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SCHOOL OF CIVIL, ENVIRONMENTAL AND LAND MANAGEMENT ENGINEERING

MASTER OF SCIENCE IN CIVIL ENGINEERING FOR RISK MITIGATION

Development of a Digital Twin-Based Early Warning System for River Flooding: A Case Study of the Tartano River

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Abstract

The rapid advancement of digital twin (DT) technology has led to its emergence as a significant tool for risk management in recent years. The Unity game engine has been identified as a suitable platform for creating 3D models within the DT framework. This thesis focuses on the creation of 3D visualizations of DTs in Unity and the utilization of DTs for Early Warning System. The Tartano area is used as a case study, and a terrain model and river model are developed using the World Composer and R.A.M tools, respectively. The research also addresses the issue of coordinate conversion between longitude/latitude and the Unity coordinate system. To apply DT to practical purposes, this thesis proposes several ideas for future research, including the acquisition of field information and its integration with the virtual world, and the establishment of threshold values for flood warnings based on simulation results. The potential benefits and challenges of this approach are explored in detail in this thesis. This study contributes to the growing body of knowledge on the application of DT in risk management and provides insights into the use of Unity as a platform for creating 3D models for DT.

Keywords: Digital Twin; Early Warning System; River Flooding; Tartano River; Unity; Flood Prediction.

Abstract in Italian

Il rapido avanzamento della tecnologia Digital Twin (DT) ha fatto emergere negli ultimi anni la possibilità di applicarla come strumento per la gestione del rischio. Il programma per applicazioni nel campo dei videogiochi Unity è stato identificato come una piattaforma adatta per la creazione di modelli 3D in ambiente DT. Questa tesi si concentra sulla creazione di visualizzazioni 3D di DT in Unity e sull'utilizzo di DT per un sistema di early-warning. Una parte dell'Alta Tartano è stata utilizzata come caso studio, dove è stato sviluppato un modello del terreno e del fiume utilizzando rispettivamente gli strumenti World Composer e R.A.M. La ricerca affronta anche il problema della conversione delle coordinate geografiche (longitudine/latitudine) nel sistema di coordinate interno di Unity. Per applicare praticamente i DT, questa tesi propone diverse idee per future ricerche, tra cui l'acquisizione di informazioni sul campo e la loro integrazione con il mondo virtuale, assieme alla definizione di valori di soglia per l'early-warning sul rischio di alluvione basati sui risultati della simulazione. I potenziali benefici e i limiti di questo approccio sono analizzati in dettaglio in questa tesi. Questo studio contribuisce ad accrescere la conoscenza sull'applicazione di DT nella gestione del rischio e fornisce informazioni sull'uso di Unity come piattaforma per la creazione di modelli 3D per i DT.

Parole chiave: Digital Twin; sistema di early warning; inondazione fluviale; fiume Tartano; Unity; previsione di alluvioni

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1   Introduction

Hydrogeological disasters represent one of the most hazardous environmental risks of our time. According to statistics released at the end of the International Decade for Natural Disaster Reduction, proclaimed by the United Nations in 1990, floods, landslides and subsidence of varying intensity and severity have affected vast areas of the five continents over the last few years, causing substantial economic losses in many countries (International Federation of Red Cross and Red Crescent Societies, 2002; UNDP, 2004). Italy is affected by flooding events fairly frequently, with devastating effects on most of its territory (Guzzetti, Stark, & Salvati,2005). Data from the latest report of the Ministry for the Environment and Territory (2003) reveal that 68.8% of Italian municipalities are exposed to high or very high hydrogeological risk levels.

Val Tartano is situated on the southern side of the Valtellina Valley in the Lombardy region of Northern Italy (46.1075° N, 9.6791° E) and covers approximately 51 km². The Tartano Valley's altitude ranges from 250 to 2250 m a.s.l., with an average of 1861 m a.s.l. The main river of the basin is the Tartano River, which is a tributary of the Adda River. This valley has been studied by various researchers (Mandelli et al., 2009; Ballio et al., 2010; Brambilla et al., 2011; Colombera and Bersezio, 2011; Longoni et al., 2016) due to the geological peculiarities of the entire catchment. Numerous flooding events and landslides have been documented in this valley, with the most catastrophic event occurring in 1987 and resulting in 20 fatalities.

Figure 1 Tartano Valley geographical setting

Analysis of the available data unambiguously indicates that, in areas with heightened disaster risk due to intense human activity, such as Val Tartano, augmenting disaster preparedness through emergency planning measures and promoting specific protective behaviors among citizens is equally imperative as risk mitigation through engineering or architectural interventions aimed at making areas safer. In line with a comprehensive interdisciplinary approach to environmental issues, gathering data on individuals and communities residing in hydrogeologically exposed regions would be advantageous for understanding the extent to which they have adopted behaviors necessary to adaptively deal with a potential catastrophic event and their level of risk perception.

The aim of this study is to develop a 3D digital representation of the Tartano River within the Unity game engine, and to formulate hypotheses on the feasibility and effectiveness of utilizing digital twins for river monitoring and flood warning purposes. This case study demonstrates the potential for using a more efficient and accessible approach to digital twin creation, enabling realistic simulation of complex environments in risk management area. Furthermore, this study has the potential to yield innovative solutions for managing flood risk in the Tartano region, through the development and utilization of digital twin

technologies. The resulting insights and outcomes of this research may inform future flood risk management strategies and enhance the overall resilience of the region. It is hoped that this approach will inspire further exploration and innovation in the field of digital twin development, facilitating wider adoption and more effective utilization of these technologies.

2 Literature review

2.1 Digital Twin

Digital Twin applications started emerging with the recent development of the Internet of Things (IoT). Both technologies share the same nature - connecting a physical artefact and its digital counterpart （Akanmu et al, 2020). Enabling tools for digital twin data, services, modelling and connection to the physical world have led to the increased popularity of digital twins (Qi et al., n.d.). Digital twins integrate Internet of Things, machine learning, artificial intelligence and data analytics to create living digital simulation models that update and change with their physical counterparts (Luo et al., 2019).

Based on the existing proposed concept, we made some further clarification. First, a DT should use virtual representations to express the physical counterpart (Grieves et al., 2016). Second, a DT connection requires data transfer from the physical object to the virtual part (Kritzinger et al., 2018), but feedback is not mandatory. Third, the virtual part can control the physical counterpart (Kritzinger et al., 2018), but this is not mandatory. Finally, the DT must provide a specific service (Tao et al., 2019), as shown in Fig. 2.
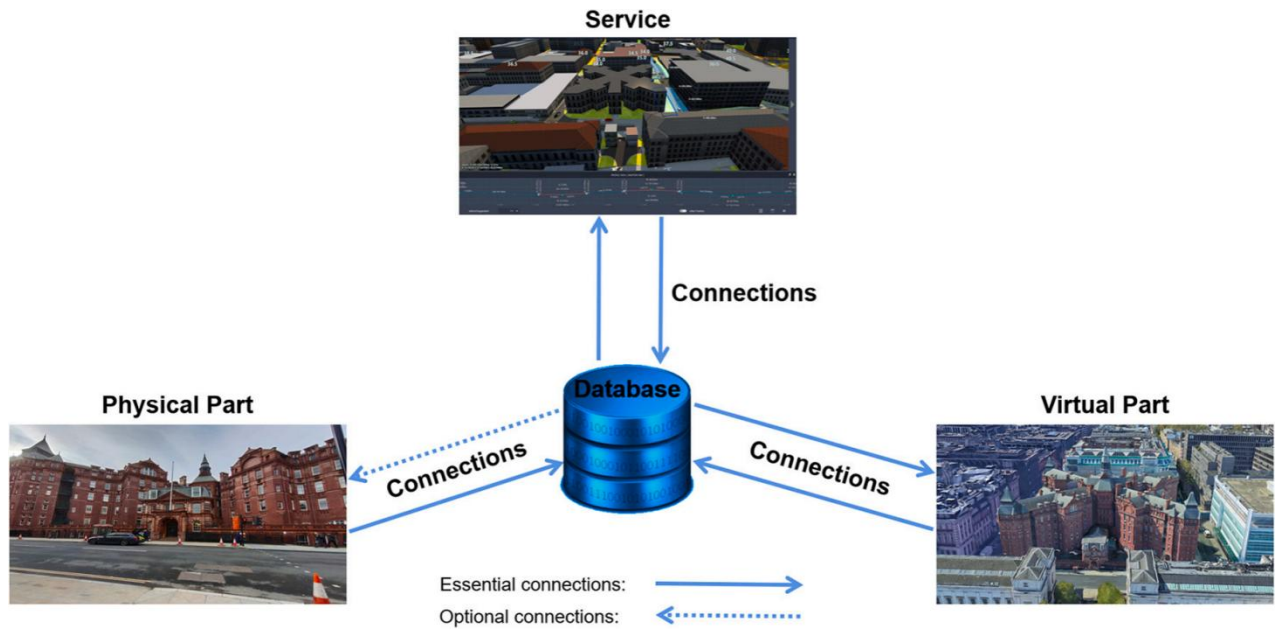

Figure 2 Five-part structure of DT.

In many areas, when several industries are experiencing a digital transformation, Digital Twin (DT) is considered no less than a linchpin for gaining a competitive and economic advantage over competitors, which provides more a realistic and holistic measurement of unforeseen and unpredictable scenarios (Parrott et al., 2017). It can be a great tool for

companies to increase their competitiveness, productivity, and efficiency（Kritzinger et al., 2018).

With the fast development of 3D surveying technology, generating a DT of existing facilities from spatial data becomes more feasible. Some studies only discuss how to build a digital twin for existing objects. Point clouds from laser scanners and LiDAR are the most common raw data for geometric information to create DT (Shanbari et al., 2016). Images from cameras and data from sensors are also widely used to provide geometric information and non-geometric information for DT (Alves et al., 2017). Various kinds of non-geometric information from sensors or other devices in the physical world can be added to the digital twin, such as type, color, light, time, temperature, humidity, materials, weight, force, pressure, vibration frequency, flow rate, cost, energy consumption, gaseous emission, manufacturer/vendor data, other semantic information, sustainability information, other environmental conditions, customer comments(Akanmu et al., 2013). They can enrich the information of DT and expand the functions of DT. DT creation is the cornerstone of DT applications. However, the main reasons that restrict DT's development are the efficiency and accuracy of DT creation (Wang et al., 2015). Thus, new algorithms for DT creating are continuously proposed.

2.2   3D Visualization

Generally, when interacting with the real world, it is done in a 3D space. This means that any replication of the real world in a digital copy is expected to be able to take the 3D space into account. Numerous studies have been conducted globally on the topic of online 3D visualization. For example, Ruzinoor, Shariff, Pradhan, Mahmud, & Rahim (2012) have done extensive study on online 3D terrain visualization. In other hand, the research conducted by Detweiler (2009) explain on developing a technique to use 3D terrain surface measurements in vehicular simulations. Furthermore, Celio, Ott, Sirén, & Grêt-Regamey (2015) have utilizing Crytek Cryengine 3.4.5 for creating 3D visualizations based on the land use modelling output. This game engine allows to establish the connection between geo-reference model and 3D visualizations output. While Aziz, Chang, Esche, & Chassapis (2014) using a commercially available 3D game engine in creating a new framework for authoring Virtual Environments (VEs) for mechanical assembly training. Vergauwen, Pollefey, & Gool (2001) found that the 3D terrain also can be used for space studies where in their research, the data from Mars uses to create a 3D terrain. Trenholme & Smith (2008) has done a report on overview several game engines such as CryEngine, id Tech 3 Engine, id Tech 4 Engine, Jupiter Extended (EX), Source Engine, and Unreal Engine.

Based on their report, all the game engine discussed in their report are suitable for developing non-game applications in VEs. Game engines are toolkits to ease the

progression of video games which usually packed with set of tools needed in the design and coding stages (Navarro, Pradilla, & Rios, 2012). A study by Humbert (2011) involved techniques on visualizing a town scale model dating from the 19th century by using a game engine. In another major study, Jie (2011) found that game engine also can be applied for scene optimization skills and problems of mobile phone based. Besides that, research on utilizing a 3D game engine to develop a virtual design review system done by Shiratuddin & Thabet (2011) stated that the strength of game engine in different criteria: real-time rendering, interactivity, lighting, real-time walk through, collision detection and multi-participatory feature.

Several available game engines, such as Unreal Tournament, Quest 3D and Morrowind, allow users to create their own Virtual Environments (Champion, 2008), but these were found to either be complex to use or limited in their ability, which lead to the choice of Unity 3D as the enabling platform.

