

Metrics to Rank Illegal Buildings

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Abstract. The problem of illegal buildings (IBs) is becoming dramatic in developing countries due to the population explosion, but, at the same time, it is still an unsolved issue also in several states usually called *advanced* (e.g., Italy). To protect the environment and, hence, people, authorities must respond to the challenge of IBs by demolishing them. However, in countries where the phenomenon is extended, it is indispensable provide land managers with IT tools that guide them in defining an order of intervention towards demolition. Through remote sensing methods, we can identify suspicious buildings with a good approximation, but they are all ex-aequo. The research described in this work proposes three *metrics* to rank the IBs located close to rivers. The ranking may be used as the IBs demolition order.

Keywords: Illegal building · Flood · Metric · Exposure · Ranking

1 Introduction

Italy is the country of contradictions. Magical and populous cities are located close to important rivers. Florence is a well-known example. It is crossed by the Arno river. In November 1966, Florence was overwhelmed by a violent flood. The balance: 17 victims, enormous damage to the city and its artistic heritage (Fig. 1).

Thousands of volumes, including precious manuscripts or rare printed works, were covered with mud in the Central National Library's. One of the most important pictorial works of all time, the Crucifix of Cimabue (preserved in the Basilica of Santa Croce) despite restoration, is lost up to 80%. Countless were the damages to the Uffizi.

To prevent the recurrence of mournings caused by events such as the one just mentioned, in Italy laws have been promulgated such as the Decree Law n.42 of January 2004. The art.142, of this DL, fixes in 150 m the width of the so-called *Band of Respect (BofR)* around rivers, that is the band of land where is forbidden to build. The prohibition applies to both sides of rivers and obviously concerns new constructions.

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Fig. 1. Two images about the flood of Florence (1966).

The ongoing research summarized in this paper proposes metrics on which to base the creation of a GIS software easy to be used by public administrations to combat the scourge of IBs that particularly afflicts developing countries, but which does not spare countries like Italy where this problem extends to all its regions. The very recent report by LegAmbiente [1] provides a detailed picture of this bad custom of Italians. Fighting this phenomenon is important for:

- hinder the destruction of the landscape, the primary source of revenue for Italy thanks to tourism;
- to punish those who violate the law;
- protect people's lives. In 2018, different Italian regions (Liguria and Sicily above all) suffered very severe episodes with damage to buildings and many victims. For example, at the beginning of November 2018, the wave of bad weather caused a massacre in Sicily with at least 12 victims.

The present study pursues the following objectives: (a) takes a census of IBs in the BofR of rivers, (b) relates the unauthorized urbanization to the flood danger to which people living in those IBs are exposed. The scope of the present contribution is the brown area of Fig. 2.

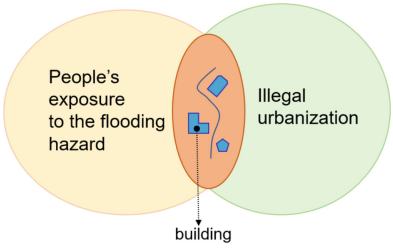

Fig. 2. The paper's scope (Color figure online)

The paper is structured as follows. Next section: (a) focuses on the relevance of the problem addressed by the research; (b) introduces definitions and notations that will be used throughout the paper; (c) formalizes the metrics

proposed to rank IBs; (d) introduces the reference software architecture on which we plan to implement those metrics and the tables of the underlying geographical database. Conclusions and a look to the future work end the paper.

2 Materials and Methods

2.1 Relevance of the Problem

Kundzewicz et al. [10] pointed out that in the near future in Europe the risk of flooding will increase. To limit the mourning events caused by this danger it will be fundamental: (a) to make urban planning that takes into account this increased danger – a suggestion that has also emerged from other studies (e.g., [8]); (b) to increase the severity of intervention against building abuses, in particular to discourage buildings in river basins. Below, we focus on points (a) and (b), in sequence.

Many published studies have investigated the impact of urbanization on flood events (e.g., [2,3,7,8,11–13]). According to the findings in the study by Agbola et al. [2], besides prolonged rainfalls and river overflows, there are *anthropogenic factors* of flooding. Uncontrolled building construction is a relevant factor because such constructions obstruct the free flow of water (and, as a consequence, they are at high risk of being flooded). Reporting about the 26 August 2011 flood in Ibadan (Nigeria), Agbola et al. [2] say that in the city there were 600 buildings close to the riverbanks.

The remainder of this section focuses on the phenomenon of IBs. In recent decades, municipalities and governments in all parts of the world are struggling against IBs. The problem of IBs is becoming dramatic in developing countries due to the population explosion, but, unfortunately, it is still an unsolved issue also in States usually called *advanced* (as Italy).

