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Identifying elements that affect the probability of buildings to suffer flooding in urban areas using Google Street View. A case study from Athens metropolitan area in Greece

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ABSTRACT

Even though numerous methods have been developed to predict the vulnerability of urban areas to flooding, there is still room for improvement in determining the susceptibility of individual buildings. This work aims to identify characteristics that affect a building's probability to suffer flooding and evaluate their influence. The study uses Google Street View to examine 1073 buildings known to have flooded after an extreme precipitation event in 2013 in Athens, Greece and to compare them with characteristics of buildings that did not experience flooding. Using logistic regression, this work investigates the influence of these elements. Results show that certain characteristics of buildings increase their probability to flood up to 4.1 times. The study develops an equation involving all influential elements able to predict the buildings that will suffer flooding on a 77% rate.

1. Introduction

Floods are one of the most destructive natural hazards, inducing extensive damages on a yearly basis [4,5] and posing a significant threat to human life [31]. In urban environments, flooding is usually more damaging as higher concentration of assets and population makes it more costly and difficult to manage. In addition, the complexity of urban environment and infrastructures (e.g. complex storm drainage systems, frequent changes in land use) hampers the prediction of locations that will suffer inundation and the degree to which intense precipitation will affect built structures. Especially, within the context of climate change, this problem is becoming more important, as the frequency of extreme precipitation phenomena are expected to increase [13].

Efforts to increase resilience, require identification of the elements of the built environment with the higher susceptibility to flooding (or propensity to experience harm [24,43,49]. Literature suggests that distinct building components can be critical to their susceptibility to flooding ([6,33,42]; Stephenson & D'Ayala 2014), including their design and the construction materials [24,43].

Previous works suggest a number of different building properties that are related to a building's propensity to experience damage from inundation such as.

- the construction material [42,52],
- the position of the building in relation to the ground level [42],
- the adjacency to other buildings [6],
- the elongatedness, the orientation to flow and other geometrical properties [6,27,37],
- the number of storeys [52],
- windows under ground level [22]
- the ground conditions [22]
- basements [22]
- the condition or state of repair [22]
- the age of buildings [22] as well as
- the presence of air-bricks, vents and ducts [27].

Although previous works describe the evaluation of inherent susceptibility of buildings based on their characteristics as crucial, it is suggested that data scarcity can hinder the application of loss or vulnerability models [6]. Newly introduced web-based virtual reality technologies can be used as a tool to monitor, visualize, map and examine urban environments [18]. Amongst these applications, Google Street View (hereafter GSV) is a free-license online application (maps.google.com) storing images captured by cars driven

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along the road network [1]. The imagery provides street-level views captured at specific locations where the user can navigate along a street and change the viewing aspect by rotating the view, as well as zoom in and out. GSV was introduced in limited cities around the world in 2007 and has since then extended to a large part of the global road networks.

Regardless its relatively recent launch, GSV has been used for a number of applications, mainly as an alternative source for data collection. GSV has been proved to be a competent tool for a virtual inspection of urban environments for a variety of purposes [2,10,41,47,54]. Carrasco-Hernandez et al. [9] used GSV imagery to reconstruct buildings and neighbourhood geometries as well as to estimate street level irradiance. Hanson et al. [26] used GSV to audit a variety of pedestrian and road infrastructure features and to analyse how they affect the severity of pedestrian accidents. Curtis et al. [11] used GSV to capture the recovery of New Orleans neighbourhoods after Katrina disaster, whereas Guo [25] exploited it to identify different parking types in New York City region. Odgers et al. [44] used GSV imagery for systematic social observations of neighbourhoods and linked them with effects on child health. Recently, GSV cars have used extra sensors to examine air quality and identify possible methane leaks [48].

This work uses GSV to examine the characteristics of buildings that experienced flooding during the 2013 event in Athens.

In the context of contributing to a more systematic knowledge of the specific intrinsic attributes of buildings that affect their physical susceptibility to flooding, this study aims:

(1) to examine the applicability of GSV as a tool to audit the relevant external characteristics of buildings that have suffered flooding
(2) to identify which of these characteristics affect the probability of buildings to suffer flooding and
(3) to explore the possibility to predict the outcome of a similar storm on a building based on the above characteristics.

