FloodGame: An Interactive 3D Serious Game on Flood Mitigation for Disaster Awareness and Education

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Abstract

The number and devastating impacts of natural disasters have grown significantly worldwide, and floods are one of the most dangerous and frequent natural disasters. Recent studies emphasize the importance of public awareness in disaster preparedness and response activities. FloodGame is designed as a web-based interactive serious game geared towards educating K-12 and college students and raising public awareness on flood prevention and mitigation strategies so that they are more informed about the implications of future floods. A web-based interactive gaming environment with rich 3D visuals and models is developed that allows users to experiment with different flood mitigation strategies for a real-world location of their choice. This immersive, repeatable, and engaging experience will allow students and the public to comprehend the consequences of individual mitigation measures, build a conceptual understanding of the benefits of mitigation actions, and examine how floods may occur in their communities.

Keywords: gamification, flood management, flood risk, community resilience, serious gaming.

Highlights

- A serious game to inform communities on flood mitigation.
- Intuitive visualizations and real-world parameters for holistic analysis.
- Potential to build conceptual understanding of flood prevention for students.
- Immersive environment applicable worldwide given local data is provided.
- Key issues and recommendations are specified for wider adoption.

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1. Introduction

The number and devastating impacts of natural disasters have grown significantly worldwide. According to a comprehensive review from the World Meteorological Organization (2021), a disaster-related to a weather, climate, or water hazard caused $202 million in losses and 115 casualties per day on average over the past 50 years. Also, the latest report from Munich Re (2022) states that natural disasters such as hurricanes, floods, and other disasters caused more than $280 billion in estimated damage worldwide, while $145 billion of the damage occurred in the US, along with thousands of casualties, damage to properties and infrastructure (Alabbad et al., 2023). Recent studies show that, as a result of climate change, it is expected to have more extreme and severe natural disasters with higher frequency in many parts of the world in the near future, resulting in more casualties and losses (WMO, 2021; Banholzer et al., 2014).

Floods are the most frequent type of natural disaster and have caused billions of dollars in losses and countless lives over the years (WHO, 2021). In 2020 alone, more than 60% of the natural disasters that occurred were floods, and 41% of the total fatalities suffered as a result of these events (NDRCC, 2021). Many studies show that the frequency and impact of flooding increase in certain regions as a result of climate change (Davenport et al., 2021; NOAA, 2022; Tabari, 2020) due to an increase in sea level (Strauss et al., 2016), the frequency of extreme precipitation (Diffenbaugh et al., 2017), or intensifying hurricane rainfall (Trenberth et al., 2018). Recent studies emphasize the importance of public awareness and the training of first responders in disaster preparedness and response activities (Kapucu, 2008). However, the strategy of simply conveying the potential disaster risks to communities is not a complete solution. The probability and potential consequences of rare extreme events are likely to be underestimated by the public (Green et al., 1991).

Web technologies have the capability of connecting the public with the concept of flood risk and the potential implications of a disaster event. Information systems and online decision support frameworks can support informed decisions by enabling multiple stakeholders (Demir and Beck, 2009). Recent studies have shown the significant potential of risk communications through information systems (Xiang and Demir, 2022), geospatial data analytics (Xu et al., 2019; Sit et al., 2021), and mitigation frameworks (Alabbad et al., 2022). Such systems can be integrated with flood mapping models (Hu and Demir, 2021; Li and Demir, 2022) and urban and agricultural flood risk assessment studies (Yildirim & Demir, 2022) to educate communities on flood risk to support smart city (Beck et al., 2010) and digital twin applications.

Developments in serious games have shown the capabilities of web systems to fulfill this need (Carson et al., 2018). Serious games utilize interactive and gamified story-telling environments for education. The genre of serious games has existed for many years and has had impacts on areas such as mental health, design, safety, and construction (Din & Gibson, 2019). These learning styles have been shown to have a positive effect on both student engagement as well as performance and attitude (Garneli et al., 2017). Furthermore, digital games have gained increased attention as an educational tool in the last two decades (Sousa et al., 2016; Tsekleves et al., 2016), as demonstrated by the United Nations Environmental Program initiative (Patterson & Barratt, 2019) for sustainability education.

Several studies have examined the use of serious games in the education of environmental and climate-related subjects (Valkering et al., 2013; Sterman et al., 2015; Onencan et al., 2016; Salvini et al., 2016; Craven et al., 2017; Aubert et al., 2018). Flood et al. (2018) provide a comprehensive review of serious games for climate change adaptation, their features, and how they play roles in social learning (i.e., cognitive, normative, and relational). In the area of flood management, the Stop Disasters game has shown feasibility as a serious game for societal preparedness to floods, with proven historical successes (Felicio et al., 2014), and Forrest et al. (2022) provide the latest developments for serious gaming in flood risk management. More recently, web-based serious gaming approaches have gained traction for decision support and stakeholder education in water-related hazards (Sušnik et al., 2018; Khoury et al., 2018; Carson et al., 2018; Xu et al., 2020). However, these recent studies focused on a much more informed and technical audience and required a significant amount of training before gameplay.

This study aims to create a web-based serious game geared towards educating students, and the public on flood prevention and mitigation strategies, such that they are better informed about the implications of future flooding events. A web-based interactive gaming environment is designed and implemented to allow users to experiment with different flood mitigation strategies for a real-world location of their choice. As part of the gameplay, the user will be presented with a community at risk of flooding and various potential mitigation and preparedness action options. Users will be faced with challenges in decision-making and will have to evaluate the trade-offs in terms of the assignment of monetary resources with respect to the societal gain. Once the decisions are finalized, a realistic flood event will be generated and visualized so that the user can examine how and in what ways the community was affected. In addition to visual inspection, the proposed game will allow for interactive analysis of the economic damage and casualties. This immersive, repeatable, and engaging experience will allow students and the public to comprehend the consequences of individual measures, build a conceptual understanding of the costs and benefits of mitigation actions, and examine how floods may occur in their own towns.