In 2007, LegAmbiente, an Italian non-Governmental Organization, published the results of a nation-wide study [5]. In the report, it is mentioned that 402,676 IBs were built in Italy from 1994 to 2003. In 2018, LegAmbiente, published the results of another study [1]. The data refer to the registered violations (i.e., the infringements for which a demolition sentence was issued) in *all* the Italian regions. The report covers the period 2005 - (June) 2018. In 2004 in Italy there was the last building amnesty. The total number of registered infringements is 57,432. A big value. Obviously the figures of the actual violations are greater the official ones.

So far, several methods have been proposed for automatic building detection from high-resolution remote sensing images [4,15,16]. Moreover, there are few papers specifically focused on IBs detection (e.g., [9,14,17,18]) Soon, most of them will be available as plug-in of GIS software on the marketplace. Hence, this is the easiest and fastest way to produce cyclically up-to-date datasets about the study area of interest to keep updated also the underlying geographic database.

Today, many urban planning departments all over the world use IT software systems to detect illegal buildings; for example Yang et al. [17] describe the architecture of one of them. A relevant part of those systems is the spatial

database storing city maps in the vector data format. Our proposal can also be seen as an extension of those systems, since it operates on data stored into the spatial DB.

In order to protect the environment and, hence, people, authorities must respond to the challenge of IBs by demolishing them. However, where the phenomenon of construction against the law is extended, it is essential to help land manager with IT tools that guide them in prioritizing demolitions. Using the remote sensing methods just mentioned, we arrive at the identification of the suspicious buildings with a good approximation (even if rarely with 100% accuracy), but all them remain ex-aequo. Returning to the land managers the ranking of IBs overcomes this shortcoming.

2.2 Notations

Hereinafter we use the following notations:

GeoArea is the portion of land of interest for the study, (e.g., a municipality, a region, or a state). *GeoArea* is defined as the pair ⟨*description*, *geometry of the boundary of GeoArea*⟩, where *description* is a string.

$\mathcal{C} = c_g(g = 1, 2, ..., card(\mathcal{C}))$ where c_g is a contour line, that is a curve whose points have the same elevation with respect to the sea level. A generic contour line is defined as the tuple ⟨*ID*, *elevation*, *geometry*⟩.

$\mathcal{R}(Rivers) = r_k(k = 1, ..., card(\mathcal{R}))|r_k$ is a *river* that crosses the *GeoArea*}. The generic river is described by the tuple ⟨*ID*, *name*, *geometry*⟩. $RiverBuffer(r_j)$ denotes the buffer around river r_j, of width m.

$\mathcal{B} = b_i(i = 1, 2, ..., card(\mathcal{B}))$ where b_i denotes a building in the *GeoArea*. Each building in $\mathcal{B}$ is defined by the tuple ⟨*ID*, *name*, *position*, *geom*, *elevation*, exp_i⟩, being ID an identifying code, *position* the geographic coordinates of the centroid of b_i, and *elevation* the value of the building's higt. exp_i is a positive numeric value denoting the degree of (spatial) exposure of b_i to the flood hazard. Next sub-section introduces three alternative metrics to compute the value of parameter exp_i. $BuildingBuffer(b_i)$ denotes a circular area centered on building b_i. Hereinafter, this geometry is used as a surrogate of the building footprint (parameter *geom*) that it is not necessarily available for any *GeoArea* in the world. The concepts introduced are general, therefore it is trivial to adapt the equations to the lucky case where the *geom* of buildings is made available.

2.3 Metrics

Figure 3 shows six different geometric configurations of a generic building (b_i), described by its centroid (the purple dot) and its buffer (radious of 25 m), and a generic river, described by the line (blue) and its buffer (width of 150 m). Moving from right to left, the six cases show the geometric configurations that give rise to IBs, with a violation that becomes gradually more severe.

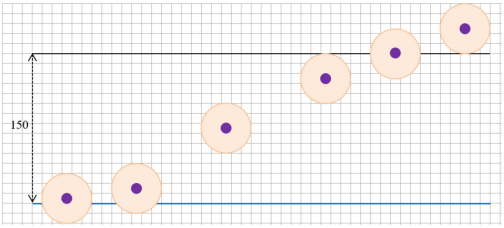

Fig. 3. The seven geometric configurations of IBs (Color figure online)

In the following, first, it is shown *how* to detect IBs inside the *GeoArea*, (that is buildings that intersect the *BofR* of some river); then, three metrics are introduced. The metrics allow to rank the severity of the violations according to different criteria.

