Geoinformatics for Caribbean hurricane risk management and improved community resilience

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Abstract

Caribbean countries face increasing risks from the pressures of population growth and climate-driven geohazards, particularly those associated with hurricanes. This study illustrates how geoinformatics can assist emergency planning and community resilience. Data from geomorphological and civil engineering surveys in Dominica, carried out after Hurricane Maria (2017), have been augmented with digital elevation models from satellite and aerial sensors Those datasets have been integrated into a “Digital Twin” of neighborhoods, on which computational fluid dynamics analysis has been carried out, modeling hurricane wind impacts. A decision support system has been produced for testing climate change scenarios, as well as the impacts on resilience of changes to building locations or building designs. The information provided via those technologies can guide decision makers, from national emergency planners, to community leaders and householders.

I. INTRODUCTION

Caribbean countries are exposed to many hurricane- driven hazards, notably wind damage, storm surges, flooding, landslides and debris flows. They face ongoing impacts of population growth, alongside global heating with increased storm frequency. The mountainous island of Dominica was devastated by Category-5 Hurricane Maria in 2017 [1]. The lead author led a team that assessed post-hurricane damage, using satellite imagery and drone photogrammetry, with civil engineering and geomorphological surveys, examining infrastructure damage at 40 locations around Dominica [1]. The results formed the basis of ‘Build Back Better’ guidelines for disaster risk reduction and improved community resilience in Dominica and similar tropical volcanic islands.

We present here two methodologies that can improve hurricane risk management. The first uses freely-available

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geospatial datasets with global coverage; the second uses sub- meter pixel elevation data to create a 'Digital Twin' of neighborhoods, with which a Decision Support System has been developed to provide guidance on hurricane resilience.

II. DATA & METHODS

The datasets used in this study range from the 12.5m-pixel ALOS PALSAR Digital Elevation Model (DEM) developed by the Alaska Satellite Facility (https://asf.alaska.edu/), for national to district levels of detail; through to a 0.5m-pixel aerial laser scanning (LIDAR) DEM (https://dominode.dm/) and cm-pixel drone photogrammetry of buildings and neighborhoods [2]. The road network and village/town locations are downloaded from OpenStreetMap (www.openstreetmap.org).

The Dominica ALOS PALSAR DEM is processed using geomorphometric terrain analysis algorithms, available in ArcGIS and/or QGIS, to derive information regarding the slope gradient, the landform types and the stream network delineation, following a methodology developed by [3]. Locations of towns/villages and the road network are then used to determine transport "Pinch Points" where damage by flooding and debris flows could destroy bridges, as well as areas of road with a high risk of landslide damage (Fig. 1), following a methodology developed by [3].

The Kassandra Decision Support System (DSS) developed for this project uses a Digital Surface Model (DSM) derived from the Dominica LIDAR data and digital photogrammetry, to create a 3-D visualization (Fig. 2). The DSM is processed within Autodesk's Revit software (https://www.autodesk.co.uk/products/revit/architecture), to produce a Digital Twin showing a 3-D representation of buildings, roads, bridges and trees (Fig. 3). Linked to the Digital Twin is a relational database containing details about the environmental setting of each building, its design and its construction materials. That database is populated with crowdsourced data collected by surveyors using the *Epicollect* mobile phone app (https://five.epicollect.net/). The *Epicollect* survey tool collects data at individual buildings, via GPS-tagged photos, and a construction checklist, along with data about the environmental setting of each building and indications of local geohazards (e.g. floodplain or steep slope locations). Revit's Flow Design tool (https://sustainabilityworkshop.venturewell.org/buildings/flow-design- revit.html) is used to carry out Computational Fluid Dynamic analysis, from individual houses or streets, through to the landscape in which villages are located.