This article is organized as follows: Section 2 presents the system design and components as well as the data sources and metrics. Section 3 introduces the interface of the game, its methodology, and its evaluation to highlight its strengths and drawbacks. Section 4 concludes with final marks and future works.

2. FloodGame and Its Components

2.1. Scope and Purposes

Flooding directly impacts properties, critical infrastructure, transportation networks, and the population. Meanwhile, its implications can be magnified by considering parameters like demographic, socioeconomic, environmental, preparedness, and vulnerability factors (Haltas et al., 2021). Decision-makers evaluate structural and non-structural mitigation measures to reduce potential flood risk in communities. Some measures directly focus on the root of the problem to deal with the risk by altering the hydrological processes (i.e., reservoirs and dams). However, complete risk reduction is not possible in most cases, and it often requires significant investments and time. On the other hand, property owners can individually lower the risk by applying building-specific measures. Yet, individual efforts may not always be sufficient or feasible to reduce the risk.

A comprehensive approach is essential for a better understanding of the risk and taking the required precautions. Therefore, mitigation should be tackled with the consensus of multiple parties to address the risk reduction. Local authorities, stakeholders, and property owners should collaborate to find a feasible solution through informed decisions. Because total risk elimination is almost impossible, an ideal solution is desired to be cost-effective so that benefits can be maximized with the allocation of limited resources (Alabbad and Demir, 2022). At this point, simulations and modeling become crucial to supporting informed decisions. They can provide valuable insights into risk assessment from various perspectives. Hydrological models, property information, and mitigation applications can be enabled in a serious game platform for supporting such decisions.

Serious game platforms can be enriched with the recent development of internet technologies. Engaging mapping, domain datasets, and custom functions can be facilitated in the game. Engaging mapping tools allow users to interact with features on a map (i.e., buildings, land use) and the actual or synthetic satellite imagery (Gautam et al., 2020). Domain datasets cover real-time stream gauge data and data-driven flood maps. Custom functions contain the potential cost and benefit of mitigation choices based on governmental institution guidelines (i.e., FEMA, USACE). Therefore, the serious game experience enhances the perception of the risk and possible ways to lessen its impact with a versatile approach. A basic understanding of costs and benefits and the potential implications of a disaster event can be conveyed to the audience. Community rating systems (CRS) can also be improved by community involvement to encourage federal floodplain management activities.

FloodGame is a web-based, serious game aimed at educating students, as well as the general public, about flood prevention and mitigation measures, so they can better understand the consequences of future flooding disasters. Using a web-based interactive game environment, users can experiment with various flood mitigation measures for a real-world location of their choice or predefined maps. As part of the gameplay, the user will be provided with a community at risk of flooding and a variety of mitigation and preparedness alternatives. The users will confront difficulties in decision-making and will be required to analyze the trade-offs in terms of the allocation of monetary resources in relation to the societal benefit. After finalizing the decisions, a realistic flood event will be simulated and shown so that the user may analyze how the town was affected. In addition to visual assessment, the suggested game will allow interactive assessment of economic damage and casualties. Students and the general public will be able to gain a conceptual understanding of the costs and advantages of flood mitigation methods by participating in this immersive, repeatable, and engaging experience.

2.2. Data Resources and Available Mitigation Options

Serious gaming environments should be designed based upon realistic data and solutions in order to fulfill their goal and promote action in real life. To support this goal, the proposed system uses various data resources for mapping, alongside actual mitigation options and damage/flood calculations, to provide real-life solutions. The game is designed to provide environments that reflect real-time locations. This goal can be achieved with two options, providing custom map data or creating the game map from online map services by selecting a region. In the first option, the user needs to select the predefined map data, which is fed into the application to create the game environment. The predefined map data contains all building information, such as the number of people in a building or the building type, along with ground/earth information (e.g., tile type, elevation value). If the flood map of the region is available, that information will also be integrated into the game.

The second option is automatic map creation. For this option, the user needs to select a region in the game using Google Maps, and the system will create the map data automatically, similar to the first option. During this process, building and ground/earth information will be created with data combined from Google Maps and Open Street Maps (OSM) Buildings. Also, Digital Elevation Models (DEMs) will be used to provide actual elevation values to the system in order to have realistically flooded regions and appropriate calculations. In the game, there are a limited number of building types, and each of these buildings has its own specifications, such as the relocation costs, number of occupants, or structural value. However, for the custom map option, buildings may have a different number of occupants than default values, and all calculations in the system will use provided occupant numbers until the building is ever removed from the game as a result of the user's actions.

Alongside the map data, the system utilizes mitigation and depth-damage functions created by the Federal Emergency Management Agency (FEMA) and the United States Army Corps of Engineers (USACE). The mitigation and depth-damage functions, that are adopted in the system, are explained below.

Dry Floodproofing: It provides an impermeable perimeter for the building at a certain design level, which ranges between 1 and 4 feet. This method is often applied to non-residential structures in the United States (FEMA, 2021).

Elevating Structure*:* This mitigation method deals with the process of raising a home to a level where the risk of flooding is absent or minimal. The flood risk can be entirely eliminated or substantially reduced after the application is completed. However, the associated costs are relatively higher than other applications. FEMA recommends elevating structures within the 100-year floodplain by satisfying a certain benefit-cost ratio (FEMA, 2020).

