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TOWARDS A 3D WEB TOOL FOR VISUALIZATION AND SIMULATION OF URBAN FLOODING: THE CASE OF METROPOLITAN CITIES IN CAMEROON

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ABSTRACT

Today, 3D geo visualization of flood data is perceived as a more realistic and detailed solution for making decisions regarding flood mitigation and adaptation measures. In this paper, after a multi-criteria comparative study of four virtual globes used in the visualization of geospatial flood data, it is found that CesiumJS stands out the most from the other solutions, with a score close to 100% on all criteria grouped in 4 categories (Visualization, Interaction, Quality of support and Experiences). Using CesiumJS and other libraries, we proposed a 3D web solution to dynamically simulate and visualize floods in urban areas of Cameroon. The main objective of this tool is to strongly involve water experts, policymakers and the general public in flood management. Without considering a precise 3D city model, this tool, however, represents a good compromise between the quality of flood management and the cost of better Flood Management by an expert.

KEYWORDS: 3D Web Solution, 3D Geo visualization, CesiumJS, 3DTiles, Geospatial Data, 3D City Model, Urban Flooding in Cameroon.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) has concluded that low-lying coastal areas are more vulnerable to the effects of sea level rise and storms due to climate change [1]. Subsequently, a

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recent study published in the journal Nature reported that sea levels may rise faster than expected over the next few decades [2].

Floods are the most frequent, damaging, and deadly of all natural disasters that strike the world each year [3]. They are the source of almost half of all deaths from natural disasters over the past fifty years and are responsible for almost a third of global economic losses [4]. The risks are therefore enormous and very alarming as floods cause infrastructural damage and loss of life. Thus, there is a need for mitigation and adaptation to climate change.

Cameroon is one of the countries facing severe flooding. Some areas are below sea level and a large population lives there. One of the most recent floods was in Buea on 18 March 2023. In addition, some low-lying urban towns are not spared. The floods in the city of Douala, the central post office in Yaounde. Without forgetting the populations residing in influence of the Logone and Benue rivers are also under the strong influence of floods. According to CRED (Center for Research on the Epidemiol-ogy of Disasters) in 2016, Cameroon recorded frequent floods that affected 367,276 people between 2007 and 2015, making floods the most frequent disaster in the country.

Today, there has been a growing need to develop tools that address issues related to disaster management and mitigation. [5]. Such applications quickly convey clear and powerful messages, condense complex information, and motivate personal, community and government action. [6].

This paper provides a first attempt to develop a 3D web-based flood visualization and simulation tool, especially in three flood-affected urban areas of Cameroon - Ya-oundé, Douala and Garoua. In order that effective strategies can be developed to im-prove resilience and mitigate the effects of flooding, this tool visualizes and simulates flooding in 3D using Cesium's 3D terrain, Open Street Map's 2D buildings, which have been converted to 3D using the 3DTiles format (an open specification for streaming massive heterogeneous 3D geospatial data sets).

The rest of the paper is organized as follows: Section 2 makes an inventory of open source and/or free solutions for flood visualization and/or mapping simulation on the web. Section 3 performs an experimental and comparative study of four virtual globe technologies to choose the most appropriate technology for flood visualization and simulation. Section 4 presents the software prototype to dynamically visualize floods in 3D in three Cameroonian urban areas: Yaoundé, Douala and Garoua. This paper ends with a conclusion and future work.

2. Review and evaluation of web-based flood visualization and simulation solutions

Flooding is a risk that is likely to increase in the future due to climate change. It is therefore essential that decision makers and experts in the field have the tools to assess the effects of flooding. Therefore, there has been a plethora of development of desk-top/web, 2D/3D, proprietary/open source/free flood map visualization solutions. This paper focuses on web-based flood mapping solutions.

