Building extraction from remote sensing data for parameterising a building typology: a contribution to flood vulnerability assessment

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Abstract—**The analysis of flood impacts on buildings in large areas require both a building typology and a method to calculate its physical impacts. This paper focuses on the importance of extraction of building characteristics from remote sensing data in areas where the characterisation of the building structure is lacking. A comprehensive description of a number of building parameters which are necessary for deriving a building typology in the context of flood vulnerability assessment is given. This paper briefly summarises different methods for the extraction of those parameters from remote sensing and GIS analyses. Finally, the application of the extraction of the parameters on one set of data is shown, concluding some advantages of this approach for further analysis of flood damages.**

Keywords: building parameters, building extraction, building typology, building flood susceptibility.

I. INTRODUCTION

Buildings have been built close to rivers, seas, or reservoirs or even inside dried up river beds, where floods will occur sooner or later [1], causing negative consequences such as fatalities and injuries to people, negative physical impacts on buildings and infrastructure, and economic losses [2]. Assessment of flood impacts on buildings cannot be implemented worldwide due to a lack of the availability of detailed data or due to access restrictions to these data or due to the unfeasible extensive field surveys in some regions like large flood plain areas.

The implementation of approaches for flood impact assessment in developing countries is even more challenging, because there are areas with high population density, security problems, permanently dynamic, unplanned or uncontrolled urban development, where buildings have been built up at different periods, with heterogeneous structures, neither without any urban regulation, nor with any defined patterns in blocks or streets.

With this background, the paper first presents the challenges of flood impact assessment with a focus on buildings and then provides an overview of different available methods. Second, the paper shows a comprehensive analysis of a number of building parameters which may be involved in arranging a building typology in the context of flood vulnerability assessment. Third, some methods for acquiring these parameters from remote sensing data are listed based on literature review. Finally, the application of the extraction of the parameters on one sets of data is shown.

II. A CHALLENGE IN FLOOD IMPACT ASSESSMENT

Most frequently, institutions use questionnaires or forms for the assessment of damages after flood events, but the results of these surveys do not always cover a spatial reference for each building making difficult the analysis of the vulnerability and exposure.

Cadastral data in vector format are a good source to obtain geometric and legal building information such as boundaries of parcels, lot blocks, information about the ownership, building use, licenses, rights, restrictions, land value, purchase price, taxation, etc. In most cases, this information collected by terrestrial surveys requiring too much effort. Additionally, in many countries, cadastral data are not available or they are not accessible due to restriction policies in the cadastral agencies or local council. Another data source such as building footprints can be purchased from commercial map vendors, but their prices are not always affordable for risk management institutions. Land use maps could also support the analysis of impacts but normally they are rather specific for regions and countries or their scale of information is not sufficient.

The assessment of potential flood impacts on buildings must not be done one by one, because the survey would cost a fortune. Therefore a building typology is required in order to transfer knowledge from the assessment of in-depth investigations of individual buildings to other buildings with similar characteristics.

There are many approaches for building typologies, which have been applied in many different fields. For instance, the concept of urban structure types (UST) defined by Blum and Gruhler [3] as basic urban spatial units with morphological and functional homogenous character, demarcated by characteristic structures and development patterns of buildings, infrastructures and open spaces. However, the recognition of a spatial pattern system in some urban areas in developing countries in terms of block, street patterns and open areas is a complex task which may not be evaluated with a unique method. The combination of each component of UST may result many arrangements of urban types, which methods may not be always standardised, compared or transferred.

To overcome these obstacles, the analysis of remote sensing data seems to be the solution which allows the collection of building information with consistent quality and spatial reference. These data provide a much more flexible data set, capable of a comprehensive coverage at multi-spectral wavelengths, captured across multi-temporal intervals, and they are globally available at relatively low costs [4] in comparison to expensive field work.

However, the suitability of these data to support vulnerability assessment of buildings on large scales needs to be considered in more detail to identify methodological requirements and possible outcomes for the extraction of relevant building parameters for a flood vulnerability assessment. As a basis, the relevant parameters for the derivation of a building typology need to be determined.

III. Building Parameters for a Building Typology

From the comprehensive research underlying this paper, a number of parameters could be found which play a particular role in setting up building typologies in the context of flood vulnerability assessment. These parameters are:

- Building height
- Building size
- Building form
- Building roof structure
- Building topological relation to the neighbours
- Building topological relation to the open space.

To begin, *building height* is necessary for determining the building storeys and the position from the ground level of the building components such as stairs, furniture, appliances, windows doors, balconies, basements, etc. Building height defines the structure, design and functionality of a building in terms of foundations, system for vertical transportation of fluids, gases and solids, gravity systems, lateral load-resisting systems [5].