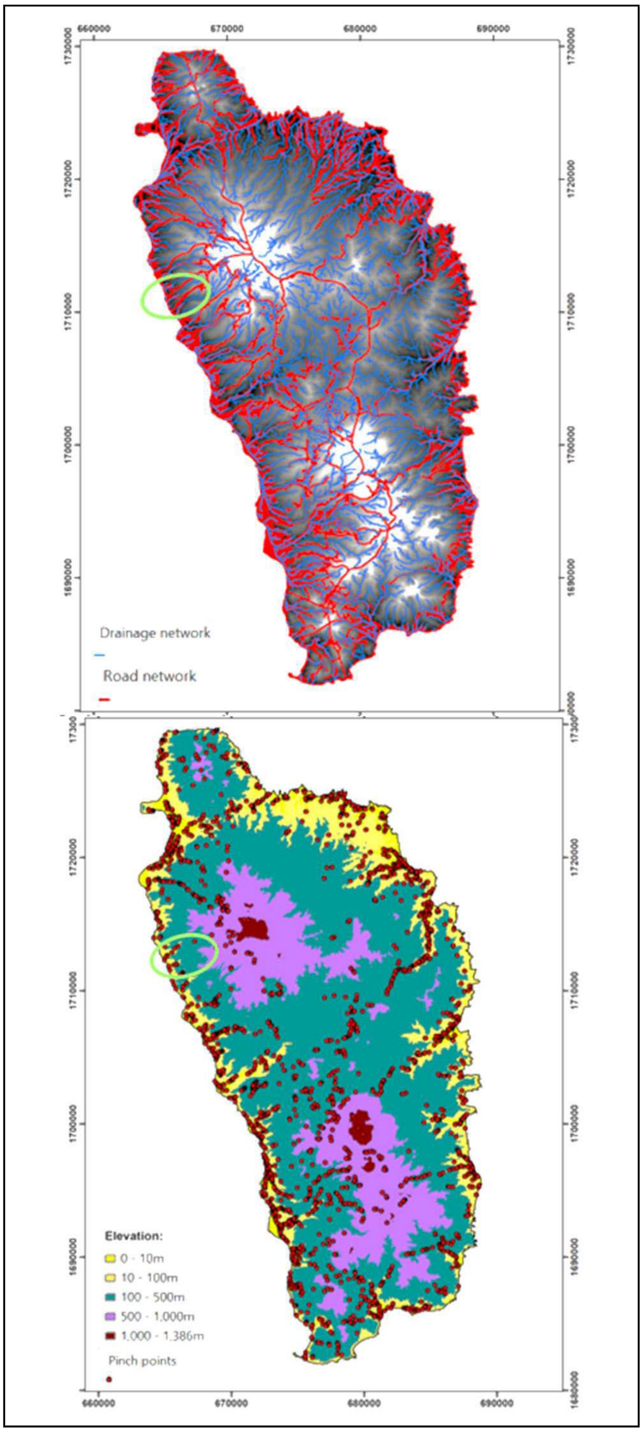

Fig. 1. Dominica: emergency preparedness mapping using the PALSAR DEM and OpenStreetMap. Top: DEM with drainage (blue) and road networks (red); Bottom: Elevation; the overlain red dots are locations of 'pinch points' in the road network. Green circle indicates the location of the Coulibistrie village study area.

The Kassandra Decision Support System uses various parameters to determine a Resilience Index for each building or cluster of buildings displayed in the Digital Twin. The main Parameters for this Dominica study were: Buildings, Environment, Infrastructure and Air (for the wind hazard).