Web-based flood mapping solutions are applications that exploit web browsers to visualize and analyze geospatial flood data. This type of application has become immensely popular and is also the means of deploying applications in the geospatial community. We have identified twenty-seven (27) web applications that provide 2D or 3D cartographic visualization of flood data. Most of these web applications are freely available to anyone with an Internet connection and a web browser. We therefore do not claim to be exhaustive here in the presentation and description of these solutions. We perform a quick evaluation of these solutions to identify the essential technologies and functionalities for the development of our proto-type 3D flood visualization solution. Table 1 lists the 2D or 3D web solutions dedicated to flooding and determines the web technology used in the back of each solution. This technology includes all the computer technologies that will be used for the implementation of the flood-related map data display tool. A total of three (03) evaluation criteria were defined: client-side API criteria, programming language and data exchange format.

In terms of the client APIs identified, ArcGIS is the most used proprietary solution. CesiumJS, Itowns, OpenLayers, Leaflet, and Three.js are the most used open-source tools. For the exchange formats, we have identified the proprietary Shape-file format, vector data in KML format, and imagery data in GeoTiff format. For 3D ex-change formats, in addition to KML, we also identified solutions that process data in CityGML, CityJSON, DXF and Collada formats. As far as programming languages are concerned, the ones we have identified the most concern web development technologies with HTML5, CSS and JavaScript.

These web applications offer functionalities (zoom in/out, panorama and location search ...) with the possibility to add, query and visualize data (vector and/or raster) and to access metadata. They are mostly easy to use and initially display a 2D flood map. They add 3D for more realism and detail and help to better under-stand the severity of the flood.

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Table 1. Summary of 2D or 3D web solutions dedicated to flooding.

Web-based flooding	*Client*	*View*	*Reference*
1. La carte interactive des zones inondables au Québec	ArcGIS	2D	[7]
2. IGO2-Geo-inondations	ArcGIS	2D	[8]
3. Surveillance de la crue	ArcGIS	2D	[9]
4. scenarios de crues	Map Box	2D	[10]
5. UNOSAT flood portal	ArcGIS	2D	[11]
6. Sea Level Rise Viewer	ArcGIS	2D	[12]
7. NJFloodMapper	ArcGIS	2D	[13]
8. Flood Maps	Google	2D	[14]
9. Surging Seas: Risk Zone Map	Mapbox /Turf.js	2D	[15]
10. EFAS	Leaflet	2D	[16]
11. Flood Map	Mapbox	2D	[17]
12. Iowa Flood Information System (IFIS)	Google	2D	[18]
13. Spatial Flood Early Warning System	OpenLayers	2D	[19][20]
14. National Flood Vulnerability Assessment System	OpenLayers	2D	[19][21]
15. Lakes Entrance Visualization	Adobe Flash	2D	[22][23]
16. Inundated	Leaflet /Shiny	2D	[24]
17. IDDSS	CesiumJS	3D	[25]
18. Simplified Millbrook visualization	3D three.js	3D	[26]
19. FEMA (Federal Emergency Management Agency)	Adobe Flash	3D	[27]
20. Urban Geo Big Data	CesiumJS / WebWorldWind	3D	[28]
21. Inondation de la ville de Lyon	Itowns	3D	[29]
22. E-nundation	ArcGIS	2D	[30]
23. Pin2Flood	ArcGIS	2D	[31]
24. StormTools	ArcGIS	2D	[32]
25. Dynamic 3d visualization of floods	CesiumJS	3D	[5]
26. Web 3D GIS application	CesiumJS	3D	[33]
27. Sea level	Itowns	3D	[34]

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Finally, regarding all the solutions analyzed here, we consider that there is room for improvement in visualizing floods cartographically, especially with regard to 3D visualization and mapping. Thus, in the next section, in order to choose the most ap-propriate technological solution for the development of our software prototype, we will carry out a comparative study of virtual globe type technologies used in the 3D visualization of floods (CesiumJS, Itowns, WebWorldWind and Google Earth).

3. Experimental and comparative study of 3D virtual globe solutions

This section deals with an experimental and comparative study of virtual globe client technologies. The first three are open source and free (CesiumJS, Itowns, Web-World Wind) and the fourth (Google Earth) is only free. These technologies were considered relevant for our work, not only because of their use in most of the 3D web solutions directly related to floods inventoried previously, but also because they are 3D open source and/or free.