A further parameter is the *building size.* Size provides information on the amount of damage by multiplying the area of the building footprint times water height. Moreover, size configures the relations with the surrounding urban structure, the contribution to the external space, the internal architecture, the flexibility to accommodate a range of uses [6]. These building functions may be also affected if the building is impacted by a flood. The building size can better be described by its form, if the form in the space is square or rectangular, or if the architecture of a house is narrow or deep. The form of a building in the space can be calculated by the ratio of width and length, here called *elongatedness.*

One can think that *building roof* does not have any inference to the potential impacts caused by floods. But building roof defines indirectly the building structure and the building style in terms of interior volume, drainage, resistance to weather and resistance to water leakage [7]. The building roof structure can be described by the planimetric roof form and the roof pitch characteristics.

The function of the facades is to enclose and protect the contents within the building against the floodwater, which can enter through windows and doors exposed to the open space. Then, building fenestration can influence the exposure to hazards and its accessibility. The amount of sides that are designed for fenestration is associated with the position of the building with its neighbours which can be determined by the building *adjacency.*

Moreover, the relation of a building to its open space, where the flood water can circulate (flow), can be determined by its *compactness*. Here, compactness is defined as the relation of a building with its context. Compactness assists in determining as well as other aspects such as agglomeration between buildings, contact with the open space and flexibility to perform certain activities or uses outside of the building.

IV. Building Parameters from Remote Sensing Data

Some methods for acquiring these parameters from remote sensing data are described as follows.

Building height defined here as the delta Z value from the ground to the top of the roof of a building and it is calculated by the difference between the street level and the highest point of the building, and it can be obtained from radar data e.g.: [8]; from stereo or multi-stereo images e.g.: [9][10]; from 3D surface data e.g.: [11]; from single images e.g.: [12].

For *building size, elongatedness, planimetric roof form* and the topological relation of the building to the neighbours (*adjacency*) and the topological relation of the building to the open space (*compactness*) the building outline is required, which can be acquired from aerial images e.g.: [13]; from space borne sensors, e.g.: [14]; from radar data, e.g.: [15]; or from airborne laser scanner e.g.: [16].

In general, building outline extraction requires a series of steps in order to ensure the expected accuracy, beginning with the data preparation, then identifying the semantic cues of the buildings, reducing the points of the polygons, converting the raster in vector format and finalising with the calculation the geometric characteristics.

Here, the semantic cues of buildings located on flood plain areas are defined as:

- Buildings have different spectral characteristics than vegetation.
- Floodplains are quite flat. It implies that the height variation of the terrain is very low almost constant.
- Buildings are elevated.

- A building has a homogeneous roof texture or a defined pattern.

Based on the general cues of buildings located on flood plain areas a tool has been developed in order to generate a semi-automatic process of building outline extraction. The semi-automatic process involves initial threshold parameters of vegetation and the ground height. Then, further segmentation processes, morphological filters and post-processing tasks may be carried out for cleaning the misclassification between trees, shadows and impervious surfaces for groups of buildings with similar characteristics.

The roof structure may be extracted from the following methods, from stereo images e.g.: [17], or from airborne laser scanner e.g.: [18].

The methods available in the literature demonstrate that the higher the spatial resolution of data of the surface models is, the more accurate the building features can be extracted, as well as, different levels of products can be derived. The height data can be a very informative criterion to discriminate between buildings, roof structures, and edges of roof boundaries, and differentiate the building from streets, vegetation and other impervious surfaces.

Besides the methods and the data sources chosen for the extraction of the building parameters, other aspects must be taken into account, such as data quality [19], data processing level [20], accuracy calculation [21], level of automation [22], object representation [23], and that the final results fulfil the implementation for flood impact assessments.

V. RESULTS

A set of data from a sector located in the flood plain of the Magdalena River in Colombia "La Peña" is here analysed, a town with 285 buildings. The input data comprises a pair of stereo image of the UltaCam sensor, with 15 cm of ground sample distance GSD. For this set of data an orthophoto and a digital surface model were generated using photogrammetric techniques.

The building extraction process was processed using the general cues of building in flood plain defined above with exception of the roof texture which present patches of corrosion (Figure 1). At this step 211 buildings (74%) were detected. Small houses with an area less than 50 m² were not detected due mainly to occlusion by trees.

(a) (b)

Figure 1 (a) Separating building from trees and (b) separating buildings based on elevation.