Unity 3D is a game-based development tool developed by US-based Unity Technology. Also, the Unity 3D community has 2.5 million registered developers and 500 000 active developers as of March 25th, 2014, which would indicate that it is well accepted in the Virtual Reality community (Unity 3D, 2014).

Unity offers a range of features that make it well-suited for creating digital twin applications. In interest of researching performance, the Unity Engine comes equipped with the Unity Profiler, a tool for conveniently observing performance of a project regarding load and wait times, memory usage and other data that could be seen as relevant. (Unity-Manual, 2022). Custom scripts must be created to achieve some functionality. These risks being a large time-sink for the project and as such the Unity Asset Store will be used to acquire a plugin/asset that provides some functionality. Several options should be available which can be evaluated and compared against each other as to give insight into which suits the projects specified goals the best (Unity-Manual,2022).

For this study, Unity 3D is a professional virtual reality simulation engine integrated with simulation tools which has a perfect function of the terrain editor and a powerful third-party terrain development plug-in (Qiao Maomao,2014).

2.3   Early Warning System

Several definitions of Early Warning System (EWS) can be found in the literature. Medina-Cetina and Nadim (2008) define them as "monitoring devices designed to avoid, or at least to minimize the impact imposed by a threat on humans, damage to property, the environment, or/and to more basic elements like livelihoods." According to United Nations International Strategy for Disaster Reduction (UNISDR, 2009) they are " the set of

capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss."

Indeed, an efficient EWS should comprise the following activities (DiBiagio and Kjekstad, 2007):

•monitoring, including data acquisition, transmission and maintenance of the instruments;

• analysis and forecasting, which can be done by using thresholds, expert judgment, forecasting methods and so on;

• warning, i.e. the dissemination of understandable messages alerting for the impending threat.

•response, concerning if people are able to understand and how they react to the warning.

Of all these components the one representing the major constraint for the effectiveness of an EWS is probably the response of people, i.e., how they will react to the alarm. In order to answer this question, preparedness training of the public must be considered within an EWS, otherwise even the most sophisticated monitoring system can fail, as happened for instance for the EWS at San Francisco Bay (Keefer et al., 1987; Wilson, 2004).

An excellent example of how to face this social issue is reported in Mak et al. (2007) where a detailed description of the awareness campaigns adopted for the EWS in use in Hong Kong (Pang et al., 2000; Yu et al., 2004) is given. Moreover, a correct education of the population is by far the most cost-effective means of reducing the risk.

Finally, it is worth remembering that at present there is no EWS valid for all cases. In fact, every EWS must be designed purposely for a specific site. For instance, the precursors and monitored parameters may largely vary depending on the type of landslide (Lacasse and Nadim, 2009).

3   Methodology for creating 3D Visualization.

3.1   Create real terrain in Unity.

The Unity game engine offers several techniques for creating realistic terrain. To generate terrain procedurally, one can employ code to dynamically generate the terrain in real-time. In this context, two distinct approaches are commonly used: utilizing height maps as input or utilizing the World Composer tool. The former involves the creation of terrains based on user-defined height maps, which are essentially grayscale images that determine the elevation levels of the terrain. The latter approach utilizes World Composer, which is a third-party tool designed to create terrains by combining various assets such as textures, vegetation, and rocks. This study will describe both.

3.1.1   The use of height maps as input

To create a realistic terrain in Unity using a heightmap, follow these general steps:

1. Obtain or generate a heightmap: A heightmap is a grayscale image that represents the elevation of the terrain. We can obtain heightmaps from online sources or field trip and transfer it to. raw format.

   Following the initial research, we obtained a digital elevation model (DEM) for a small section of the river.

Figure 3 The DEM of the part of the Tartano river

According to the illustration in Figure 3, the DEM that has been obtained exhibits a high level of clarity and resolution. However, it is noted that the geographical region covered by the DEM is significantly limited in scope. We used Global Mapper to generate a grayscale image of the river.

Global Mapper is a powerful GIS software that can be used for a variety of mapping and spatial analysis tasks. One of its capabilities is to generate grayscale images from digital elevation models (DEMs) or other data sources. These grayscale images can be used as heightmaps for terrain creation in game engines or other 3D software. To create a grayscale image in Global Mapper, we first need to import data into the software. Once the data is loaded, you can use various analysis tools in Global Mapper to create a grayscale image.
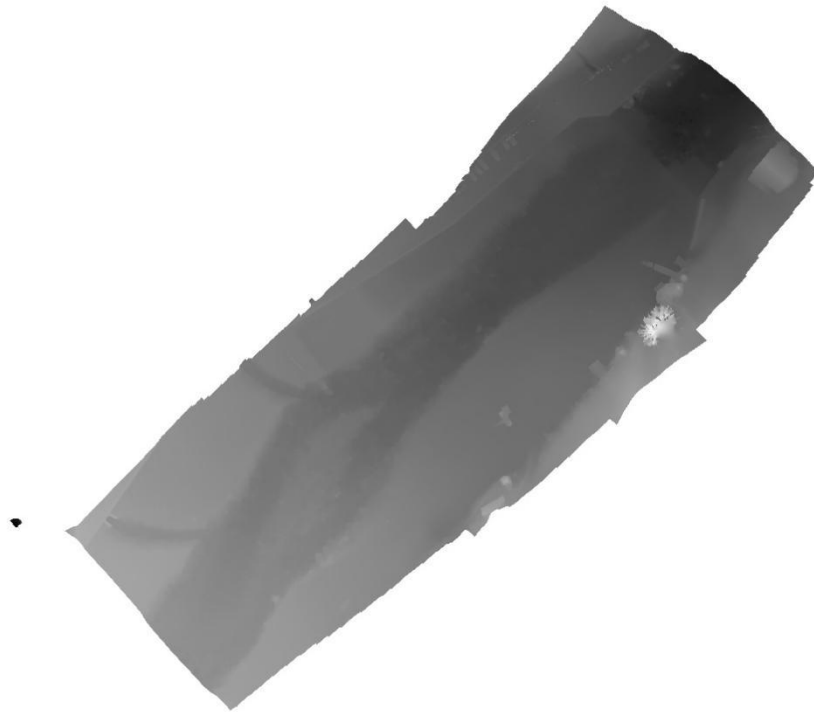
Figure 4 Grayscale visualization of DEM in Figure 3, showing the riverbed.

Grayscale image was then converted to a .raw file format using Adobe Photoshop CC 2017.

Adobe Photoshop CC 2017 is a professional image editing software that provides a wide range of tools and features for editing and manipulating images.

2. Create a new terrain object in Unity.

3. By applying the heightmap to the terrain, we can obtain a 3D representation of the terrain. (Figure 5)

Figure 5 The top view of terrain model of the part of river

In this specific model, the large number of intricate details poses a considerable obstacle when attempting to apply paint, even though the object itself holds greater inherent value.

3.1.2 Utilizing the World Composer tool

World Composer is a Unity plugin designed to help game developers and artists create large-scale, high-quality terrains quickly and easily. With World Composer, we can generate realistic terrain using a variety of algorithms, such as noise functions, erosion, and thermal weathering. The plugin also allows us to import and manipulate heightmaps, and to apply materials and textures to your terrain. World Composer provides a powerful set of tools for sculpting, painting, and blending terrains, as well as for adding vegetation, water, and other natural elements to your environment. Additionally, World Composer integrates seamlessly with Unity, allowing you to preview your terrain in real-time and optimize its performance for your specific project.

To create a realistic terrain using World Composer in Unity, it is necessary to first import the World Composer package into the project.

Selecting the area to be studied is the next step, which can be accomplished by specifying a square area of 0.475 km in Tartano in World Composer (Figure 6).

The source of World Composer is Bing Satellite Map. It is a type of satellite imagery that can be utilized to create realistic terrain in Digital twin environments. It provides high-resolution images of Earth's surface, which can be used to generate accurate topographical data for use in Unity game engine. The satellite imagery can be imported into Unity as a texture, which can then be used as the basis for creating 3D terrain models. By using Bing Satellite Map data, developers can create highly realistic and immersive digital twin environments that closely resemble real-world locations. However, it is important to note that the availability and accuracy of Bing Satellite Map data can vary depending on the location and the date of the imagery, so it may not always be suitable for use in creating digital twin environments.
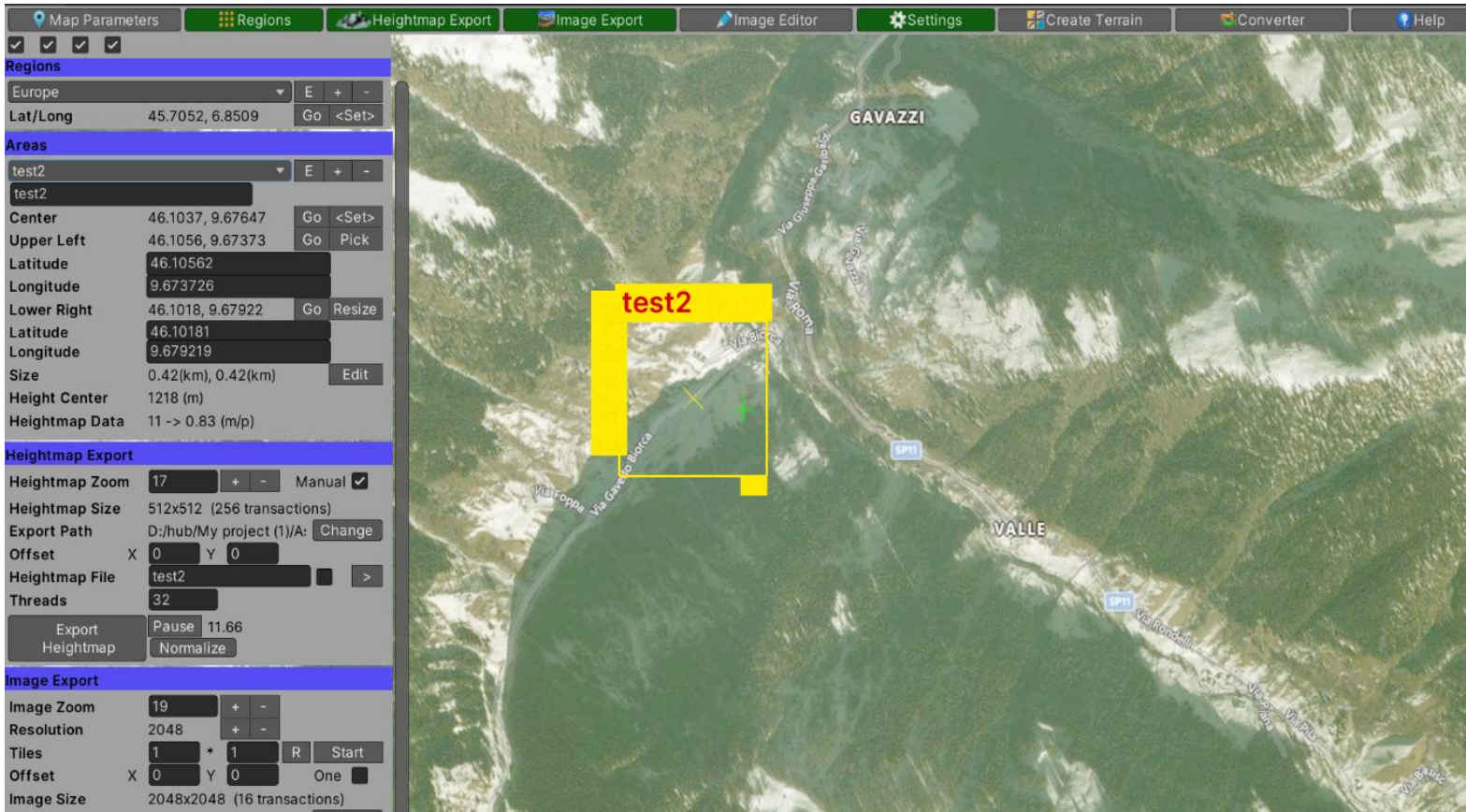
Figure 6 The area selected in World Composer

Subsequently, the heightmap and image (figure 7) can be exported, and the terrain can be generated.