Floodwall and Levees: They work as barriers against floods to prevent water from reaching multiple properties and lands. The feasibility and probability of flood events are mainly considered when they are permanently built in communities. Soil and concrete are commonly preferred materials for mitigation (Wolff, 2008). Water holding capacity varies from days to weeks, depending on the material type and design dimensions.

Relocation: It requires the structure to be removed and rebuilt outside of the floodplain. Relocation is the costliest option due to the high cost of demolishing, rebuilding, and land acquisition. However, the risk and potential for human vulnerability can be eliminated with this option. Properties that are constantly exposed to floods are likely to be selected for the relocation option (Alabbad et al., 2022).

Reconstruction*:* It is restoring the property to become more resistant towards flooding by complying with the state or federal floodplain guidelines. Although the method may not be as costly as relocation, the flood risk may not be entirely reduced (World Bank, 2012).

Sandbagging: Sandbagging is one of the most common mitigation applications and does not require sophisticated engineering like other mitigation types. It is applied at the perimeter of the desired structure or land. Storage and installation/removal time are important drawbacks of this mitigation (Massolle et al., 2018).

Shelter: Permanent shelters are generally built to protect the public from natural disasters (i.e., floods, tornados, earthquakes). Due to the unavoidable impacts of flooding, decision-makers need to ensure the timely evacuation of the vulnerable population and provide them with safe and temporary housing. The cost of constructing a shelter may vary depending on the available resources and the capacity. In some cases, schools or sports arenas can be converted into temporary shelters (Tofa et al., 2017).

Wet floodproofing: This mitigation method only reduces structural losses of a property during a flood event. Wet floodproofing allows water to enter into the unit and can still damage the contents. However, it also allows holding flood water to reach further regions (Highfield and Brody, 2017).

Depth-damage functions: These functions are employed to conduct damage and loss analysis along with the mitigation functions. They were developed by the USACE to provide the relationship between flood depth and damage percentage (Yildirim, 2017). During game development, twenty-two unique damage functions are employed to analyze damage for different occupancy types. The occupancy types include residential, commercial, industrial, and critical infrastructure. For each occupancy type, the functions also provide structural and content damage percentages to reflect losses per flood depth of a unit.

2.3. System Architecture and Design

FloodGame is implemented as a web application, with the main functionalities and visualizations working on the client-side for performance and efficiency. During the development of the game, one of the main concerns is designing a platform that has a minimum number of dependent libraries to easily maintain and distribute without compromising the performance, user-friendly design, and capabilities such as Virtual Reality (VR) support as well as cross-platform compatibility. As a result of this, the system only uses Google Maps API, OSM Buildings, and other public resources during the map creation, three.js for visualization, Bulma as a Cascading Style Sheets (CSS) framework for responsive user interfaces, jQuery, and JavaScript for main development and interactions.

Alongside the dependent libraries, the FloodGame system architecture has a modular form on each level to improve maintenance and customization. It consists of three main components (modules): Level Generation, Game Engine, and Aftermath Analysis (Figure 1). The Level Generation module is responsible for automatically creating the level map data for the game. The Game Engine module handles gaming dynamics, interaction methods, mitigation strategies and effects, and extreme event generation and simulation. Finally, the Aftermath Analysis module calculates the economic damages, fatalities, and affected buildings and presents a detailed report that can be used to understand the impact of floods on communities as well as the benefits of preparedness. Each of these modules has smaller components that handle the specific tasks in the parent module. Thus, it is easy to introduce new features or customize existing methods by manipulating corresponding components. Figure 1 presents a visual overview of the system architecture and its components.

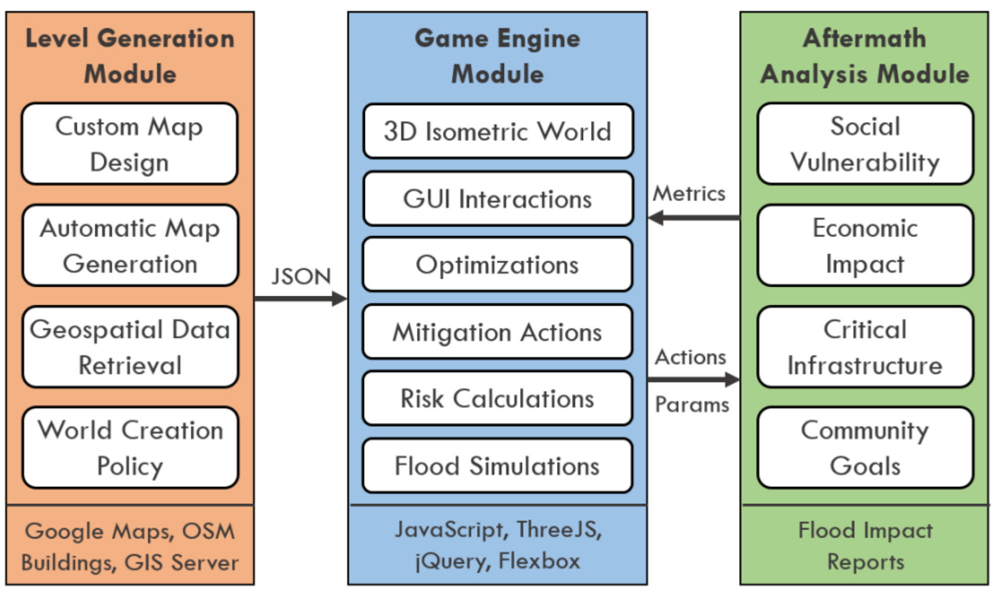

Figure 1. System architecture and modules for the FloodGame

2.3.1. Level Generation Module

The Level Generation Module is responsible for generating tile-based game maps. As mentioned above, serious game environments should represent the actual world as much as possible, so the FloodGame, it is aimed to create a platform that has a similar terrain characteristics and property distribution as the region selected by the user to offer a realistic gaming experience and more accurate representation of the flood damage and mitigation estimations.