The index selected for the verification of accuracy of the extraction of <u>building outlines</u> was the root mean square error (RMSE) [21]. Only polygons with RMSE values under 3 m were accepted. Figure 2 depicts two polygons with the calculation of the RMSE. In this step just 178 buildings fit the criterion of accuracy. Here, the index helps us to improve the identification of cues for the application of morphological and spatial filters such as simplification.

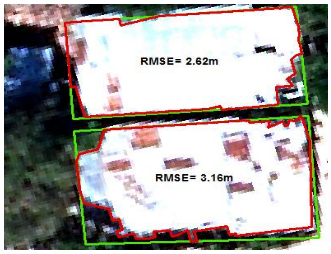

Figure 2. RMSE results of two buildings in this study area.

From the <u>building outline</u> the following parameters were derived: *building size, building elongatedness, building roof form, building adjacency and building compactness* using a python script. The planimetric roof form is calculated counting the vertices of the polygon and defining categories according to its form complexity. Adjacency is calculated by the amount of a neighbour's building- polygons in 1^{st} and 2^{nd} order. Compactness is calculated using a radial method which consists in determining the percentage of open space around the building.

The *building height* was calculated for the first set of data assuming a constant terrain height due to the fact that flood plains are quite flat and the height variation of the terrain is very low. The *building roof pitch* was calculated generating the slope in degree from the DSM and taking the majority of the values of the slope for each polygon.

The values calculated for the seven parameters were classified based on systemic keys of the building characteristics and the support of civil engineers, deriving a *building typology*. For each class a code was assigned helping to find similarities between building characteristics.

Figure 3 shows the code of seven digits for each building. For instance, the code 1111111 describes as a single building (1^{st} digit: *adjacency*); open space around the building larger than 80% (2^{nd} digit: *compactness*); size less than 100 m^2 (3^{rd} digit: *size*); a storey building (4^{th} digit: *height*); square form in the space (5^{th} digit: *elongatedness*); very simple form (6^{th} digit: *roof form*) and flat roof (7^{th} digit: *roof pitch*).

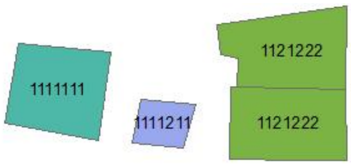

Figure 3 Building typology

After the calculation of the building typology, two representative buildings for each building typology were selected for a detailed building susceptibility analysis in the field. Building susceptibility is determined by its structural design, intrinsic properties and the material used [24]. Then, the building susceptibility analysis was transferred to the buildings with the same building typology. Afterwards, this analysis can be mapped in combination with a flood scenario. Figure 4 shows the map of susceptibility for building typology for a flood scenario in the settlement "La Peña, Colombia" with 285 buildings.

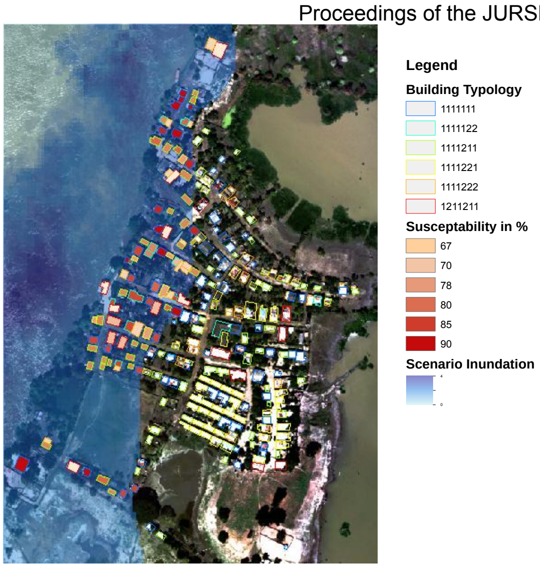

Figure 4 Map of building flood susceptibility in (%)

VI. CONCLUSIONS

Although there is still a huge challenge in terms of data resolution and techniques in remote sensing for achieving acceptable accuracy for building extraction on small buildings; the importance of building extraction for the analysis of the flood impacts in areas with lack of information about the building structure was demonstrated.

Seven building parameters which have a stronger relation to the potential flood impact were described. These parameters arrange a building typology which can serve as an instrument for transmitting further analysis of flood impacts and for supporting field surveys in large river floodplain regions.

Building height, building outline and building roof structure can be derived from a huge variety of methods and data sources. However, the most important criteria are the spatial resolution of the surface models and the indexes for measuring the accuracy are consistent. Otherwise the results for a building typology may be not automatically applied.

Overall, spatial data appeared to be a good means for analysing relevant building parameters for a building typology for flood vulnerability assessment. The latter can provide a first screening of the building stock before more detailed damage models are used such as e.g. HAZUS[25], HOWAD [25] or FLEMOps [26].

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