Figure 7 The exported image of selected area

Following the terrain generation, the terrain sculpting tools in Unity can be used to further refine the terrain, including the addition of hills, valleys, and cliffs. Additionally, textures and materials can be applied to the terrain to enhance its realism, which can be achieved using Unity's built-in terrain tools or third-party assets from the Unity Asset Store. (Figure 8, Figure 9,Figure 10)
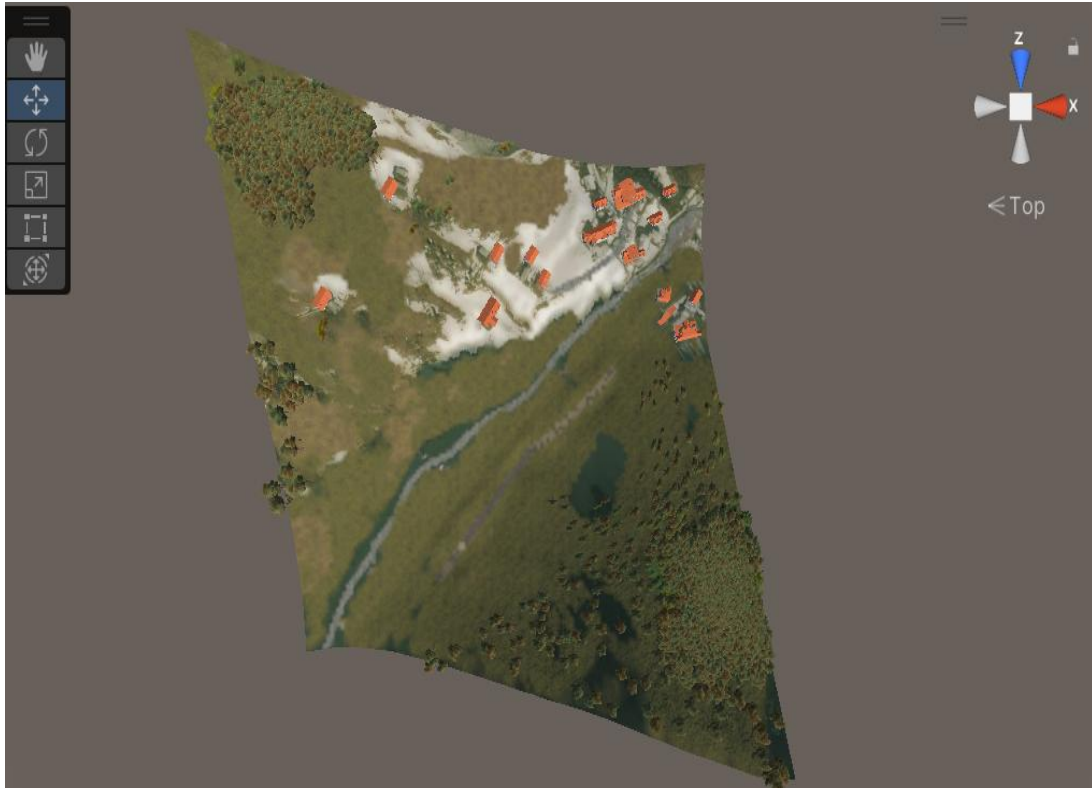
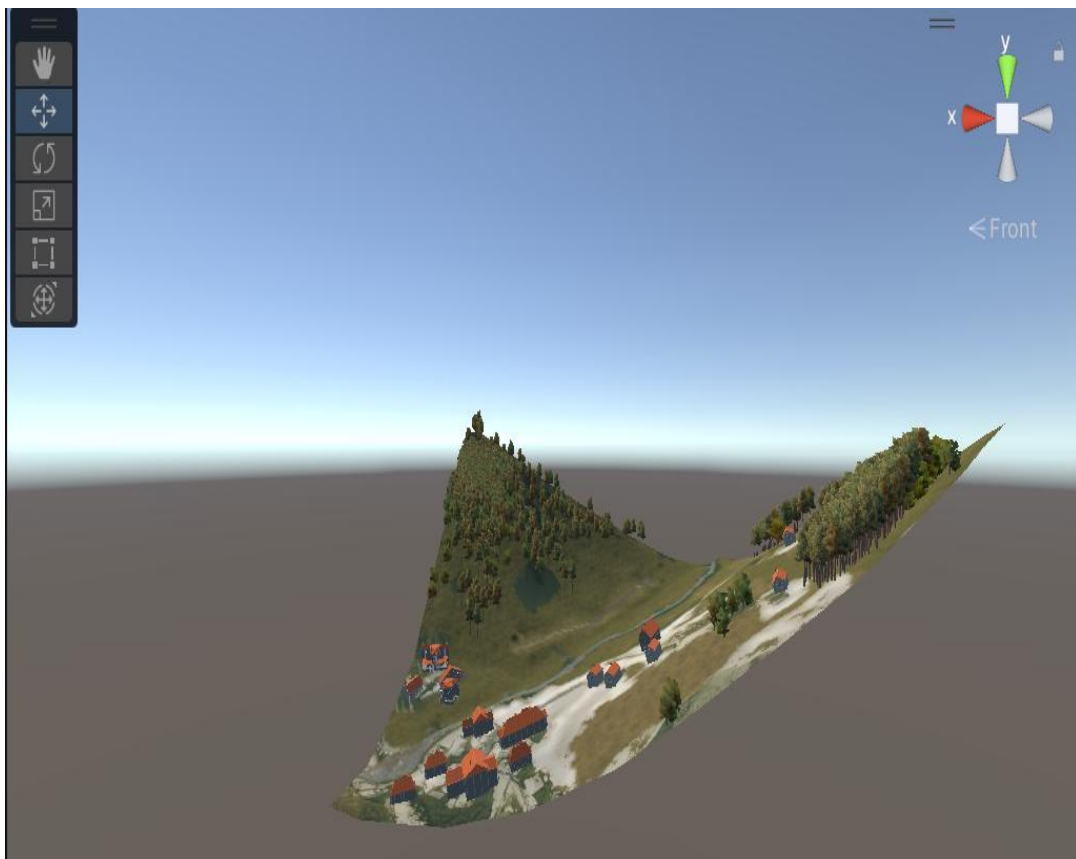Figure 8 The top view of Tartano terrain in Unity

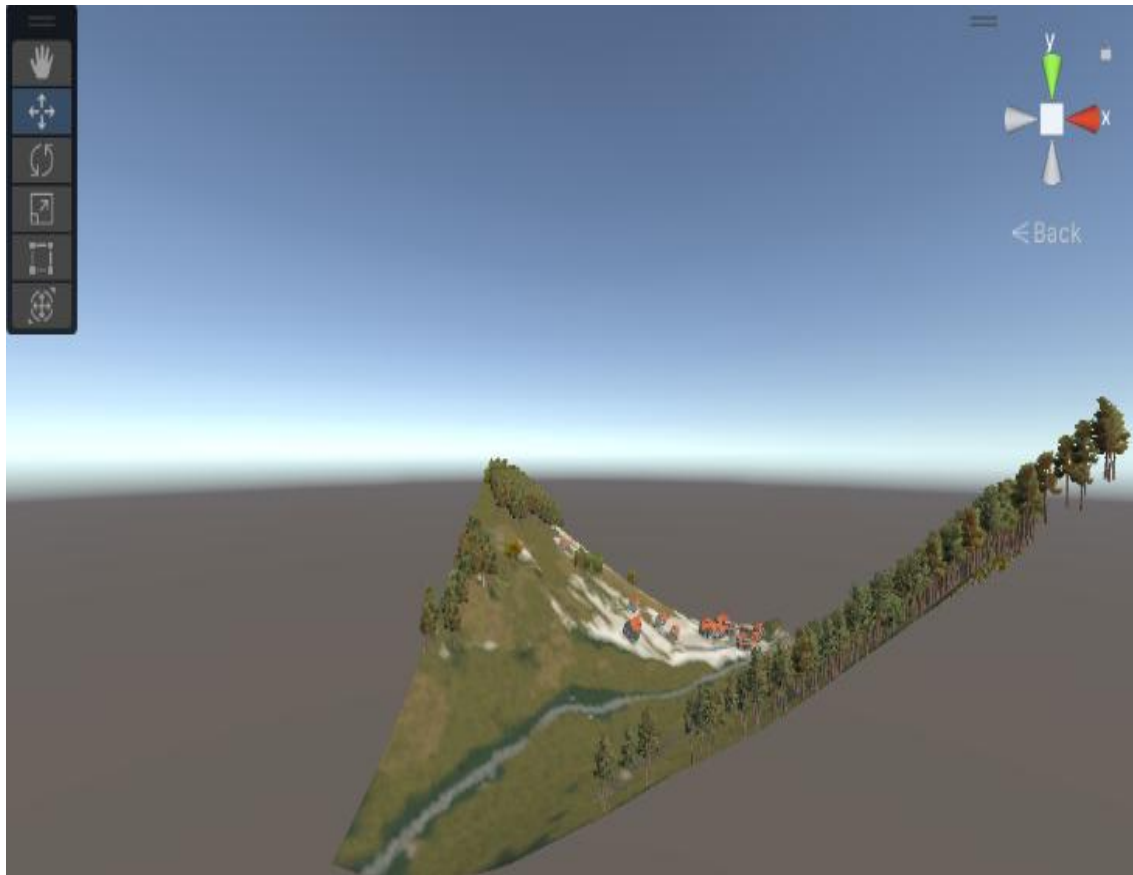Figure 9 The Front view of Tartano terrain in Unity

Figure 10 The back view of Tartano terrain in Unity

Upon comparing the two approaches, it was determined that the latter approach was more convenient due to the availability of an exported image that aided in saving time for painting terrain, as well as the ability to obtain a larger scale of terrain model based on existing data. As a result, the outcome of the latter approach was selected.

From the obtained 3D model, it is not difficult to see that this river area is in a canyon.

3.2 Simulate the river by R.A.M

R.A.M - River Auto Material is a Unity plugin that enables the creation of realistic river systems using a sophisticated physics engine. This engine simulates various natural phenomena, such as water flow, turbulence, and sediment transport, using a range of physics-based algorithms and simulations. The engine considers environmental factors such as water depth, gradient, and substrate to accurately model the behaviors of different water conditions, resulting in a highly authentic representation of real-world river flows.

In addition, the R.A.M engine enables the creation of dynamic ecosystems by allowing for the addition of various types of vegetation and wildlife that interact with each other and the

environment. This results in a more immersive and realistic representation of the natural world.

The R.A.M plugin offers a streamlined workflow for constructing rivers, with a wide range of features such as automatic river flow, customizable water and foam textures, and the ability to add and modify rocks and vegetation along the riverbank. These features make the creation of highly realistic rivers more efficient and adaptable to a variety of environments, ultimately saving time and effort compared to manual creation.

Overall, the R.A.M plugin is a valuable tool for game developers and digital artists who seek to integrate highly authentic rivers and water features into their Unity projects.

3.2.1 Create river object at scene:

After generating a river object in the hierarchy, it will result in the following view:
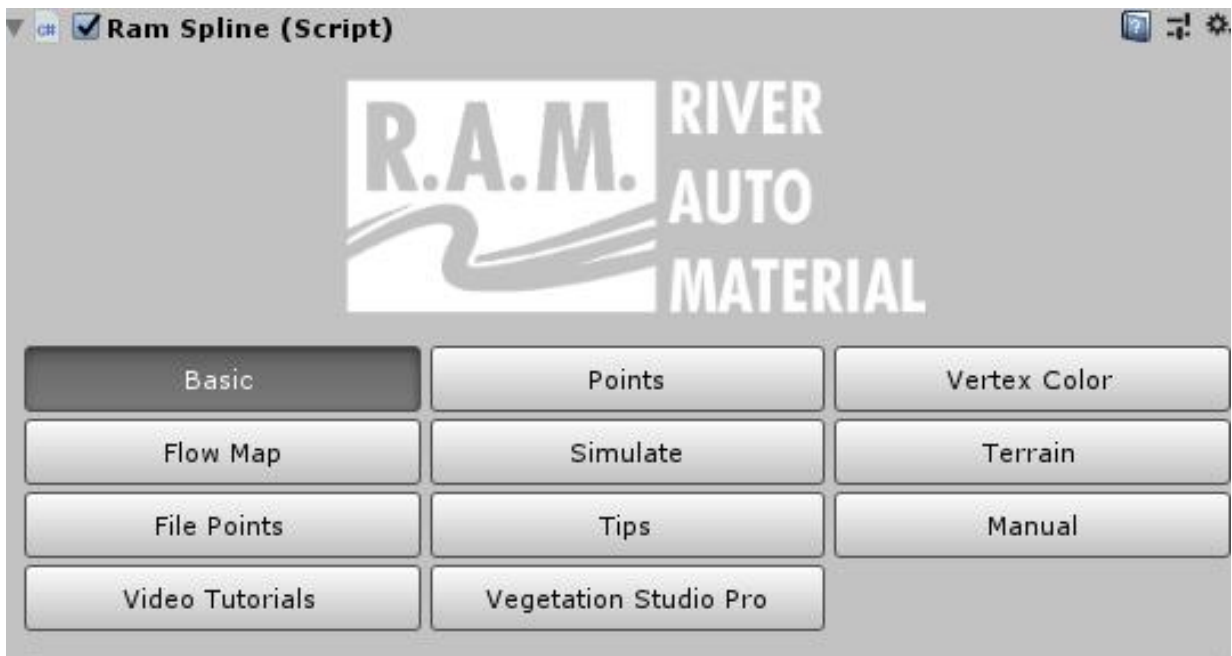
Figure 11 R.A.M user interface

To utilize R.A.M, it is essential to insert points along a predetermined path to generate a realistic river system.