The actual world in the game can be seen as a combination of different layers. For example, the surface of the Earth can be seen as a layer with different versions, such as the lands, waters, etc., and infrastructure built on the top of the ground layer can be seen as another layer. Also, the water that covers flooded regions or areas can be considered as an additional layer for that region. So, FloodGame follows a similar layer-based structure for game world representation.

In the system, there are three layers to represent the world, namely, surface, infrastructure, and flood layers. Each of these layers has its own tilemaps of the same size and is named as surfaceTiles, infrastructureTiles, and floodTiles. Each of the tilemaps is an array of objects, and each object represents a tile in the system and stores tile information. The surfaceTiles contains information about the surface of the tile, such as surface type, elevation value, already applied mitigation options. The infrastructureTiles indicates whether a building exists on the tile or not. If it exists, it shows the building's type, the number of occupants, and mitigation status. Similar to the other two layers, floodTiles contain information about whether the tile is at risk or not. If it is the case, it shows the expected water level, and initial risk level. The Level Generation Module ensures that the system has these three-game maps, and they are delivered to the next module in order to be used in the game.

In the Level Generation Module, tilemaps can be generated by two methods including predefined maps or automatic map generation. The system has also predefined maps for certain regions that the maps had been created or modified with human involvement. If a predefined region is selected, corresponding files will be read and passed to the Game Engine Module. The other option in this module is automatic map generation. This option allows generating a tile-based game map for a location selected by the user, thus allowing the game to take place at a location familiar to the user for increased effect. The module's front end consists of a welcome page guiding the users along with a dynamic map from Google Maps. The map contains a moveable and resizable area selector for the user to choose the location and extent of the region to generate the level map. Once the area is selected, a unique data structure is created combining the map and selection parameters such as geolocations and map zoom level. These parameters are used to form a GET request that will be made to Google Maps Static API to retrieve the street map image without any markers or labels.

For each tile type of FloodGame, a color range is defined that corresponds to the pixel values of the map image. As assigning a tile to each pixel would be impractical and may make the game map susceptible to signal noises, the image is divided into square-shaped pixel groups, which will correspond to a single tile type. In addition to the image from Google Maps, building information for the selected region will be retrieved through OSM Building API and integrated into the map in order to overcome the problems that might occur as a result of the simplification of the selected region. In the last step, the Digital Elevation Model (DEM) of the selected region will be gathered through a GIS server, and the elevation value of each tile will be assigned with the averaging elevation value of the area represented by the tile in the received DEM. Finally, the game maps are passed to the Engine Module for scene generation and further calculations. Figure 2 summarizes the Automatic Map Generation component.

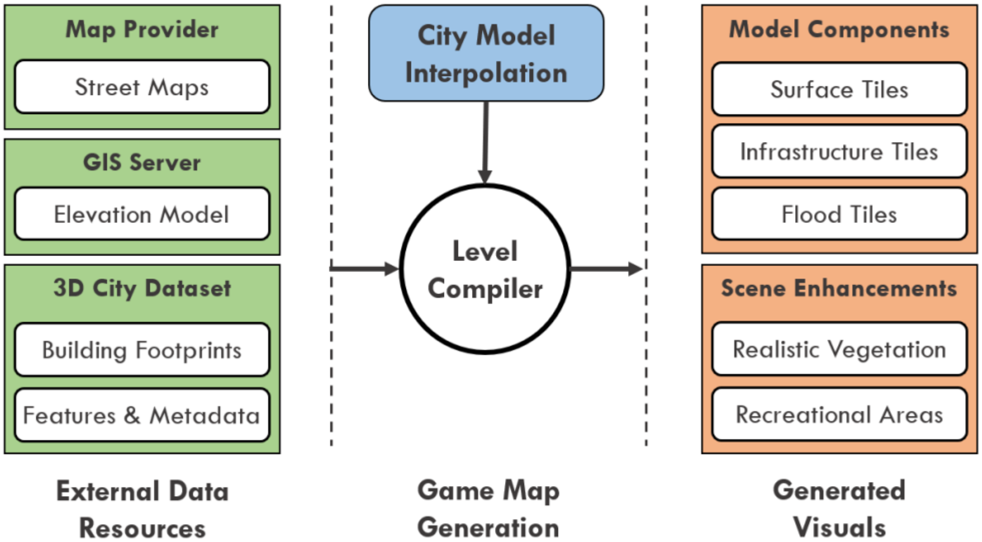

Figure 2. Automatic 3D isometric game map generation based on geospatial data retrieved real-time from external sources.

2.3.2. Game Engine Module

The Game Engine Module combines the main functionalities of the serious game with engaging visualizations, game dynamics, and disaster simulation. This section is developed with jQuery, JavaScript, and three.js. The three.js is an open-source, cross-browser JavaScript library that enables the creation and use of 3D computer graphics in a web browser using WebGL, which is a cross-platform web standard to bring 3D graphics functionality to the web utilizing client-side computational resources and is supported by most recent versions of major browsers (e.g., Safari, Chrome, Edge, Firefox) (Dirksen, 2018). Three.js is selected as a core library of this project because it has great features such as virtual reality integration (Sermet and Demir, 2022) and long-time support alongside adaptation to new technologies such as WebGPU for accelerated 3D graphics and compute (Johansson, 2021). With the help of three.js, it became possible to benefit from the power of WebGL without doing the heavy work that should have been needed in WebGL during the development and maintenance of FloodGame.