Thus, we will first explain the testing scheme by presenting the criteria and the evaluation method. Then, we will present the results of the evaluations for each technology. Finally, we will make a synthesis, highlighting the strong and weak points of each virtual globe free of charge. These technologies were considered relevant for our work, not on-ly because of their use in most of the 3D web solutions related to floods inventoried previously, but also because they are 3D open source and/or free.

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3.1 Experimental and evaluation design

3.1.1. Choice of evaluation criteria

A total of 30 evaluation criteria were grouped into four (4) categories, namely interaction, visualization, quality of the medium and experimental installation and us-age criteria. We will not go into the description of these criteria.

Table 2. Criteria for evaluating the solutions assessed.

Interaction	*Visualization*
-Zoom in / out	-Display the Bing background map
-Rotate the map	-Show OSM background map
-Pan (hover) the map	-Show Google background map
-Return to default view	-View ESRI background map
-Guidance and help	-View GeoJSON data
-Place locator	-View KML data
-Distance calculation	-View KMZ data
-Area calculation	-View 3D tiles
-Height calculation	-View Collada data
-Layer management	
-Vector data editing	
-KML export	
-GeoJSON export	
-Query data	
Installation/use	***Quality of support***
-Speed of execution	-Examples
-Ease of use	-Tutorials
-Difficulty of installation	-Documentation
-Complexity of using the API	

3.1.2. Evaluation method

For the evaluation of the virtual globes, each criterion was given a symbol according to its capabilities in the solution, as follows: (++) when the criterion is fully present in the solution. (+) when the criterion is partially present in the solution. (-) when the criterion is absent or does not work with the test data. The practical experimental evaluations were performed on the Lenovo ThinkPad computer with Nvidia Quadro M500M graphics card.

3.2 Detailed evaluation results

This section presents the detailed evaluation results for all the virtual globe solutions studied here.

3.2.1. World Wind

World Wind (https://worldwind.arc.nasa.gov/web/) is a free and open-source virtual globe written in JavaScript that allows users to quickly create interactive visualizations of geographic information on a 3D globe or 2D map. The results of experiments and tests show a weakness of this solution in interaction and visualization (see Table 3). It should therefore not be considered that the solution is poor but that its response to our present expectations is not adequate.

3.2.2 Itowns

iTowns (http://www.itowns-project.org) is an open-source framework written in JavaScript and used for the visualization of 3D geospatial data. The technology is based on three.js (https://threejs.org/) and has, according to the tests conducted, most of the criteria we were looking to evaluate. Nevertheless, its quality of support shows some weaknesses (see Table 3).

3.2.3 CesiumJS

CesiumJS (https://cesium.com/cesiumjs/) is an open-source library for creating 3D geospatial applications that can be viewed in a web browser without the use of a plugin. Throughout these experiments, we were able to see that CesiumJS goes far beyond the criteria we chose to evaluate. Thus, the overall evaluation is excellent: all the functionalities are present and provide the expected results (see Table 3).

3.2.4 Google Earth

Google Earth (https://www.google.com/earth/) is a virtual globe solution that al-lows a 3D representation of the earth based mainly on satellite images. From the evaluations conducted, Google Earth has functionalities that include almost all of those that we wanted to evaluate. The overall evaluation is therefore good. Nevertheless, the tests show a weakness in the visualization, for example it does not support 3D tiling (see Table 3).

3.3 Summary of the evaluation of the tested tools

Table 3 gives us a parallel comparison between the solutions studied. The evaluations in Table 3 represented by the symbols have been converted into scores ranging from 0 to 5. A score of 0 or 1 corresponds to the symbol (-), a score of 2 or 3 corresponds to the symbol (+) and a score of 4 or 5 corresponds to the symbol (++).