The OSM Standard (EPSG 3875) is a widely used coordinate reference system that is employed by OpenStreetMap (OSM) for representing geographic data and maps. This system is a variant of the popular Mercator projection, which is frequently used for web-based maps due to its ability to display a global view of the earth's surface in a two-

dimensional format. In this section, we refer to the OSM Standard (EPSG 3875) to locate the river and add points along its path to accurately define its position. (figure 12)
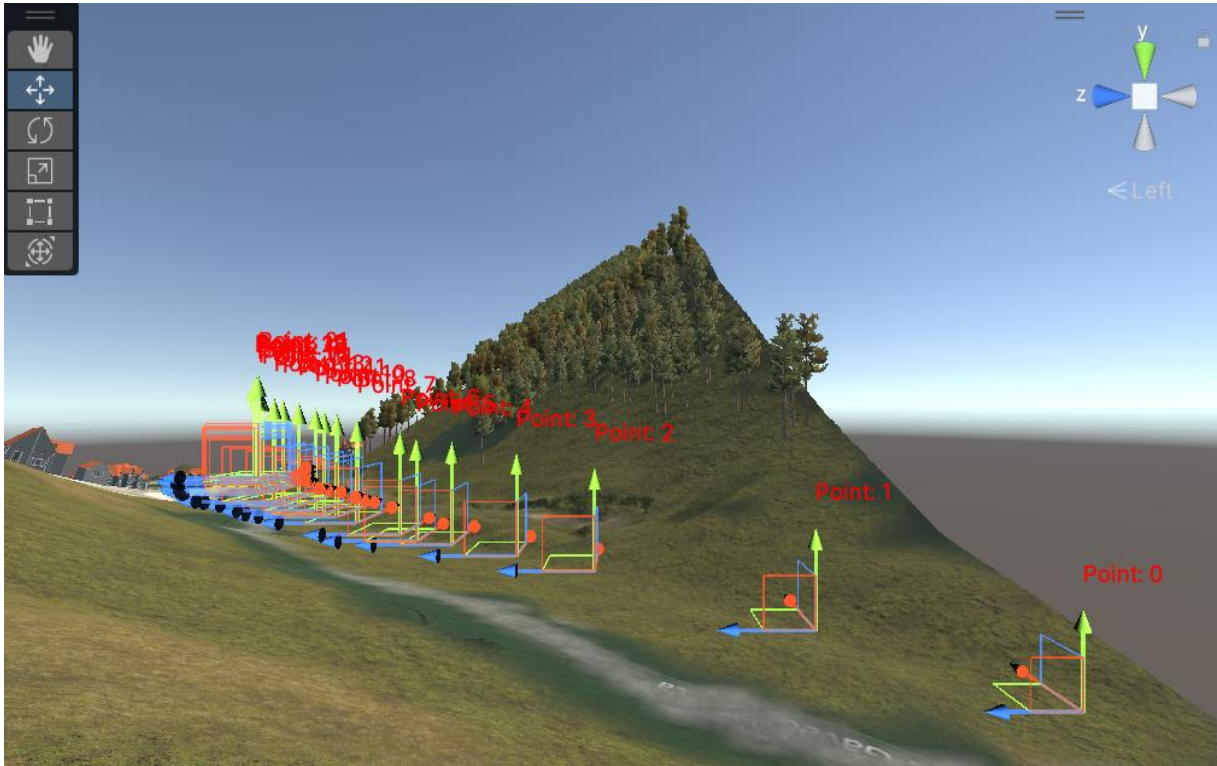
Figure 12 The points which are inserted.

To adjust the scale of the river in R.A.M, there are two available methods. The first approach involves modifying the "W" value in the "Points" section for a specific location, while the second method entails adjusting the "River width" value in the "Basic" section to scale the entire river uniformly, followed by clicking the corresponding button to apply the changes. In order to enhance the realism of the river, we opted for the first approach, as shown in Figure 13, to obtain the desired river shape.
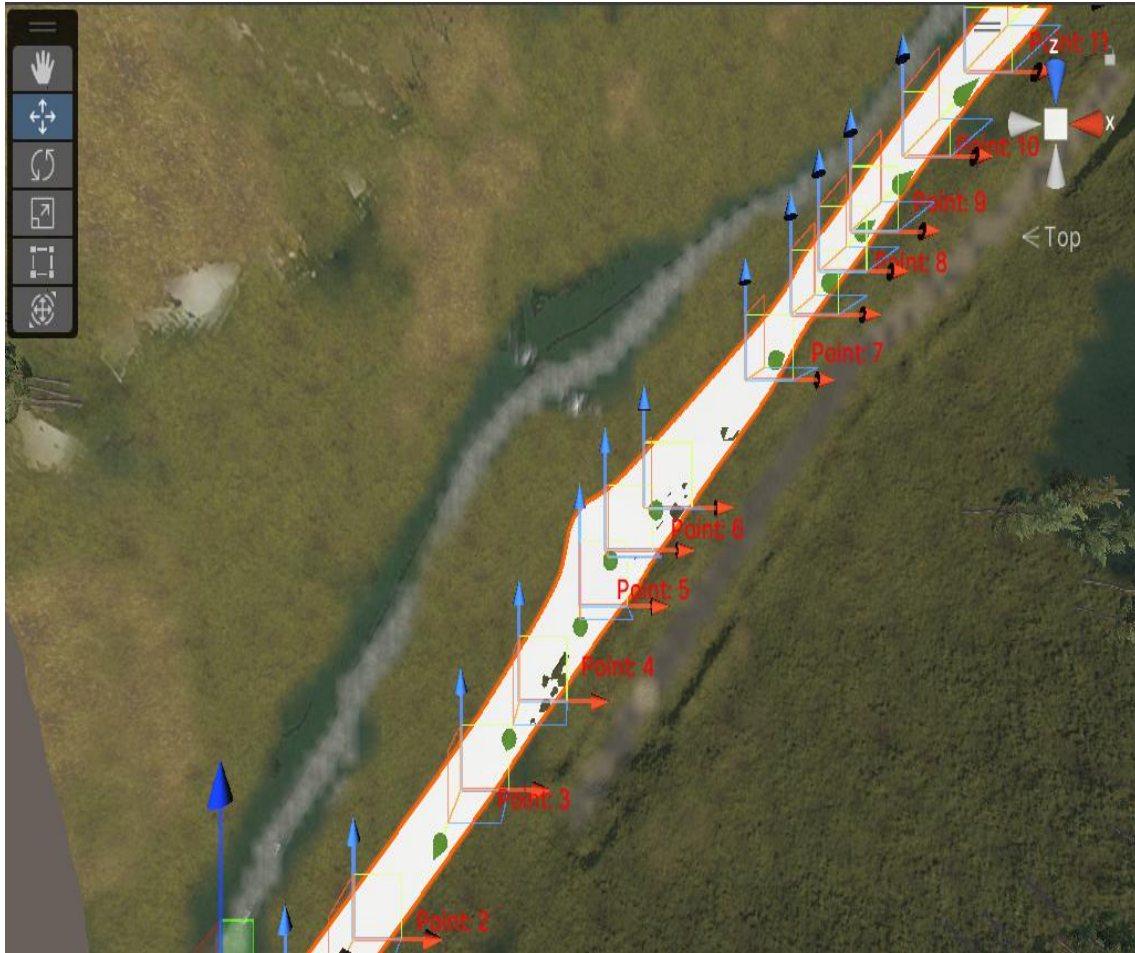
Figure 13 The shape of the simulated river

3.2.2 Set mesh for the river:

Next, we set the mesh for the river. The mesh settings within River Auto Material for Unity serve the purpose of controlling the mesh generation process for the river. This plugin employs a custom mesh generation algorithm that creates the river mesh based on the points that have been added to the spline. The mesh settings provide users with options to adjust the number of segments used to create the mesh, allowing for greater control over the mesh's level of detail.

The density of triangles in the river mesh can be adjusted by changing the "Triangle Density" value in either the U direction (along the spline) or the V direction (perpendicular to the spline). It is also possible to increase the triangle density in specific areas by adding more control points instead of adjusting the density globally using the slider.

A value of 4-8 for U and V in the mesh settings of R.A.M (River Auto Material) is a good starting point because it provides a good balance between visual quality and performance. Increasing the number of segments (higher values for U and V) will result in a more detailed river mesh, which can make the river look more realistic, but it will also increase

the number of polygons used. This can impact the performance of the game, especially on low-end hardware. On the other hand, decreasing the number of segments (lower values for U and V) can improve performance but may result in a less realistic-looking river. We set U is 8 and V is 12.
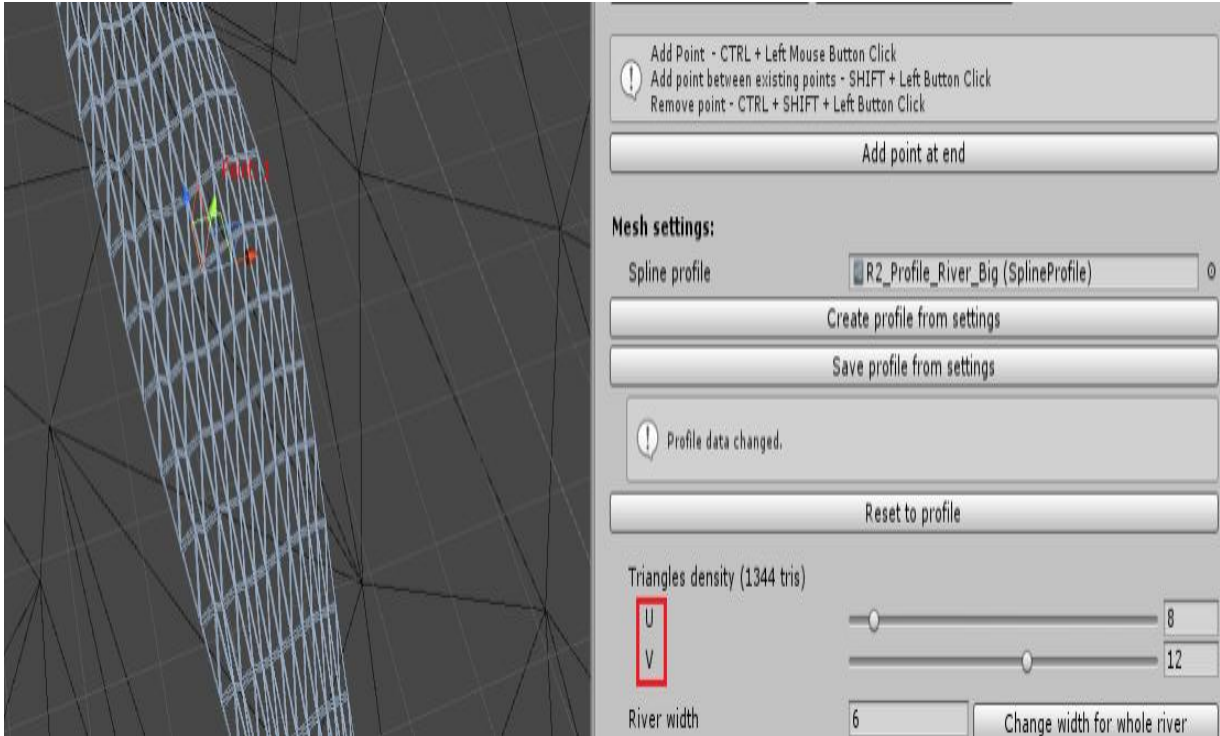
Figure 14 Mesh resolution and shape.