In the Game Engine Module, the game maps received from the previous module will be passed on to Create World Component. In this component, surfaceTiles and infrastructureTiles are read, and appropriate 3D low poly models are selected for performance and added to the scene. During this process, the benefits of the instancing are used. Instancing is the practice of rendering multiple meshes with the same geometry in a scene in one draw call. It is a very important method that allows rendering the same geometry a lot of times without performance issues. Since most of the surfaceTiles and infrastructureTiles are same in terms of geometry, instancing allows the use of 3D low-poly models for buildings, trees, and structures. For better visual appearances alongside decreasing the number of calls, textures, and geometry in the memory to dramatically improve the performance of the game.

The Game Engine Module handles interactive menus, mitigation actions, and the time-keeping mechanism, updates information panels, and runs disaster simulation with several small and medium-sized components. The GUI Interaction Component makes the menus interactive and transfers data between the interface and backend to show appropriate options on the GUI. The Information Panel Update Component updates information panels on the main screen, such as the Game Progress panel or Goals panel, whenever a mitigation action is applied to a tile.

The Mitigation Actions Component handles all mitigation interactions in the game. It keeps track of applied mitigations, allows players to apply or deactivate mitigations on tiles, shows proper mitigation options for each tile, and initiates the set of interactions that calculate new risk assessments and then update panels and information in the game when a mitigation is applied. The Flood Risk Component evaluates the map for flood risk and identifies regions and their water levels by examining the environment and applied mitigation strategies by using a similar algorithm to the Flood Fill, then updates floodTiles. The Disaster Simulation Component uses updated floodTiles and adds the flood layers to the scene by using instancing. In addition to the components mentioned in the Game Engine Module, several other components handle various tasks such as showing remaining time, checking goals, or showing risky areas.

2.3.3. Aftermath Analysis Module

Aftermath Analysis Module is designed to provide comprehensive reports related to a flood event for the selected region and its consequences. At any time in the game, specific damage information can be calculated for each property to reflect the number of people affected as well as any financial damage incurred with this module. A comprehensive report of the disaster can be generated by the system in a similar format to the flood report published by USGS to educate the user on how to interpret such reports in real life for potential future disasters. The report will have four sections: social vulnerability, economic impact, critical infrastructure vulnerabilities, and goal sections. Inside each section, many helpful metrics are provided to the user to show how applied mitigation strategies change the consequences of the disaster and which goals are achieved. Detailed information about the report will be provided in the next sections.

2.4. Game Metrics

The main game metrics are social vulnerability, economic impact, and critical infrastructure vulnerability, based on which the users are asked to minimize the effects of flooding. The following section provides details on metrics and their limitations.

Social Vulnerability: In this metric, the population is required to be protected either by applying mitigation options to structures or by providing shelter in a flood-free zone. The game encourages users by providing goals to protect the community. The population value is assigned to the residential properties in the region based on property types. The user is informed about the number of potentially vulnerable individuals on each property. The simulation may or may not have an impact on the total number of vulnerable people. Hence, the decision is expected to be made by the user to manage the risk based on realistic experience. In Table 1, social vulnerability metrics that are utilized in FloodGame are provided with brief explanations.

Table 1. Selected social vulnerability metrics in the FloodGame.

Criteria	Description
Vulnerable Population	The number of people affected by the simulated flood event
Secured People	The number of people that are located in the secured property
Secured Buildings	The number of structures that sufficient mitigation applied
Sheltered Population	The number of people who are relocated in shelters
Impacted Residential Buildings	The number of buildings that are affected by the flood
Impacted Commercial Buildings	The number of businesses that are affected by the flood

Economic Impact: The economic impact of flooding is estimated based on the direct flood losses on properties. Although the loss varies by structure, commercial and industrial buildings are generally prone to more economic losses. The user is required to reduce the economic losses and evaluate mitigation options, considering the total mitigation costs. The game provides a benefit-cost ratio (BCR) that reflects the success rate of the mitigation efforts in the game. If the BCR is lower than 1, the mitigation decisions are considered unsuccessful from an economic point of view. If the ratio is higher than 1, the mitigation is rated as feasible. Table 2 delivers the economic impact metrics implemented in the FloodGame.

Table 2. Selected economic impact metrics in the FloodGame.

Criteria	Description
Remaining Budget	The leftover budget after mitigation efforts are utilized
Avoided Losses	The number of losses expected before mitigation effort
Total Losses	Cumulative losses that are caused by a flood event
Benefit-Cost Ratio	The division of benefit and cost amount of a mitigation
Impacted Buildings	The number of industrial structures that are affected by the flood
Applied Mitigation	The number of mitigations and their types

Critical Infrastructure Vulnerability: Critical infrastructures include hospitals, fire stations, water treatment facilities, police stations, and schools. Although the flood causes a greater financial loss to critical facilities, maintaining their functionalities is more significant in a community. The critical facilities are evaluated using a different metric, and custom goals are set up in the game. So, the importance of non-quantifiable flooding impacts is emphasized to the users.