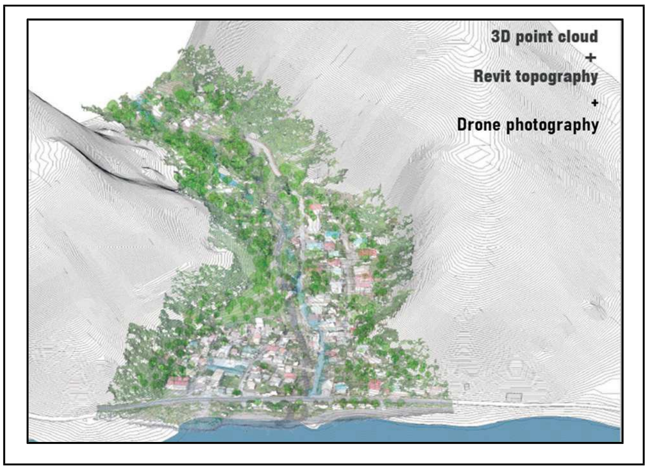

Fig. 2. A 3-D visualization of Coulibistrie, a village on the west coast of Dominica, with 137 buildings, mostly houses, produced from the Dominica LIDAR data, with overlain drone photography.

Various climate change scenarios were then run using the DSS to examine variations in the overall and individual Resilience Index, produced by varying the many factors contributing to each of the four main parameters. For instance, with regard to the Building parameters, examples of its component factors are: rectangular houses versus round houses, or variations in roof angle pitch. Also examined were variations in street geometries, e.g. clusters of buildings versus a regular grid of streets.

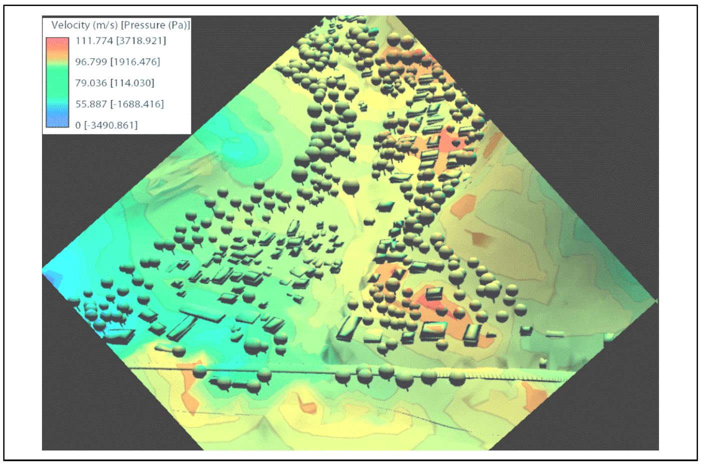

Fig. 3. The Digital Twin of Coulibistrie village, with overlain results of Computational Fluid Dynamic analysis of wind: velocity and pressure are lowest in the blue zones and highest in the red zones.

Fig. 4 illustrates output from the Kassandra Decision Support System, applied to Coulibistrie, for the many factors evaluated within the Building Parameter. There are three components forming the Building Parameter: Geographical features, Physical features and Building Use. Within the Kassandra DSS interface and in the associated 3-D visualisation maps, colour-coding provides a qualitative summary of the scores (Green: good; Yellow/Brown: moderate; Red: poor).