Subsequently, we take normal from terrain. Taking the normal from the terrain in R.A.M (River Auto Material) in Unity is a technique used to make the river mesh blend more seamlessly with the surrounding terrain. When this feature is enabled, the plugin will sample the normal data from the terrain beneath the river and use it to adjust the normal data for the river mesh. This helps to create a more natural-looking transition between the river and the terrain and can enhance the overall realism of the scene. Additionally, taking the normal from the terrain can also help to improve the visual quality of reflections and other lighting effects that are applied to the river. It's useful for analyzing floods because it helps to create a more realistic and natural-looking river mesh that blends seamlessly with the surrounding terrain.

3.2.3 Simulate the flow map:

Next we simulate the flow map of river. Using a flow map in R.A.M (River Auto Material) can help analyze flood scenarios in a realistic river and terrain environment by simulating the flow of water based on the height and slope of the terrain. By adjusting the flow map parameters, such as speed and direction, users can create a realistic representation of how

water would flow through the river and surrounding environment in the event of a flood. This allows users to identify potential areas of concern and make informed decisions about how to prepare for and respond to flooding. Additionally, the flow map can be used to generate dynamic water effects, such as waves and ripples, that further enhance the realism of the river system.

There are two primary approaches to working with flow maps in R.A.M: the manual method and the automatic method.

The manual method provides the user with the ability to set any flow map value or speed along the river spline by placing a marker. By adjusting the U and V speed on the slider, opacity, and brush size, we can precisely control the flow map values and speeds along the river spline using markers. This method allows for accurate and precise control over the flow map values and speeds and can be useful for simulating specific scenarios or conditions.

The automatic method of generating flow maps in R.A.M utilizes curves for different areas of the river, such as waterfalls and flat areas, and employs noise to simulate a more natural-looking flow pattern. The application of noise in this method has the potential to improve the authenticity and realism of simulated rivers by mimicking the inherent irregularities and variations found in real-world water flows. This technique can generate a more complex and varied flow pattern, facilitating the representation of diverse water conditions such as rapids or eddies.

In light of the limited data and materials available for the local area, we have opted to utilize the second approach for setting the flow map.

The "noise multiplier inside" parameter in the automatic flow map generation method of R.A.M can be adjusted to emulate the irregularities and variations in river flow that occur in real-world scenarios. This parameter governs the amount of noise applied to the riverbed and banks, which can influence the speed and direction of water flow. Thus, by adjusting this parameter, we can create a more realistic flow pattern that accurately represents the local river conditions. For instance, if the local river has a rocky bed, the noise multiplier inside parameter can be set higher to simulate the irregularities in the bed, resulting in a more natural flow pattern. Conversely, if the river has a smooth, sandy bed, the noise multiplier inside parameter can be set lower to generate a smoother flow pattern.

These enhanced simulation capabilities are beneficial for researchers and engineers to analyze and understand water behavior under various conditions, including flood events, and to devise more effective flood mitigation strategies.
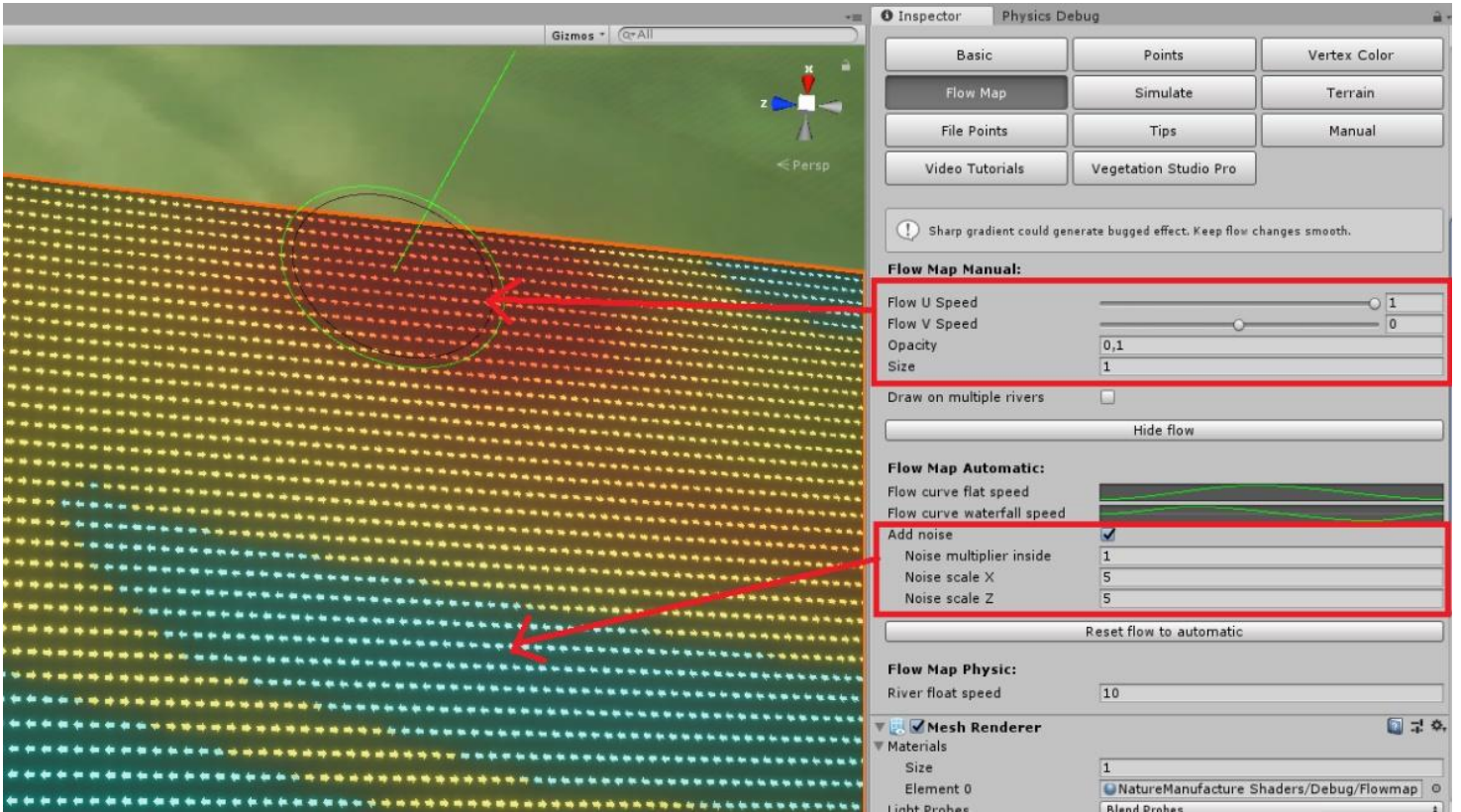
Figure 15 Flow Map Manual and Flow Map Automatic
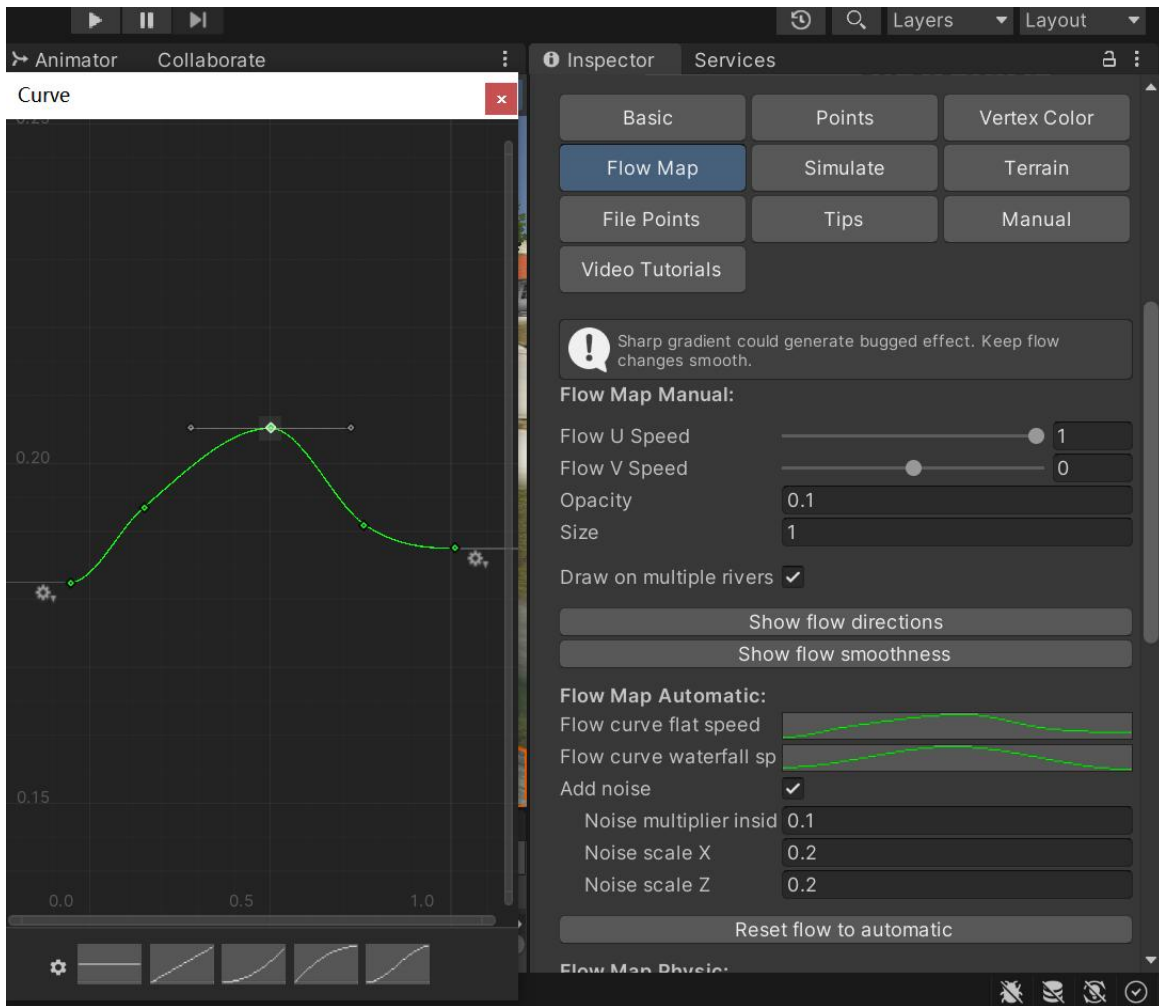
Figure 16 Flow curve flat speed

Because there is no waterfall, we can simply leave the "flow curve waterfall speed" parameter at its default value. For this study, we will focus on the width of river to achieve the goal which is formulating hypotheses on the feasibility and effectiveness of utilizing digital twins for river monitoring and flood warning purposes. So, the flow speed is random.