Limitations and Assumptions: The game utilizes diverse parameters to provide a flood impact analysis environment for the users and highlight the integrated implications of a disaster event. Although the game covers multiple metrics, combining all the metrics into an overall score is a great challenge. Such a score can be used as the sole indicator of the success rate of the decisions that are made during the gameplay. However, identifying the optimal weights of the parameters to merge countable and uncountable impacts into a single score is a difficult process.

3. Results and Discussion

3.1. Game Interfaces

FloodGame is implemented as a client-side 3D web application and publicly available freely (https://hydroinformatics.uiowa.edu/lab/floodgame/), with the main functionalities and visualizations working on the client-side for performance and efficiency. As a result of this, the current interface of the game is designed to cooperate between a scene rendered by three.js and Document Object Model (DOM) elements manipulated by the Bulma CSS framework as seen in Figure 3. The game interface consists of a map-based environment, a control menu, and several information panels. Users are provided a timer to follow their progress over time before the flood event starts. If the user completes all mitigation actions, they can start the flood simulation without waiting for the timer to run out. The user can access various critical information related to the flood event in the region and its consequences, which is covered in the Metrics section.

Figure 3: Game start page for the FloodGame with user control panels and map interface

In the second section of the interface, tile information and mitigation options are provided. The Tile Information panel shows tile type, the number of occupants in that tile, the expected water level if a flood event occurred, and its risk level. The Mitigation Option (Figure 4) section lists all the mitigation options and allows users to interact with the options that are suitable for that tile type. It provides information about the mitigation option's name, choices, cost, and options to apply or discard the current tile.

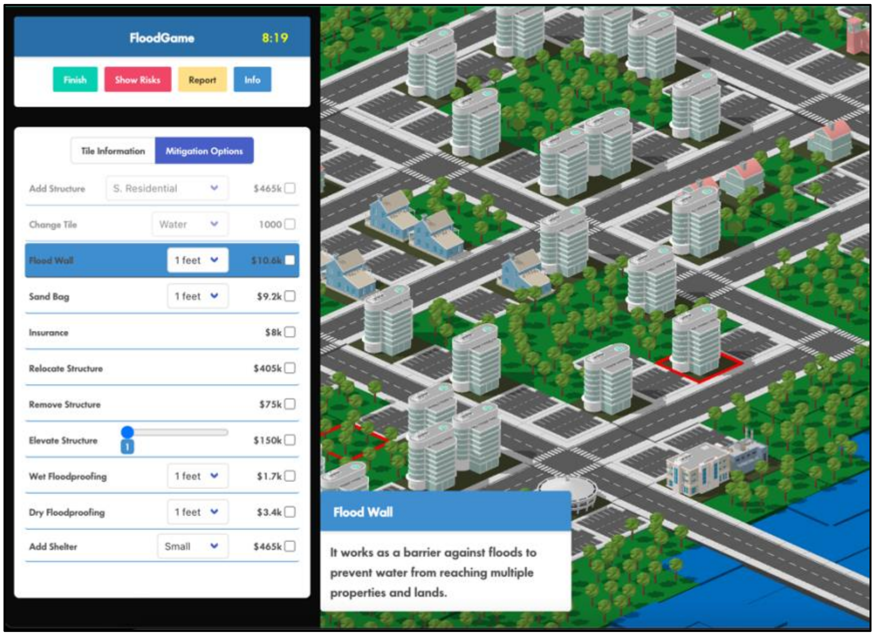

Figure 4: Mitigation Options panel for user decisions

Users can access information about the current progress of their gameplay. The Game Progress panel (Figure 5) provides the most crucial information about the current situation from different angles. It shows the total and remaining budget, the total avoided losses with applied mitigations, the total number of vulnerable people, the total number of people who live initially in flood regions, the total number of secured buildings with applied mitigations, the total shelter capacity, the total number of secured critical infrastructures, and the total number of buildings that are initially in flood regions. The Goals panel (Figure 5) provides predefined goals from a goal set with random selection to the user in the game. Goals are essential to games; they establish what the user must do to succeed and provide the user with a sense of accomplishment and progression. By adding a goal (e.g., securing people, applying floodwalls, sheltering a certain number of people), we can transform a non-game activity into a game (Weitze, 2014).

3.2. Gameplay Delivery

FloodGame offers a web-based interactive gaming environment to allow users to experiment with different flood mitigation strategies for a real-world location of their choice or one of the preselected locations. At the beginning of the game, the user will have the option to choose the map to play. If the user prefers the Automatic Map Generation option, it is expected to select a region from an interface based on Google Maps (Figure 6). Once the map is selected, it will be transformed into a tile-based game environment. In the current situation, the game allows players to select 1 km x 1 km areas, and selected areas are transformed to 50x50 tiles, but our game has the ability to support up to 200x200 tiles environment if the resolution of the game needs to be increased.

