with magnitude 10 in the city without preventive measures:
https://youtu.be/QStDOGWdeF0
7. Meteorite simulation with magnitude 5.5 in the city with preventive measures
https://youtu.be/lsvXhYHCd9w
8. Meteorite simulation with magnitude 1 in the city with preventive measures:
https://youtu.be/09DCjV0MUfA
9. Tornado simulation with magnitude 10 in the city with preventive measures:
https://youtu.be/YGDDfikX7ow
10. Tornado simulation with magnitude 10 in the city without preventive measures:
https://youtu.be/ygdnsghJcxw
11. Tornado simulation with magnitude 5.5 in the city with preventive measures:
https://youtu.be/KfpPwUHKdFc
12. Tornado simulation with magnitude 1 in the city with preventive measures:
https://youtu.be/JuiWPSQFQpc
13. Simulation of magnitude 10 sinking in the city with preventive measures:
https://youtu.be/Cz8Wa_coG8c
14. Simulation of magnitude 10 sinking in the city without preventive measures:
https://youtu.be/fom6w5SJjK8
15. Simulation of 5.5 magnitude sinking in the city with preventive measures:
https://youtu.be/eJEa-rxI4Ak
16. Simulation of magnitude 1 sinking in the city with preventive measures:
https://youtu.be/8NPu3tJdu2U

17. Simulation of forest fires with magnitude 10 in the city with preventive measures:
https://youtu.be/Lty3d4NrsYw
18. Simulation of forest fires with magnitude 10 in the city without preventive measures
https://youtu.be/x0O_Lm8tpE4
19. Simulation of forest fires with magnitude 5.5 in the city with preventive measures:
https://youtu.be/2PKmJsXD1Ks
20. Simulation of forest fires with magnitude 1 in the city with preventive measures:
https://youtu.be/RjzgKweafhg
21. Simulation of storm with magnitude 10 in the city with preventive measures:
https://youtu.be/5G7JrIhtaM8
22. Simulated storm with magnitude 10 in the city without preventive measures:
https://youtu.be/4feCsdVVD80
23. Storm simulation with magnitude 5.5 in the city with preventive measures:
https://youtu.be/fCShGKExN7o
24. Storm simulation with magnitude 1 in the city with preventive measures:
https://youtu.be/Hw_LKxaESBA