3.2.4 Get the result of simulation:

One of the final steps in the river simulation process involves applying a material to the spline in order to achieve the desired visual effects. Once this material has been successfully applied, the user can generate a simulated river flow.
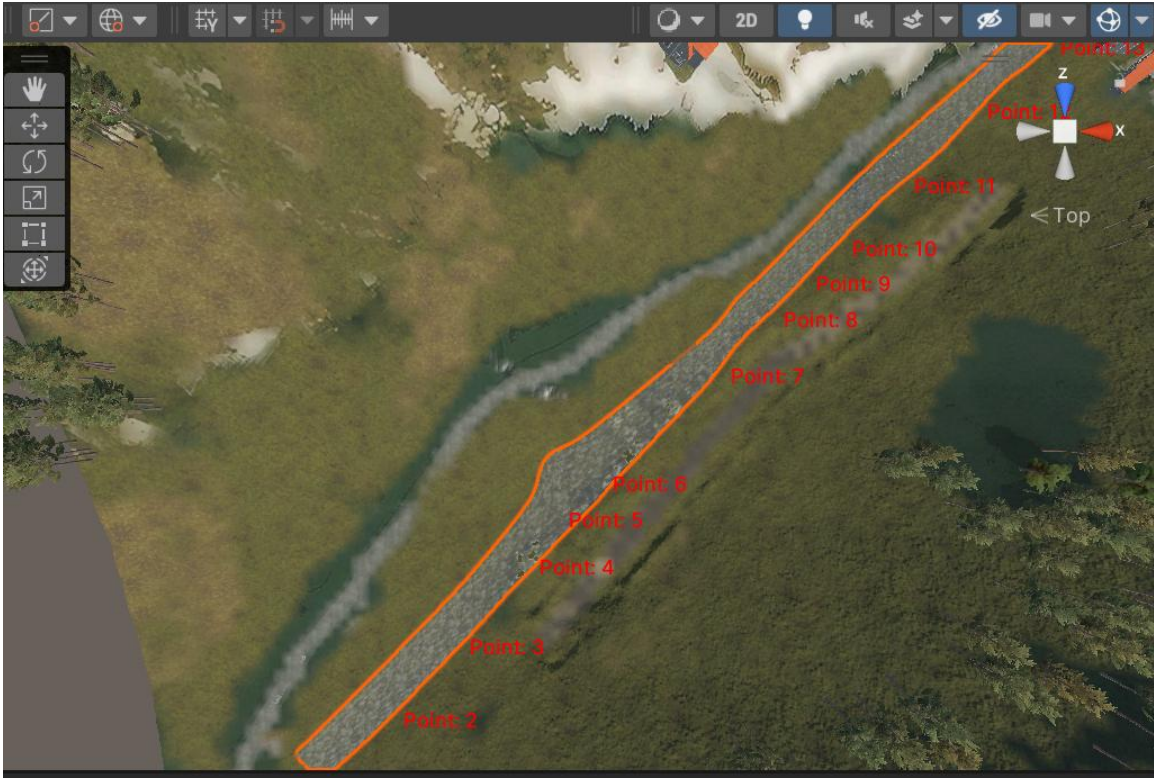
Figure 17 The top view of the simulated river
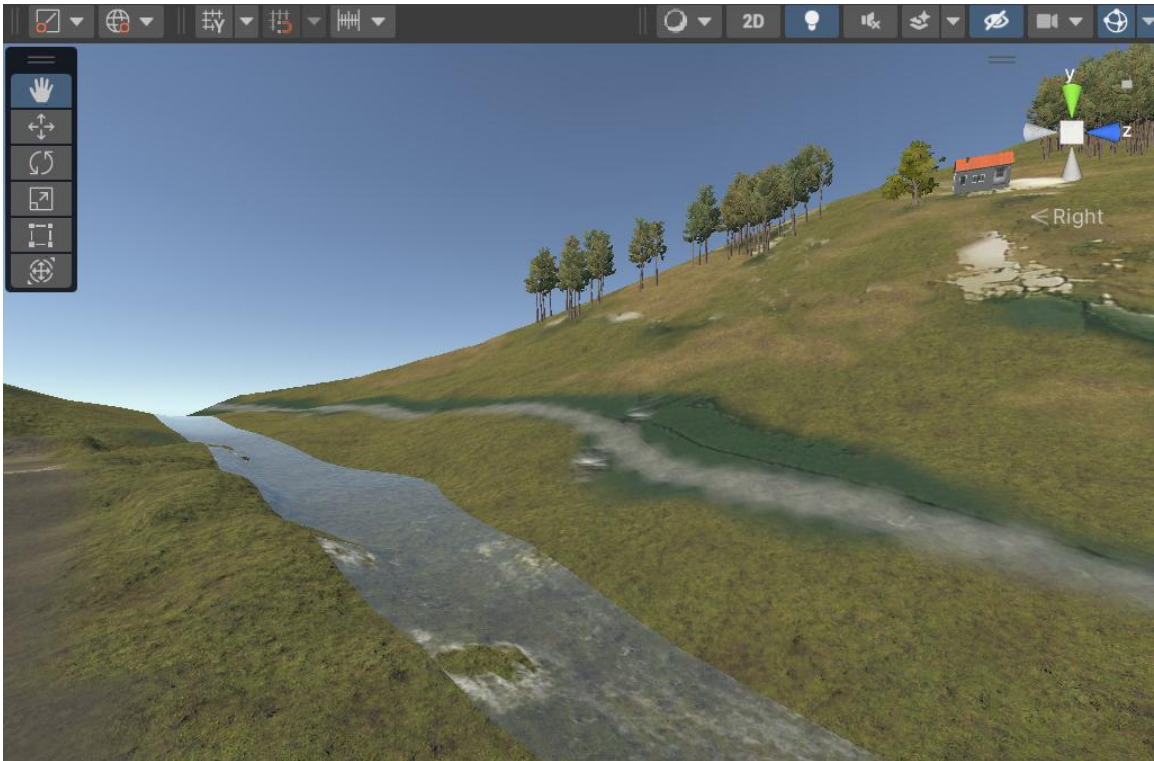
Figure 18 The right view of the simulated river

3.3 Solve the coordinate problem in Unity.

The integration of field survey data with 3D modeling techniques demands a rigorous examination of coordinate systems, which is an essential element of this process. Within the Unity platform, there exist multiple categories of coordinate systems utilized for the representation of object position, rotation, and scale within a scene. These coordinate systems include:

1. World Coordinate System (WCS): The WCS represents the global coordinate system for the scene. It is the default coordinate system in Unity and all objects in the scene are positioned and oriented relative to it.

2. Local Coordinate System (LCS): The LCS represents the coordinate system of an individual game object. It is relative to the parent object if the game object has one, otherwise, it is relative to the WCS.

3. Viewport Coordinate System (VCS): The VCS represents the coordinate system of the viewport, which is the area of the screen where the game is displayed. It is used to position and size objects relative to the screen.

Within Unity, game objects can be organized in a hierarchical manner through the utilization of parent-child relationships. A parent object is defined as a game object that encompasses one or more child objects that are affixed to it. This hierarchical relationship allows child objects to inherit the position, rotation, and scale of their parent object, resulting in the application of any transformations on the parent object affecting all of its children. Hence, the parent-child relationship offers a robust mechanism for structuring and organizing game objects in Unity.

Regarding coordinates in Unity, the position of a game object is relative to its parent object. T Specifically, the position of a child object is calculated based on its offset from the parent object's position. As an example, if a child object is located at coordinates (1, 0, 0) relative to its parent object, and the parent object's position is (5, 0, 0) in the world space, the absolute position of the child object would be (6, 0, 0) in the world space. Consequently, the position of a game object in Unity is dependent on the position of its parent object and its own offset from its parent's position.

It is essential to note that the local coordinates of a child object are independent of the position, rotation, or scale of its siblings or any other objects in the hierarchy. However, the world coordinates of the child object will be affected by the position, rotation, and scale of all of its parent objects, all the way up to the root object in the hierarchy.

The establishment of an accurate correlation between the spatial coordinates of the river points and the surrounding terrain within the Unity environment is of paramount importance for the creation of a realistic 3D model in the context of digital twin technology. This is particularly relevant for applications aimed at monitoring and predicting river flooding, as any inaccuracies in the alignment of the virtual model with the physical environment can lead to erroneous results and flawed predictions. To ensure that the virtual model is aligned with the real-world terrain, GIS data is typically employed to obtain the spatial coordinates of the river points and surrounding features. In this study, we acquired GIS data for the points corresponding to Geo-electric sensors deployed on the riverbank, which includes their longitude and latitude. This information is then used to establish a precise correlation between the river and terrain models, thus ensuring that the virtual model accurately represents the physical environment.

Index	name	longitude	latitude
1	Castello	9.676480187	46.10318442
2	G1	9.675413251	46.1023505
3	G2	9.675724502	46.10257895
4	G3	9.675768271	46.1026117
5	G4	9.675812237	46.10264506
6	G5	9.675853536	46.10267722
7	G6	9.675898918	46.10271056
8	G7	9.675942635	46.10274398
9	G8	9.67598575	46.10277672
10	G9	9.676030008	46.10281008
11	G10	9.676071465	46.10284368
12	G10	9.676070636	46.10284386
13	G11	9.676114183	46.10287761
14	G12	9.676160928	46.10290847
15	G13	9.676199214	46.10294442
16	G14	9.676243535	46.10297663
17	G15	9.676288004	46.10300978
18	G16	9.676332453	46.10304217
19	G17	9.676377882	46.10307426
20	G18	9.676420286	46.10310746
21	G19	9.676464279	46.10313988
22	G20	9.676508437	46.10317352
23	G21	9.676552013	46.10320712
24	G22	9.676594453	46.10324048
25	G3	9.676637142	46.10327436
26	G24	9.676681808	46.10330662
27	G25	9.676722586	46.1033434
28	MasterTartano	9.677335346	46.10363212
29	S1	9.677850984	46.10399686
30	S3	9.67781928	46.10391562
31	S2	9.677996641	46.10389408
32	D1	9.677766741	46.10400131
33	Sez3	9.676374963	46.10373631
34	S4	9.675967668	46.10338196
35	S5 buco	9.675667484	46.10322956
36	Sez6	9.675264414	46.10285208
37	Fucile1	9.676904074	46.10341027
38	Fucile 2	9.675603081	46.10247189
39	Fucile 3	9.675473685	46.1023723

Figure 19 The longitude and latitude of points acquired by field survey
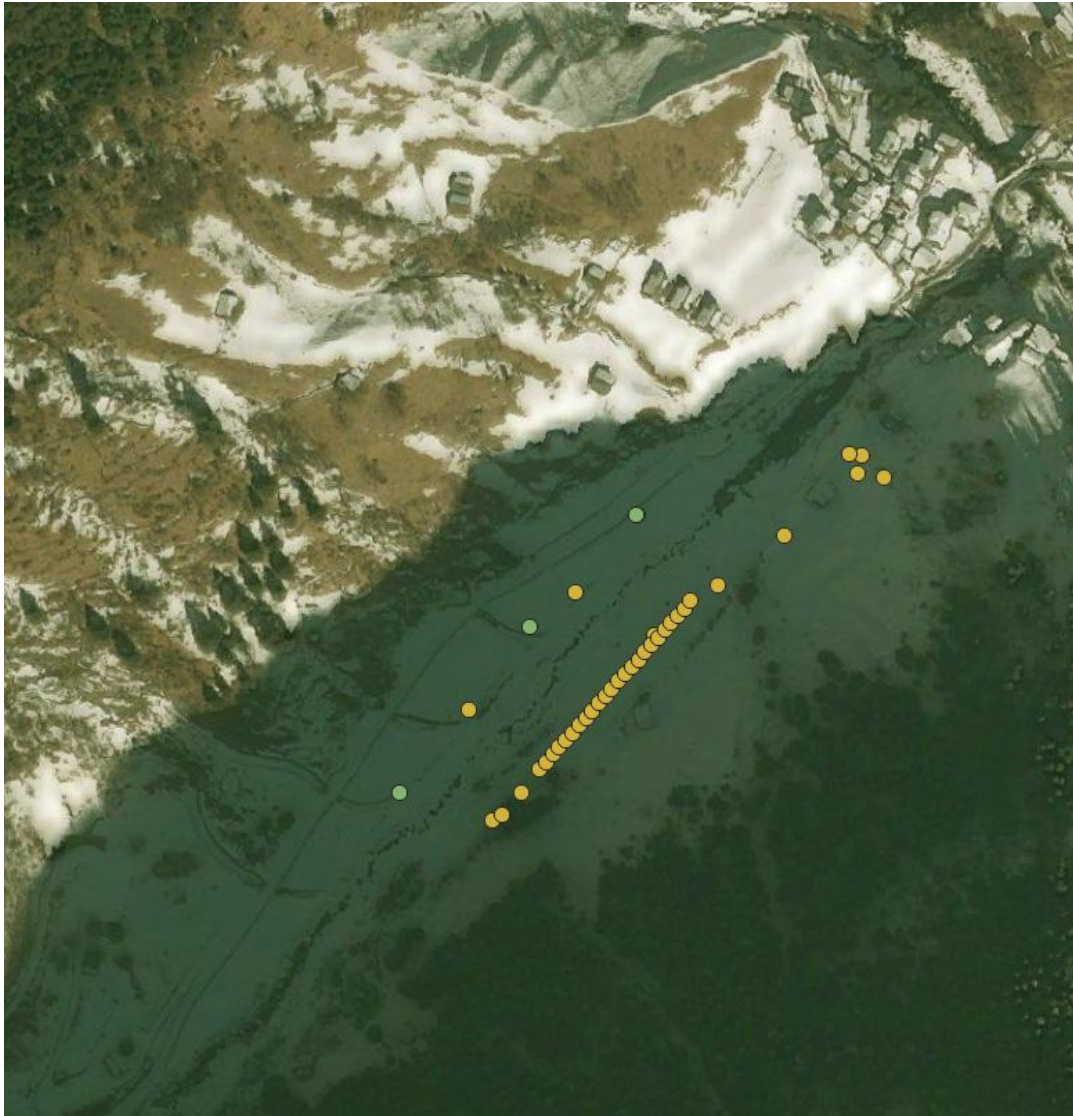
Figure 20 The positions of points in QGIS

Then it is necessary to establish a common coordinate system. This can be achieved by first identifying an original point in the terrain and obtaining its longitude and latitude data using the World Composer tool in Unity. We choose the left lower point of squared terrain as the original point.