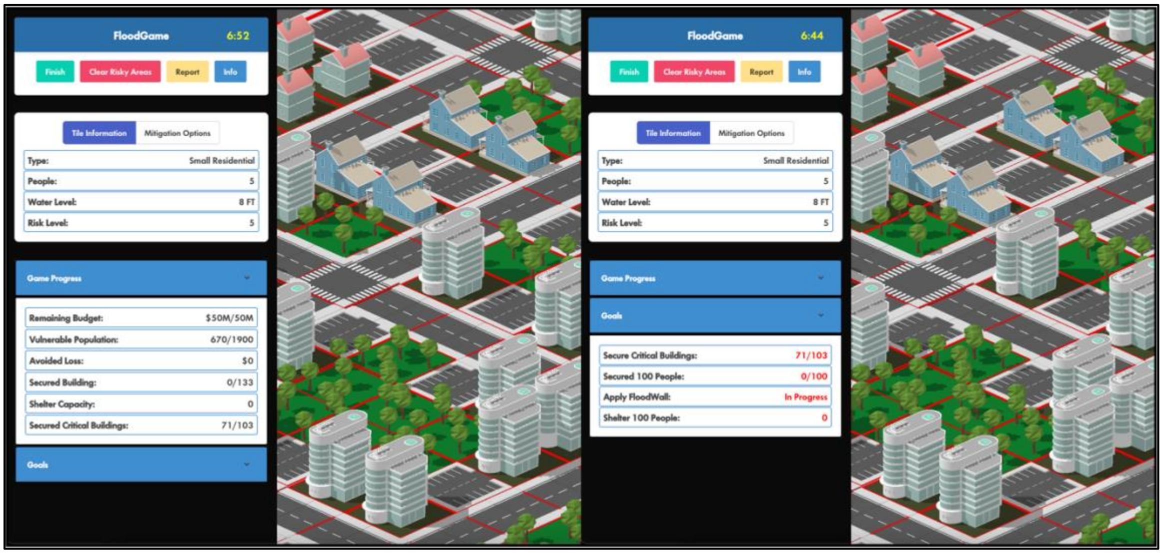

Figure 5: Game Progress and Goals panels providing live information during gameplay.

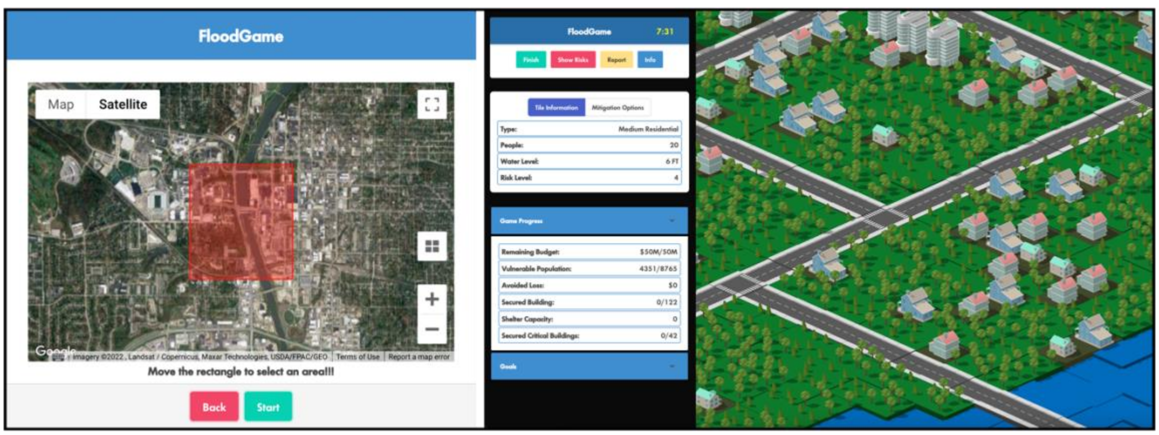

Figure 6: Google Maps game map generation screen

After the game is started, users can see the current situation of each tile on the Tile Information panel. In addition to the detailed information about each tile, the game adopted a color scheme to show the current risk or mitigation situation effortlessly while moving on the map. With this color scheme, users can identify risky and secured areas, as well as the need for more mitigation. Since it is required to see the general situation in the area to come up with better mitigation strategies, the Show Risk function is provided on the main interface for easy access to show the current risk levels in all tiles by using the mentioned color scheme. Figure 7 shows the risky regions in a game.

All mitigation options in the game are provided in the Mitigation Options section. The Mitigation Options section will be updated interactively to show accurate cost and benefit situations and allow for the application or updating of mitigation options in the selected tile. As a result of the action, all panels and information sections on the game will be updated appropriately. During the game, a user can monitor the current risk status with the help of the Game Progress and Goals sections. These sections have easy access to optimize efficiency in the game.

Figure 7: Representation of regions with pertinent flood risk.

Alongside the mentioned sections, FloodGame provides crucial information on flood risk and mitigation from different angles. Once the user requests the flood risk report, Aftermath Analysis Module generates an extensive report. Users can have a chance to see more details about the expected effect of the disaster and the outcome of the applied mitigation actions in the current scenario. Since this is a game that is required to be played within a limited time, the user has the option to finish the game early and see the results. In Figure 8, a detailed gameplay experience is provided.

3.3. System Evaluation and Limitations

FloodGame provides a web-based, interactive gaming environment in which users can experiment with various flood mitigation strategies for a real-world location of their choosing or one of the pre-selected locations. Before it can be evaluated on a production level in a professional setting, it would be better to be evaluated (e.g., through quantitative, qualitative, and/or interview-based studies) in a controlled environment with potential users to measure effectiveness and usefulness, identify issues, and elicit additional improvements (Rosson and Carroll, 2002). These evaluation studies have been shown to be effective for receiving constructive input while the system continues its incremental development and are therefore utilized to enhance the system rather than to determine binary conditions for a final product (Kaplan and Maxwell, 2005). FloodGame is presented to domain experts, professionals, researchers, undergraduate and graduate students, and interested parties to receive feedback about the current development progress. According to this feedback, the following strengths and drawbacks have been identified.