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Table 1. Evaluation summary of the virtual globes

Functionality	*World Wind*	*Itowns*	*Cesium sJS*	*Googl e Earth*
Zoom in / out	++	++	++	++
Rotate the map	++	++	++	++
Pan (hover) the map	++	++	++	++
Return to default	-	-	++	-
view	-	-	++	++
Guidance and help	+	+	++	++
Place locator	+	+	++	++
Distance calculation	+	+	++	++
Area calculation	-	+	++	++
Height calculation	+	++	+	++
Layer management	+	+	++	++
Vector data editing	-	-	++	++
KML export	++	-	-	-
GeoJSON export	++	++	++	++
Query data				
Examples	+	+	++	+
Tutorials	+	-	++	+
Documentation	++	++	++	++
Speed of execution	-	-	++	+
Ease of use	+	-	++	++
Ease of installation	+	+	+	++
Complexity of API	++	+	++	-
usage				
Display the Bing	++	++	++	-
map.	++	++	++	-
Show OSM map.	-	++	+	++
Show Google map.	-	++	++	-
View ESRI map	++	++	++	-
View GeoJSON data	+	+	++	++
View KML (3D) data	+	+	++	++
View KMZ data (3D)	-	+	++	-
View 3D tiles	++	++	-	++
View Collada data				

As we can see, for the interaction we realize that Google Earth and CesiumJS are the best performing solutions overall. Even as some interactive features are not offered such as export to GeoJson format. On the other hand, Itowns and Wordwind are penalized because of the lack of functionalities such as guidance, return to the default view and export in KMZ/KML format. Regarding visualization, those that are for the best are Itowns and CesiumJS compared to the other two which have certain weaknesses such as the absence of certain base maps and the failure to take into account 3D tiling which is important in the field of 3D geovisualization with the arrival of large volumes of data. Regarding the quality of support, Itowns seems to have a limitation in the absence of online tutorials compared to other solutions. Based on the experiences made through the installations and the use of these technologies, CesiumJS meets the

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necessary criteria, while WorldWind and Itowns have certain limits related to the speed of execution and/or the ease of installation. Google Earth has a technical limitation as it is not open source.

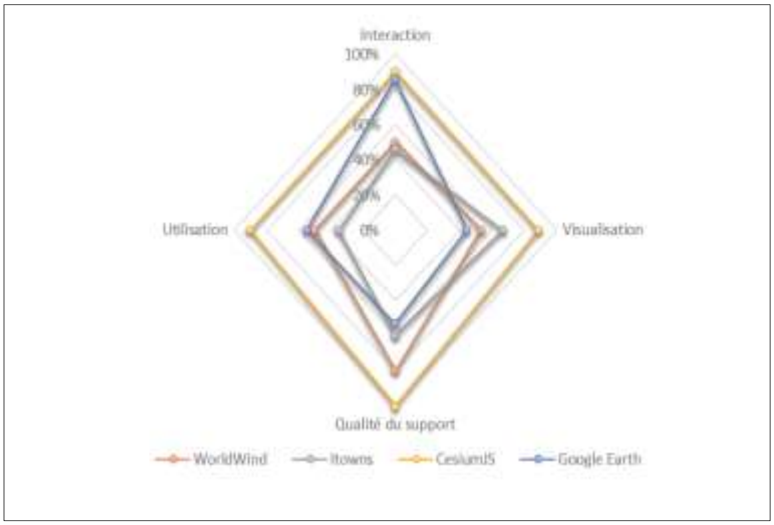

Figure 1. Synthèse graphique d'évaluation des globes virtuel.

In the end, according to this comparison, CesiumJS is the solution that stands out the most and therefore satisfies all the criteria, followed by Google Earth and Itowns. So CesiumJS is not only 3D, but also open source and free. This is what justifies the choice of this technology in the rest of this paper.

4. RESULTS

4.1 Study area and datasets

In this research, we propose a first attempt at a 3D web application for visualization and simulation of flooding in three Cameroonian urban regions: Yaoundé, Douala and Garoua to involve decision makers and stakeholders in mitigating and adapting to climate change and making informed decisions.

For the implementation, we used the CesiumJS technology to visualize the floods cartographically. This choice is justified by its free open-source nature and it dis-tinction in the previous comparative study. The housing data in GeoJson format comes from Open Street Map and has been converted to 3DTiles format (an open specification for streaming massive heterogeneous 3D geospatial datasets) to enable 3D visualization. The details of the implementation of our Framework are explained in the next section.