Name	Longitude	Latitude
Original point	46.1056	9.67992

Figure 21 The longitude and latitude of original points in terrain

Next, the longitude and latitude data of both the original point and the GIS data must be converted into projected XY coordinates using an appropriate transformation method, which ensures accurate alignment between the two datasets.

To transform longitude and latitude, we use ArcMap. ArcMap is a desktop GIS software developed by Esri that allows users to create, analyze, and manage geographic data. It provides a wide range of tools for data visualization, editing, querying, and analysis, and is widely used in various fields such as urban planning, environmental management, and natural resource exploration. One of the key features of ArcMap is its ability to transform latitude and longitude coordinates into projected XY coordinates, which can be used to create points or other geometric features in a map. This process, known as geocoding, involves converting the geographic location of a feature to a point on a coordinate system, allowing it to be displayed on a map and analyzed in relation to other features.

The coordinate Reference System we choose is WGS84/UTM zone 32S(EPSG:32732).

OBJECTID	name	X	Z
1	Castello	552283.9265	15105734.51
2	G1	552202.2522	15105641.15
3	G2	552226.0928	15105666.74
4	G3	552229.4448	15105670.41
5	G4	552232.8114	15105674.14
6	G5	552235.9729	15105677.74
7	G6	552239.4489	15105681.48
8	G7	552242.7962	15105685.22
9	G8	552246.0976	15105688.89
10	G9	552249.4867	15105692.62
11	G10	552252.6591	15105696.38
12	G10	552252.5949	15105696.4
13	G11	552255.9287	15105700.18
14	G12	552259.5124	15105703.64
15	G13	552262.4374	15105707.66
16	G14	552265.8325	15105711.27
17	G15	552269.2381	15105714.98
18	G16	552272.6429	15105718.61
19	G17	552276.1237	15105722.2
20	G18	552279.3697	15105725.92
21	G19	552282.7391	15105729.55
22	G20	552286.1202	15105733.32
23	G21	552289.4564	15105737.08
24	G22	552292.7049	15105740.81
25	23	552295.9722	15105744.61
26	G24	552299.3939	15105748.22
27	G25	552302.5107	15105752.33
28	MasterTartano	552349.5964	15105784.82
29	S1	552389.1032	15105825.68
30	S3	552386.7298	15105816.63
31	S2	552400.4579	15105814.36
32	D1	552382.5881	15105826.12
33	Sez3	552275.2723	15105795.76
34	S4	552244.1283	15105756.12
35	S5 buco	552221.0716	15105738.99
36	Sez6	552190.2754	15105696.79
37	Fucile1	552316.4743	15105759.88
38	Fucile 2	552216.8094	15105654.77
39	Fucile 3	552206.9025	15105643.61

Figure 22 The coordinate of points in WGS84/UTM zone 32S(EPSG:32732)

Name	X	Z
Original point	552069.0956	15105582.96

Figure 23 The coordinate of original point in WGS84/UTM zone 32S(EPSG:32732)

Upon the completion of GIS data transformation from longitudinal and latitudinal coordinates to a designated coordinate reference system, the organized points of the GIS data may be incorporated as child objects within the Unity environment, with their relative positions established based on their transformed coordinates. The calculation of the relevant X and Z values may be accomplished by subtracting the X and Z values of each point from the X and Z values of the original point, which is 552069.1 m and 15105583.0 m, respectively. This process can be readily performed utilizing tools such as Microsoft Excel.

OBJECTID	name	Related coordinate X	Related coordinate Z
1	Castello	214.8265	151.5096
2	G1	133.1522	58.1532
3	G2	156.9928	83.7408
4	G3	160.3448	87.4079
5	G4	163.7114	91.1432
6	G5	166.8729	94.7435
7	G6	170.3489	98.4784999
8	G7	173.6962	102.22
9	G8	176.9976	105.8862999
10	G9	180.3867	109.6214
11	G10	183.5591	113.3824
12	G10	183.4949	113.4013
13	G11	186.8287	117.1801999
14	G12	190.4124	120.6399
15	G13	193.3374	124.6597
16	G14	196.7325	128.2671
17	G15	200.1381	131.9792
18	G16	203.5429	135.6075
19	G17	207.0237	139.2029
20	G18	210.2697	142.9202
21	G19	213.6391	146.551
22	G20	217.0202	150.317
23	G21	220.3564	154.0795
24	G22	223.6049	157.8142
25	23	226.8722	161.6064
26	G24	230.2939	165.22
27	G25	233.4107	169.3337999
28	MasterTartano	280.4964	201.8155
29	S1	320.0032	242.6812999
30	S3	317.6298	233.634
31	S2	331.3579	231.3582
32	D1	313.4881	243.1207
33	Sez3	206.1723	212.7606
34	S4	175.0283	173.1216
35	S5 buco	151.9716	155.9918
36	Sez6	121.1754	113.786
37	Fucile1	247.3743	176.8828
38	Fucile 2	147.7094	71.7657999
39	Fucile 3	137.8025	60.6148

Figure 24 The related coordinate of points in Unity

Regarding Y coordinates, a feature within Unity enables the automatic alignment of points to the terrain, obviating the need to explicitly consider Y coordinates during the transformation process. This is achieved by setting the Y coordinate of each point to the corresponding terrain elevation, as determined by the elevation data, at that specific location. Thus, manual transformation is not required for the Y coordinate.

As evidenced, this method facilitates the establishment of an accurate and precise relationship between the points of a riverbank and the neighboring terrain in the Unity environment.

4 Future Research

The provision of specialized services is a crucial aspect of digital twin. For this study, providing instant warnings in areas at risk of flooding is the final goal.

4.1 Collect relevant data.

To use digital twins for river monitoring and flood warning purposes, the first step is to collect relevant data.

Based on previous research and work, we propose a hypothesis for utilizing the described approach of collecting information which is the width of river to monitor rivers and provide alerts. However, it is important to note that this remains a hypothesis, as current limitations prevent us from obtaining precise data.

Various devices can be utilized to measure the width of a river for creating a digital twin in the context of Tartano River. Drones equipped with cameras or LiDAR sensors can be used to capture aerial images or measure the width of the river. A total station, which is a surveying instrument that utilizes an electronic theodolite and a distance meter to measure angles and distances, can also be used for this purpose. Additionally, sonar devices that transmit and receive sound waves can be used to measure the depth and width of the river. The Global Positioning System (GPS) can capture the coordinates of two points across the river and measure the distance between them to calculate the width of the river. In some cases, traditional measurement methods such as using a rope or measuring tape can be used, but this method is less precise and more time-consuming compared to the other methods mentioned above. By utilizing these devices, the width of Tartano River can be accurately measured to develop an effective digital twin.

The variable 'w' denotes the width of the river at the corresponding location. It is posited that during normal periods, the sensor-derived width value corresponds to 14 at point 13. After a specific precipitation event, the sensor-derived width value corresponds to 35 at point 13. These respective values are individually inputted into the Unity platform.

Figure 25 The river with 14 which is the value of 'w' at point 13.
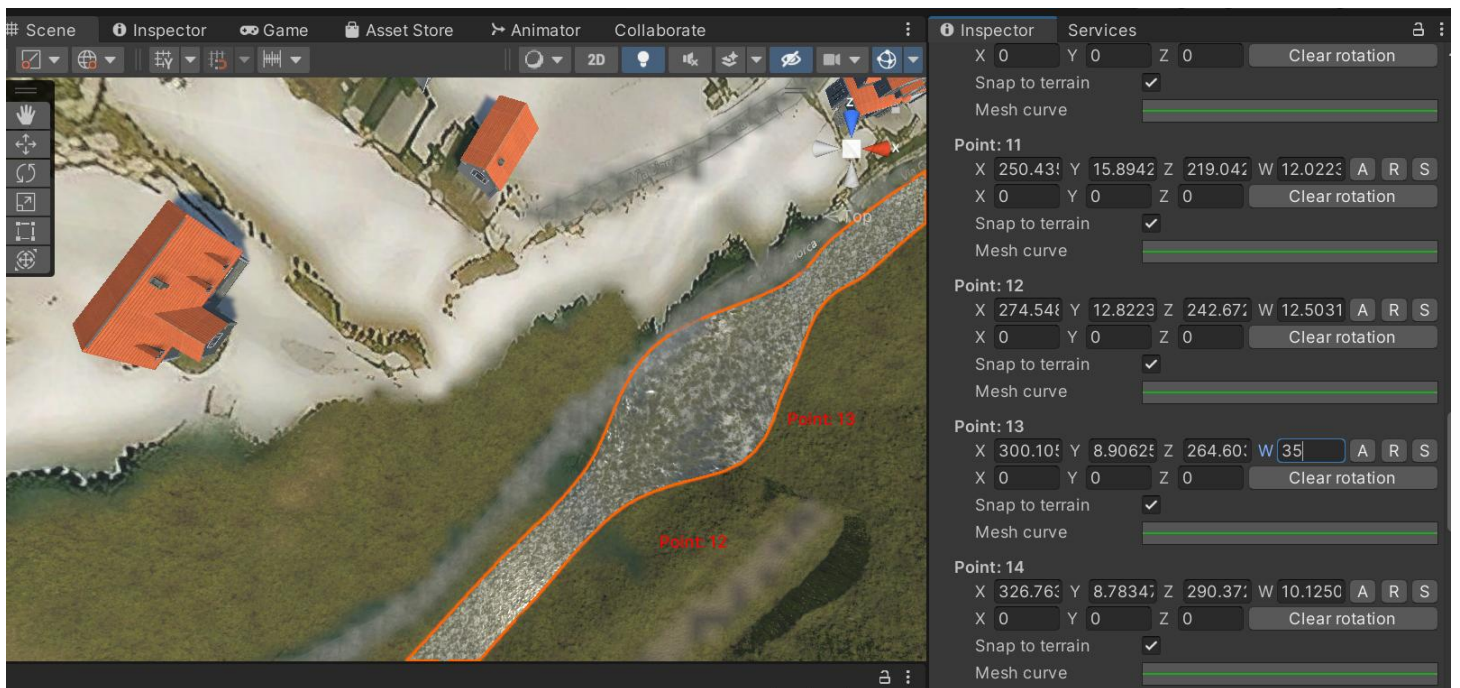

Figure 26 The river with 35 which is the value of 'w' at point 13.

The visualization shows that when the width value of point 13 increases to 35, the corresponding river area has already covered the road, indicating that a flood disaster has occurred.

As we gather increasingly more data, the resulting 3D model becomes more realistic and can offer more accurate information. In future research, in addition to river width, pertinent data such as water quality, water level, water temperature, water flow velocity, and other related parameters can be gathered for comprehensive analysis.

Here, I will propose several avenues for future research. A combination of remote sensing, in-situ monitoring, and IoT devices can be used during a field trip to Tartano.

In-situ monitoring is a method of collecting data by placing sensors at specific locations along the river to measure various parameters related to water quality and quantity. The data collected from these sensors is used to monitor changes in the river over time and provide insights into its health and functioning.

Water level sensors are commonly used in in-situ monitoring to measure changes in the river's water level. These sensors can be placed at fixed locations along the river and can be either submerged or placed above the water surface. They can measure water level changes with high accuracy and provide real-time data. However, they may be affected by environmental factors such as debris and sediment accumulation, which can affect their accuracy.

Temperature sensors can also be used in in-situ monitoring to measure the temperature of the water in the river. These sensors are usually placed at fixed locations and can provide data on water temperature changes over time. They are relatively simple and inexpensive to use but may be affected by external factors such as solar radiation, which can cause fluctuations in temperature readings.

Water quality sensors are also commonly used in in-situ monitoring to measure parameters such as pH, dissolved oxygen, and turbidity. These sensors can provide information on the health and quality of the river water, as changes in water quality can indicate potential pollution or other environmental issues. However, these sensors can be relatively expensive and require regular calibration and maintenance to ensure their accuracy.

The Internet of Things (IoT) devices refer to physical devices that are connected to the internet and can exchange data with other devices or systems. These devices can include various sensors and measurement tools that are installed in or near the river to collect data.

One of the IoT devices that can be employed to gather information about a river is an ultrasonic sensor. The ultrasonic sensor is capable of emitting high-frequency sound waves that propagate through the air and subsequently bounce off objects present in the water, such as the riverbed or the surface of the water. The sensor then calculates the time taken for the sound waves to return to the sensor. The sensor can compute the distance between the sensor and the object in the water by knowing the speed of sound in air and the time taken for the sound waves to return.