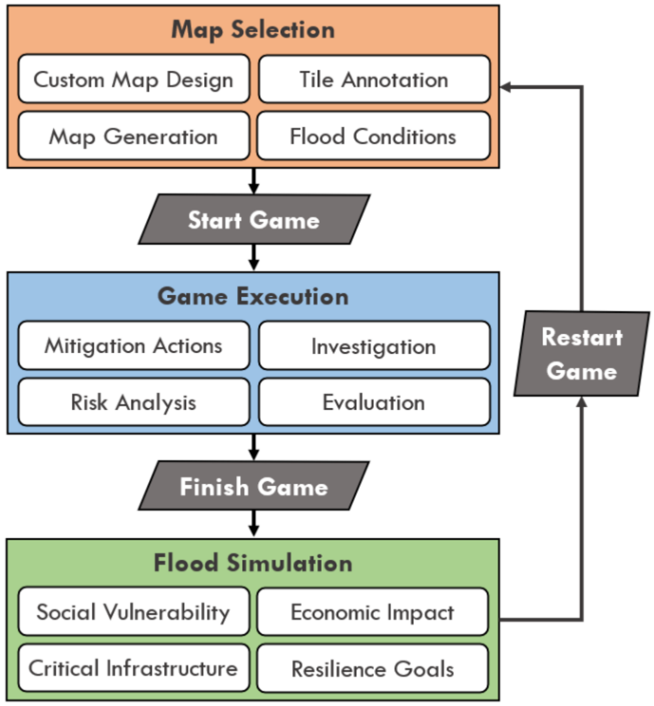

Figure 8. Overview of the gameplay.

As mentioned, FloodGame enables the retrieval of real-world locations and gamifies them by changing to tile-based environments. It uses as many possible realistic data sources to create environments that are as close to the real-world experience as possible during that process. It improves engagement since the user has a chance to play in an area that they are already familiar with. In addition to automatic map generation, it allows for the integration of custom maps into the game with actual flood maps. Since it uses actual scientific datasets and methodologies regarding flood damage estimation and mitigation calculations, FloodGame is a great platform to show realistic simulations to the public. It offers various mitigation options with easy-to-understand explanations and results.

During the game, extensive reports will be delivered to examine the consequences of the floods in various aspects by using accurate calculations. In addition to the game's features, FloodGame is a web-based game that can be used on many platforms without needing any additional adjustments. During the game's development, a limited number of open-source libraries are used to make it easier to maintain, learn, and improve the platform. Also, the system design is based on the combination of various data and information layers, which enables the integration of other user-provided layers into the system with minimum effort. This gives the opportunity to use the base of the game on different educational applications and projects easily.

FloodGame has a number of limitations and challenges in comparison to its capabilities. In the game, single tile representation might lead to a misrepresentation of the land use and properties in certain neighborhoods in the selected region. The current tile system enforces one tile per object, which means each infrastructure or property is represented with one tile despite the size differences, and this situation may confuse the user when a user plays in a familiar area.

Similarly, automatic map generation has some weaknesses due to the single tile representation and the limited number of tiles in the game. Since the game supports a limited number of tiles, the map data retrieved from Google Maps is downscaled, and during that process, some information may disappear. For example, if there are three buildings in an area and the area is represented with two tiles, the game can only show two buildings. In addition to that, some buildings cover more area than the tile represents. In such cases, the mentioned buildings may be represented within multiple tiles with building groups.

Also, FloodGame only works in the State of Iowa with automatic map generation currently because of the limitation on the elevation data. In the background, the elevation data is received from a GIS server, which currently provides statewide information. However, the game is applicable worldwide if the resources are provided. Another missing part is the lack of multiplayer options for collaborative educational opportunities. It may be helpful if there is an option to solve or investigate the problems in an area by collaborating with others. Moreover, there was no qualitative system to show the executive summary of the mitigation effort in the game. Due to ethical concerns, weighing the implications of a flood event such as public versus private loss or environmental impact versus critical infrastructure damage is a great challenge. Thus, further research is necessary to address the ethical concerns (Ewing and Demir, 2021).

4. Conclusion

Studies suggest that building a conceptual understanding of mitigation strategies results in a significantly higher probability for individuals to take action and fulfill their responsibilities in their communities in response to natural disasters. The proposed game enables this vision by letting the members of communities be more informed on flood risk management, and understand the potential damages and casualties caused by a lack of preparedness. A major motivation to use engaging graphics and games in the disaster domain is that they are an effective method of teaching hydrological processes, natural disasters, and social responsibilities to students.

The proposed flood game can allow students to experiment with flooding scenarios for their communities to see the outcomes that were impossible to reproduce in real life. Due to the flood game's utilization of real-world data for topography and hydrology, it has the potential to build a conceptual understanding for students with regard to extreme hydrological events. One of the main goals of the proposed serious game is to increase flood resilience in communities via education. In support of this purpose, the game can be exhibited on a touch-screen tablet display in museums and at various outreach events for hands-on exploration by students and the public.

As a future study for the FloodGame, it is planned to focus on several points to overcome the aforementioned drawbacks and offer new features to improve the game in many aspects. The maps in the game are an important component that affects the game's quality, and automatic map generation capabilities will be improved by introducing new data sources and allowing multi-tile representation instead of a single tile design. Also, it is possible to integrate digital twin representations on demand for any location along with live data such as traffic, weather, and flood forecast. In addition to map-based representation, FloodGame will be expanded with immersive technologies such as virtual reality (Sermet and Demir, 2020) to provide more realistic and impactful visualizations and simulations (Demir et al., 2009). It will have more game options, such as cooperative or multiplayer game mods, to enhance the gaming experience and cooperation. Along with technical improvements, a case study will be conducted and evaluated in museums and schools for public awareness and the educational impact of the game.

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