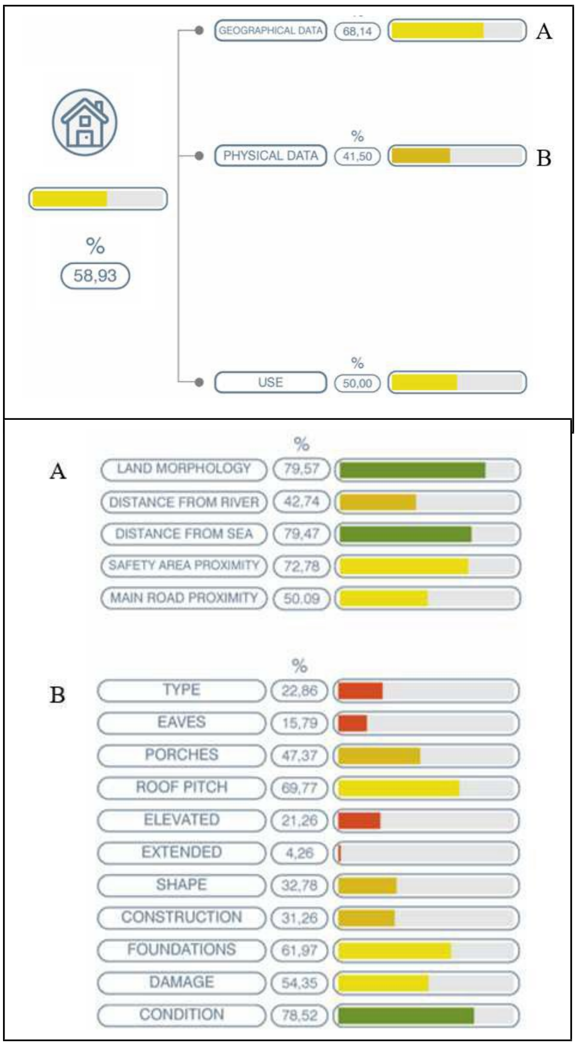

Fig. 4. Building Parameter output from the Kassandra DSS, applied to Coulibistrie. Top: scores for Geographical features (A), Physical features (B) and Use, each contributing to the Building Resilience Index score (58.93%); Bottom: scores for Geographical and Physical factors contributing to the Building Parameter: color-coding gives a qualitative summary of the scores: Green = good; Yellow/Brown = moderate; Red = poor.

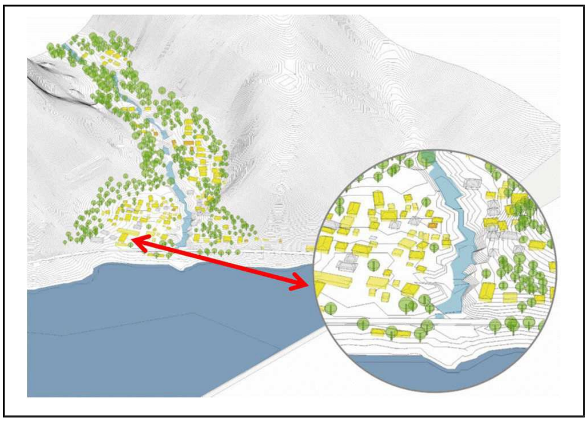

Fig. **5**. Digital Twin visualization of the Kassandra DSS scenario presented in Fig. 4; inset circle shows detail of the village near the main road and sea

III. DISCUSSION & CONCLUSIONS

This project has illustrated how DEMs at various scales can be used to produce hurricane preparedness maps to guide emergency managers with their contingency planning. This study illustrates that the freely-available ALOS PALSAR 12.5m-pixel DEM can be used for basic mapping of risk to transport infrastructure from flooding or landslides. Such maps highlight potential ‘pinch points’, enabling emergency planners to identify communities likely to be cut-off from humanitarian response during hurricane events, guiding disaster mitigation measures. This methodology is particularly useful for emergency planning and disaster preparedness mapping in countries or districts with limited financial resources and limited GIS expertise, as has been shown in the Solomon Islands [4], Fiji and Vanuatu [5].

If available, aerial LIDAR DEM data or drone photogrammetry data, with sub-meter pixels, can be used to produce Digital Twins of the buildings, road infrastructure and trees in communities. Such Digital Twins can then be

examined using computational fluid dynamic modelling to test the resilience of various building types and street layouts/ geometries to the extreme winds and air pressures. Particularly useful was modelling the proximity of large trees with regard to hurricanes (e.g. for wind shelter benefits, or for tree-fall hazard) and for assessing the cool shading that trees can provide during heatwave events.

There are cost barriers associated with the detailed mapping and modelling that the Kassandra DSS requires, but some of those costs can be reduced by using free software such as QGIS; or when creating the the Digital Twin, by replacing expensive aerial LiDAR data with relatively low- cost drone photogrammetry [2]. Despite the cost barriers with the Kassandra DSS, the numerous scenarios that it can test for both existing building types and street geometries, and for ‘what if’ scenarios with regard to extreme weather events, makes it a very powerful tool for informing decision makers and guiding policy for improved hurricane resilience.

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