By placing ultrasonic sensors at different positions along the river, data on the river's width and water flow speed at each point can be collected. Once the data has been collected, it can be used to create a digital twin of the river system. This involves creating a virtual model that replicates the physical river system, including its geometry, topography, and hydraulic properties. The digital twin can be used to simulate different scenarios, such as changes in water flow, to assess the potential impact on the river system and surrounding areas.

Remote sensing is a technique used to collect data about the environment without physically being present. In the context of river basin analysis, remote sensing data can be utilized to gather information about the topography and morphology of the river basin. This includes data on factors such as elevation, slope, and land use/land cover.

Various techniques can be used to collect remote sensing data, such as LIDAR (Light Detection and Ranging), satellite imagery, and aerial photography. LIDAR utilizes laser pulses to measure the distance between the sensor and the earth's surface, resulting in high-resolution topographical data. Satellite imagery can provide information about land use/land cover, vegetation cover, and surface water bodies. Aerial photography involves capturing images from aircraft or drones and can provide high-resolution visual data about the terrain and land cover.

By using remote sensing data, river basin analysts can gain a more comprehensive understanding of the physical characteristics of the basin, which can be useful for a variety of purposes such as flood risk assessment, land use planning, and environmental impact assessments.

However, this increased complexity requires a more advanced application of Unity, ofen including the use of data analytics tools and machine learning algorithms. Thus, while the benefits of incorporating additional data into the model are clear, the process of developing an accurate and effective 3D model using Unity may require a higher level of technical proficiency and programming expertise.

4.2   Development of warning thresholds

Utilizing the data obtained through various monitoring and simulation techniques, warning thresholds can be established to facilitate timely alerts when specific conditions are met.

In our case, it doesn't even require historical data. In the 3D model, it is very intuitive to see when flooding will spread to the road at what width.

Using the simulated river model in Unity, predict potential flooding scenarios based on different width. This can help identify which areas are most at risk for flooding. As an illustration, suppose the width value 'W' is above or equal to 21 at the 13th point in the simulation model, indicating that flooding has potentially covered the road. In this case, a threshold can be established at 20 to generate an alert, thereby providing an early warning to the relevant authorities and residents.

Figure 27 The river with 21 which is the value of 'w' at point 13

We can also set different thresholds for different severity. The system generates alerts that are differentiated by three color-coded categories, namely red (indicating a high alert level), orange (indicating a medium alert level), and green (indicating a low alert level). As an example, the thresholds for different alert levels at the 13th point can be set as follows: 20 as the threshold for triggering a red alert, indicating an imminent danger; 18 as the threshold for triggering an orange alert, indicating a warning of potential danger; and 16 as the threshold for triggering a green alert, indicating a notification of the current condition.

This approach leverages the 3D model to identify critical points and establish a threshold based on the width parameter, enabling efficient monitoring of the river and timely response to potential flood events.

In a more accurate and detailed 3D model, more information is included, and it is not possible to simply observe the threshold at which flooding occurs. To identify the threshold or conditions for triggering alerts, historical data on the river's behavior during various weather and environmental conditions is needed. This can provide valuable information on the severity of past floods. It may also be useful to consult with experts in the field of hydrology and water management to determine appropriate threshold values based on the characteristics of the river and the local environment.

4.3   Uploading sensor data to the cloud

Uploading sensor data to the cloud is important in digital twin. The ability to collect and process data from sensors in real-time has significant implications for decision-making and problem-solving, particularly in scenarios where quick action is required to prevent or mitigate negative impacts.

Internet of Things (IoT) platforms have emerged as a popular option for collecting sensor data and uploading it to the cloud. These platforms provide a centralized hub for managing multiple sensors and collecting data from them. IoT platforms utilize wireless communication protocols such as Wi-Fi, cellular networks, or satellite communication to transmit the data to the cloud. For instance, some examples of popular IoT platforms include Microsoft Azure IoT Hub, AWS IoT, and Google Cloud IoT. In addition, IoT platforms may also include data management tools that can process and transform the raw sensor data into a format that is suitable for analysis and simulation. This allows the data to be fed into real-time simulation models, such as the river simulation model in Unity, to predict the behavior of the river under different conditions.

Edge computing devices are another option for uploading sensor data to the cloud. These small computers can be deployed close to the sensors to perform some data processing and analysis before sending the data to the cloud. This approach can help reduce the amount of data that needs to be transmitted to the cloud, which can save on bandwidth and reduce latency. Moreover, edge computing devices can provide more real-time data processing and analysis capabilities. For example, some examples of edge computing devices include Raspberry Pi and NVIDIA Jetson.

Direct cloud-to-device communication protocols, such as MQTT or CoAP, can also be utilized to upload sensor data to the cloud. These protocols enable lightweight communication between devices and the cloud, which can be useful in low-bandwidth environments. MQTT is a popular protocol for IoT devices that require low power consumption and limited bandwidth. Ultimately, the choice of data upload method will depend on factors such as the type and number of sensors being used, the available communication infrastructure, and the required latency and data processing capabilities.

4.4 Setting up an emergency response plan

Establishing an emergency response plan is critical to mitigate the impact of floods on the local community. The plan must outline the roles and responsibilities of all stakeholders, including government agencies, emergency responders.

The use of a digital twin in Unity presents an opportunity to enhance emergency response planning and preparedness for floods. In order to establish an effective emergency response plan, it is crucial for government agencies to coordinate their efforts, and the utilization of a digital twin can provide a comprehensive view of the area at risk and the potential impact of the flood.

The simulation with data can disseminate timely and accurate information to the public regarding the flood situation, including updates on potential hazards and evacuation orders.

The use of a digital twin in Unity can also benefit emergency responders, such as police, firefighters, and medical personnel. By leveraging the digital twin, responders can quickly identify areas at risk and prioritize evacuation efforts. Additionally, the digital twin can provide valuable information on the location of residents in need of medical assistance and aid in the coordination of rescue efforts.

The emergency response plan incorporated within digital twin should include procedures for evacuation, rescue, and recovery. This may involve identifying evacuation routes, establishing shelters for displaced residents, and providing necessary resources such as food and water. Additionally, the plan should include a comprehensive strategy for the recovery

phase, which may involve rebuilding damaged infrastructure and providing support to affected families.

4.5   Create an effective communication system:

In order to warn public in Tartano, it is important to have an effective communication system in place. One such system is an emergency alert system that utilizes various communication channels to reach a broad audience quickly.

A mobile application can be developed that sends push notifications to users in affected areas, alerting them of the potential danger and providing instructions on what actions to take. Additionally, sirens or loudspeakers can be installed in strategic locations that can broadcast emergency messages to people in the vicinity. It is also important to ensure that the warning messages are clear and easy to understand, using plain language and avoiding technical jargon. The messages should provide specific information about the type and severity of the threat, as well as instructions on what actions to take in response. Moreover, it is necessary to regularly test and update the communication system to ensure that it is functioning properly and can effectively reach the intended audience. By implementing such measures, the risk of loss of life and property damage due to flooding can be significantly reduced.

Alternatively, cloud storage is a concept of cloud computing that enables significant real-time data storage in remote third-party servers. Internet users may access these servers at any time. Cloud storage is also known as utility storage. Several recent works have exploited cloud storage for data logging and networking in early warning systems (Fang et al., 2015). A platform currently being used by several research hers is the WebGIS platform. WebGIS facilitates client–server information exchange through the web. WebGIS may be accessed from anywhere using a web browser, and its databases are stored in the cloud. It is possible to transmit the status and associated information of rivers obtained within Unity, such as the areas covered by river water, to this platform. This transmission of data could potentially provide access to additional information on the platform.

Public awareness and education is an integral part of any flood warning system, as it plays a crucial role in reducing the impact of flooding on the affected communities. Educating the public on the risks and potential hazards associated with floods, as well as providing information on how to prepare for and respond to flooding events, can help to minimize the loss of life and property damage.

Social media campaigns are another effective way to reach a large audience and provide real-time updates and information during flood events. Platforms such as Twitter and

Facebook can be used to share updates on river levels, weather conditions, evacuation orders, and other important information.

Community engagement activities can help to build trust and foster collaboration between the public and the agencies responsible for managing the warning system. This can involve partnering with local schools, churches, and community organizations to host events and activities that promote flood awareness and preparedness.

4.6   Challenges for future research:

The utilization of digital twins for river monitoring and flood warning purposes through monitoring the width and flow speed of the river presents several challenges.

In the context of sensor-generated data, accuracy and reliability are crucial for effective decision-making and problem-solving. However, several external factors can significantly impact the accuracy and reliability of such data. These factors can include environmental conditions, such as temperature, humidity, and precipitation, which can affect the functioning of the sensors themselves. Additionally, debris in the water, such as leaves, logs, and other objects, can interfere with the sensors' readings, leading to incorrect or inconsistent data. Another significant factor that can affect the accuracy and reliability of sensor-generated data is signal interference. Signal interference can arise from a variety of sources, such as electromagnetic radiation from power lines or other electronic devices, which can disrupt the sensors' signals and lead to incorrect data. Additionally, the presence of multiple sensors near one another can also cause interference, leading to inaccurate readings.

Implementing a flood warning system requires a collaborative approach among various stakeholders, including government agencies, emergency responders, and local communities. This collaborative approach is important to ensure that the system is accessible, responsive, and reliable for all stakeholders. However, there are several challenges that need to be addressed to achieve an effective implementation. A challenge is ensuring accessibility of the system to all stakeholders, especially those in remote or underserved areas. This may require the deployment of additional sensors or the use of alternative communication channels to reach these areas. Another challenge is the responsiveness of the system to rapidly changing flood conditions. The system must be able to quickly detect and respond to changing conditions to provide timely and accurate warnings to the public. Reliability of the system is also a critical concern. The accuracy and reliability of sensor-generated data can be impacted by various external factors, such as environmental conditions, debris, and signal interference. Therefore, measures must be taken to ensure the acquisition of precise and dependable data. In addition to these technical challenges, effective implementation also requires addressing social and institutional

barriers. For instance, there may be a lack of awareness and understanding among the public and stakeholders regarding the purpose and functionality of the system. Addressing these barriers requires a coordinated effort that involves education, outreach, and engagement with stakeholders.

The maintenance and updating of a digital twin model to accurately reflect changes in the physical environment also poses a persistent and resource-intensive challenge. This necessitates a continual investment of expertise, time, and resources to ensure the continued accuracy and reliability of the model. The development and implementation of effective strategies to address this challenge are critical to ensure the sustained success and usefulness of the digital twin in the context of flood warning systems.

5   Discussion and conclusion

This study demonstrates the creation of a 3D visualization model in Unity using Digital Twin technology to represent Tartano's terrain and river. The model is designed to predict flood events primarily based on river width. However, the study acknowledges that in practice, additional data sources can be integrated, and more sophisticated models can be developed to improve the monitoring and forecasting of floods.

The disparities between the conventional flood monitoring and early warning systems and the monitoring and early warning systems based on Digital Twin technology are evident.

Traditional flood monitoring and early warning systems typically rely on physical sensors, such as river gauges and rain gauges, to collect data on water levels and precipitation. These sensors are placed at fixed locations and transmit data to a central monitoring station for analysis. While these systems have been effective in providing some level of warning to flood-prone areas, they have several limitations, including the need for significant investment in infrastructure, reliance on manual data collection and analysis, and limited ability to provide detailed information on flood dynamics.

In contrast, digital twin technology enables the creation of virtual models of the physical environment that can simulate real-world scenarios and predict potential flood events. Digital twin-based systems can incorporate a wide range of data sources, including satellite imagery, aerial surveys, and ground-based sensors, to provide a more comprehensive and dynamic understanding of the flood risk. With real-time data collection and analysis, digital twin-based systems can issue warnings more quickly than traditional systems. This is especially critical in flood-prone areas, where timely warnings can help communities and infrastructure to prepare for and respond to flood events.

Additionally, digital twin-based systems can be cost-effective in the long run, despite the initial development costs. Traditional monitoring and early warning systems for floods often require significant investment in infrastructure, such as gauges and weather stations, which can be costly to install and maintain. In contrast, digital twin-based systems rely on virtual models, which can be easily updated and maintained with new data. This makes digital twin-based systems a more flexible and cost-effective solution over the long term.

Overall, the use of digital twin technology represents a significant advancement in flood risk management, offering the potential for more accurate and detailed monitoring and early warning systems that can help protect communities and infrastructure from the devastating effects of flooding.

Considering the potential benefits and challenges, further research is needed to explore the feasibility and effectiveness of digital twin-based systems for flood monitoring and early warning.

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