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4.2 Proposed framework

Figure 2 illustrates our proposed framework for flood visualization using CesiumJS and other libraries. We started from data in 2D format GeoJson has data in 3Dtiles format using a trial version of the spatial ETL (Extraction, Transformation, Load), FME (Feature Manipulation Engine) which is based on several modules including FME Workbench, which interests us here and allows processing to be chained using tools called 'Transformers' and 'Writers'. These tools first made it possible to generate random elevations of all the buildings in the GeoJSON file, then made it possible to extrude all the buildings and finally create a 3D tile. These data were exported for visualization on Cesium.

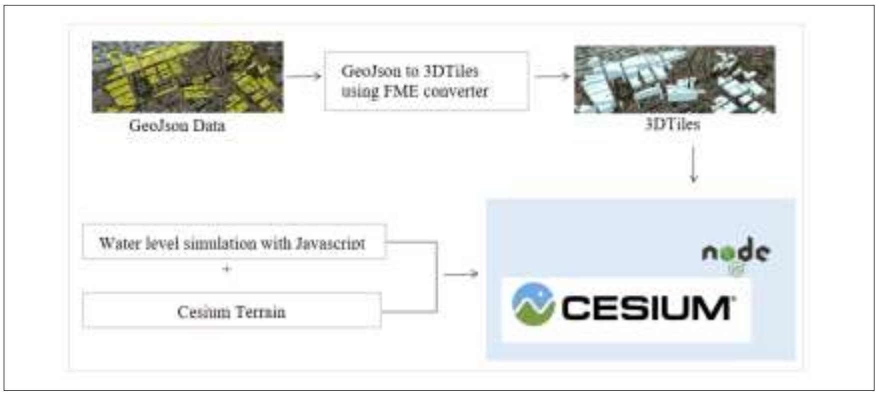

Figure 1. Overall architecture of the proposed prototype

The simulation of the water level in each of the three regions was carried out using a JavaScript code that can be useful in the urban planning of a new city. The course of the algorithm is as follows: for each region the smallest polygon delimiting the area has been created, then this polygon has been superimposed on the cesium terrain which is very precise, and finally different heights have been dynamically assigned to it, this approach made it possible to simulate the water level in our three (03) study areas.

The visualization interface has been implemented with CesiumJS using HTML5, JavaScript and CSS. The NodeJS library has made it possible to host our solution locally so that it is accessible on modern web browsers such as Mozilla Firefox, Google Chrome, and Microsoft Edge etc.

4.3 Implementation results

Figures 3, 4 and 5 show successively the extracts of a flood provided by the proposed software prototype in three different regions of Cameroon (Yaoundé, Douala and Garoua). This solution allows to simulate floods and to visualize their effects in 3D to sensitize and motivate the public in the fight against floods.

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Figure 1. Simulation and visualisation of a flood at the Yaoundé central post office

Figure 1. Simulation and visualization of a flood in Douala

Although this work provides a first attempt to develop a 3D web-based flood visualization and simulation tool, especially in three urban areas of Cameroon. The objectives were achieved as we were able to visualize three regions of Cameroon in 3D and dynamically simulate the rising water levels in these

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regions. Compared to similar preliminary works [35], [36], [37] and [38] on 3D flood visualization that use a small scale of visualization, the present work adds enormous value in displaying the data, the massive 3D data on the web. However, there is room for future improvements.

Figure 5. Simulation and Visualization of a flood in Garoua

5. CONCLUSION

This paper has introduced a new 3D web-based flood visualization and simulation tool for urban areas in Cameroon. The tool was developed using CesiumJS, other packages such as FME, NodeJS and 3Dtiles data. This user-friendly interface allows water experts and decision makers to assess the severity of the flooding situation and make informed decisions. This web-based tool offers a good compromise be-tween the quality of flood management and the cost required by experts for better flood management. However, in addition to the lack of support in the visualization of an accurate 3D model and other city features, several interactive functionalities need to be implemented at the interface level such as adding 3D spatial analysis support. For example, change the colour of buildings or roads according to the level of water flowing over them, displaying information about each flooded building or road, visualizing historical flood data in the form of dashboards, integrating the outputs of flood simulation software such as TUFLOW, Flood Modeler, MIKE FLOOD, TELEMAC and Open Foam into our software prototype.

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