This study approaches the problem by comparing buildings that experienced flooding with buildings that did not during a heavy rain event in Athens metropolitan area in February 2013.

2. Study area

Athens is the capital and the most extensive urban area in Greece. The city is situated in central Greece in the region of Attica. Athens is built in a morphologic basin that occupies an area of approximately 534 km^2 flanked by Penteli, Parnitha, Hymettus and Aigaleo mountains and Saronikos Gulf in the south (Fig. 1). Primarily, both Kifissos and Ilissos river networks shape the basin. Athens is a typical urban area in the Mediterranean area being relatively dry [39] with a mean annual rainfall of approximately 390 mm [34] and a poorly developed river network dominated by streams with small amounts of water for most of the year.

Since 1950 s, Athens has been a rapidly evolving urban centre, both in terms of population and spatial expansion leading to a gradual urbanization of a significant part of the basin [3,21,46,51]. Nowadays, approximately 68% of the basin is occupied by urban expanses and hosts about 4 million people [19].

The increased pressure for development has led to the expansion of human activities and infrastructure within the vicinity of Athens' ephemeral watercourses, in many cases in areas susceptible to floods. Studies of the temporal evolution of floods in the basin has shown a positive trend during the last century. Though immediate loss of life is not showing a respective increase [16] fatalities still remain an issue [12,14,15]. Flash flooding caused by high intensity rainfall is the most common type of flooding in the area, with high water velocities that cause extended effects and in some occasions erosion of building foundations that lead to structural damages.

The majority of buildings in Athens, as well as in the rest of the country, follows the Greek Building Codes (issued in five gradually stricter editions since 1959) that describe the basic principles and standards for construction. Based on these standards, the majority of structures have been constructed using reinforced concrete (87%), whereas a small percentage (7%) of buildings normally constructed earlier than 1950 s is made from masonry, stone or other materials [17,20]. Primarily, due to the significance of earthquake risk, buildings have been constructed on high standards and have shown an overall good structural endurance [36]. In fact even though, flash flooding is particularly common [16,45], structural damage or collapses of buildings due to flooding are very rare after 1980 s due to the structural integrity of buildings [14].

3. The flood event of 21st February 2013

On 21st February 2013 most of the western and north-western part of Greece was affected by a low barometric which moved northeast from the shores North Africa towards the south Ionian Sea. The system moved eastwards over Central Greece and eventually over Athens during the night of the same day. Increased transmission of perpendicular positive vortices and the atmospheric instability caused the activation of the cold front just after 4:00 a.m. on 22nd February [35].

After the first hour of the storm (shortly before 5:00 a.m.), cool air masses were confined to the lower atmospheric layers creating the conditions for strong upward movements that triggered more precipitation. The system was trapped over Athens basin for a prolonged period of time, leading to a re-feeding phenomenon and resulting in increased rainfall amounts [35]. Although precipitation was firstly recorded in the western part of the city, the system expanded eastwards relatively quickly, affecting the central and north-eastern parts of Athens basin. These phenomena were accompanied by greatly increased electrical activity, high winds and hail. Although there are variations in the intensity and rainfall accumulation across the basin, the storm recorded between approximately 45 and 113 mm in 6 h [40].

The flooding phenomena caused significant damage to properties and infrastructures, overturned or swept away numerous vehicles, flooded internally residences, commercial or industrial buildings and basements. In addition, inundation on the road network induced significant effects on vehicle circulation, including increased travel times and changes in routing [40] and caused the death of a vehicle occupant [12].

4. Data and methods

The main idea of the approach was to compare the characteristics of buildings that experienced internal flooding during the 2013 event, with buildings that did not, in order to understand which of their elements made a difference. To record these characteristics, the Street View service provided by Google was used to virtually visit and examine the buildings.

4.1. Data

Data on buildings that suffered flooding during the 2013 event were collected from the database of emergency calls, announcing flooded properties to the Greek Fire Service [23]. The information were in the form of a database within which each entry corresponded to one building, containing details on:

(1) the location (exact address) of the call
(2) the location (exact address) of the flooded building (including floor)
(3) the time of the call
(4) the nature of the incident and
(5) the action that was eventually taken by the Fire Service