Step 1: Census of IBs. The buildings (b_i) that violate the law are those for which it happens that there is a non-zero intersection between $BuildingBuffer(b_i)$ and $RiverBuffer(r_j)$.

Step 2: Ranking of IBs. The (dimensionless) parameter P (Eq. 1) measures the extent of the penetration of building b_i (modeled by its buffer) into the *BofR* of the generic river, whose width is established by the law. $P = 0$ denotes the absence of violation, while any other value of P in the range (0,1] denotes the opposite; therefore, the IB "at hand" is to be added to the list of those to be demolished.

$$P = \frac{Area(BuildingBuffer(b_i) \cap RiverBuffer(r_j))}{Area(BuildingBuffer(b_i))} \tag{1}$$

The three metrics attribute to each IB a value that measures their degree of exposure at the risk of flooding, following prolonged periods of rain. For this reason it is correct to state that the such metrics pursue the purpose of suggesting to land managers the priority of demolition in order to prevent, hopefully, casualties. In the following the letter S denotes the score attributed to the generic IB (b_i). S takes decimal values greater than zero. S corresponds to the exp_i parameter of Sect. 2.2

Metric S1 (Eq. 2)
Geography teaches that rivers can have tributaries. For buildings that are near the points where two waterways merge, it can happen that their geometry overlaps the *BofR* of both waterways. Therefore, for the same building we can have more values for P. Metric $S1$ is defined as in Eq. 2.

$$S1 = max\{P_k\}, \text{for } k \in [1, 2, ..., n] \tag{2}$$

being n the number of intersections building-rivers.

Metric S2 (Eq. 3)
The value of metric $S2$ is given by Eq. 3, where d denotes the Euclidean distance between the boundary of the building (or the $BuildingBuffer(b_i)$, when the geometry of b_i is not known) and the geometry that models the river.

$$S2 = max\{P_k/d_k\}, \text{for } k \in [1, 2, ..., n] \tag{3}$$

Table 1 shows the value of metric $S2$ for the configurations of Fig. 3 (moving from left to right). If d is less than 1m, then d is set to 1 to avoid *division by zero*.

Table 1. Values of metric $S2$

P	1	1	1	1	0.5	0
d	0..1	10	50	100	125	150
$S2$	1	0.1	0.02	0.01	0.004	0

The values in Table 1 show that $S2$ fluctuates from the maximum value 1 (if $0 \leq d \leq 1$) to the minimum value 0 (if $d = 150$, that is, if the buffer of b_i touches, from the outside, the boundary of the river buffer).

Metric S3 (Eq. 5)
Metric $S2$ is simple to understand and to calculate, but it has a fragility: it ignores the territory elevation inside the *GeoArea*. $S3$ overcomes this limit. Figure 4 shows four different configurations of hypothetical IBs, in pairs of two. In each couple, what changes is the relative altimetric position between the building and the river. Below, we comment the two pairs of geometric scenes, in sequence.

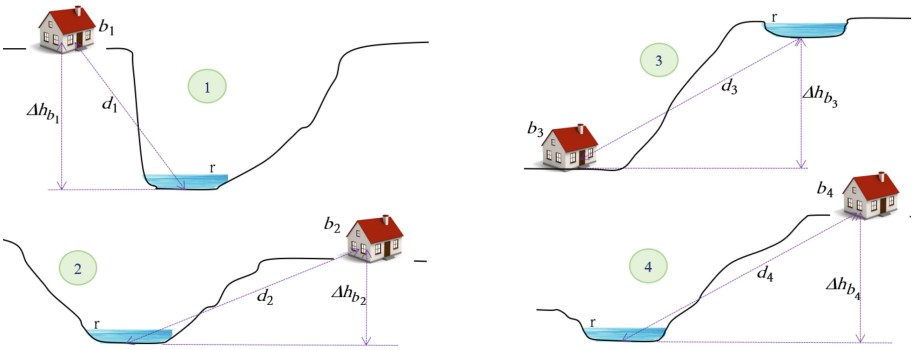

Fig. 4. Four IBs

Figure 4 (*left*) – Buildings b_1 and b_2 satisfy the following: $d_1 < d_2$ (their Euclidean distance from the river bed), while $\Delta h_{b_2} < \Delta h_{b_1}$ (the elevation difference, in meters, above the sea level, between the centroid of building b_i and the geometry of the river bed, at the point of minimum distance between those two geometries).[1] With respect to the flood risk due to the river (r_j), building b_2 is more exposed than b_1 as the barrier separating it from the river is lower than the barrier separating b_1 from the river. Δh_{b_1} and Δh_{b_2} are both positive.

Figure 4 (*right*) – Buildings b_3 and b_4 satisfy the following: the values of d_3 and d_4 and the values of Δh_{b_3} and Δh_{b_4} are comparable. The values of d_1 and d_4 are comparable too, while $\Delta h_{b_3} < \Delta h_{b_1}$. With respect to the flood risk due to the river (r_j), building b_3 is more exposed than b_4 since does not exist any protective barrier in case of river flooding, unlike what is observed for building b_4. Finally, Δh_{b_3} and Δh_{b_4} have a discordant sign; negative and positive, in order. In summary, the ranking that correctly reflects the degree of exposure to the flooding danger of the four IBs of Fig. 4 is: b_3, b_2, b_4, and b_1. Metric $S3$ (Eq. 5) returns the expected result, if applied to the configurations of Fig. 4.

$$S_3 = max\left\{\frac{P_k \times H_k}{d_k}\right\},\ k \in [1, 2, ..., n] \tag{5}$$

where

$$H_k = \begin{cases} |\Delta h_{b_i}|\ , \text{ if } \Delta h_{b_i} < 0 \\ 1/\Delta h_{b_i}\ , \text{ if } \Delta h_{b_i} > 0. \end{cases} \tag{6}$$

Equation 5 corrects the values of metric $S2$ by taking into account the height difference between the centroid of building b_i and the geometry of the river bed, at the point of minimum distance between the two geometries. In fact, Eq. 5 amplifies the value of metric $S2$ when the IB is located below the river, while reducing it in the opposite case. For the remaining case, the value of $S3$ is identical to that of $S2$. The final effect on the ranking is that the buildings below the level of the river raise towards the "top" positions, while the buildings above the level of the river slide in the "queue".

2.4 A GIS Technological Setting for the Implementation of the Proposal

Figure 5 shows the reference software architecture to implement the method summarized in the previous section. The architecture can be interpreted at two different levels: one *abstract*, the other *concrete*. The abstract level highlights

[1] The elevation of point Q is its height above the sea level; while the elevation variation of building b_i (described by its centroid) with respect to a river (described by the point, belonging to the river geometry, most close to b_i) is the value, taken with sign, of the difference given by the equation:

$$\Delta h_{b_i} = h_{b_i} - h_{r_j}. \tag{4}$$

the basic element of the solution, namely the *Spatial DataBase Management System* (SDBMS). It is on top of a *Geographic DataBase* (Geo-DB) where to store the input data of the problem as well as the ranking about the IBs in the *GeoArea*. The concrete level, vice versa, details a software technology that might be chosen, i.e., PostgreSQL/PostGIS.

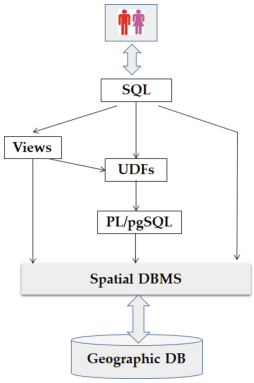

Fig. 5. The proposed reference software architecture

Table 2 shows the mapping of the theoretical concepts into database entities.

The four tables of the Geo-DB are shown below. The underlined attribute denotes, as usual, the *primary key* of the table it belongs to. Columns `P`, `S1`, `S2` and `S3` store the value of the exp_i parameter (Sect. 2.2).

- `GeoArea(id, geom)`
- `ContourLines(id, elevation, geom)`
- `Rivers(id, name, geom)`
- `Buildings(id, name, centroid, geom, elevation, P, S1, S2, S3)`.

Within the setting of Fig. 5 the computation of the proposed metrics takes place by writing SQL spatial queries. To keep the queries easy, it is helpful to make recourse to *views* and PL/pgSQL *User Defined Functions* (Fig. 5).

Table 2. Entity mapping

Definition	Entity
GeoArea	`GeoArea`
$\mathcal{C}$	`ContourLines`
$\mathcal{R}$	`Rivers`
Buildings	`Buildings`

3 Discussion and Future Work

This paper formalised the main ideas of an ongoing research was final goal is to implement a software that fed with datasets about the *GeoArea*, the contour lines of the territory delimited by the *GeoArea*, the rivers crossing the *GeoArea*, and the buildings in the *GeoArea*, outputs the IBs (if any) as a ranked list. State government and local stakeholders fighting against the infringement of the urbanization planning rules are looking for an IT tool like this because it offers to them a numerical criteria on which a demolition strategy might be based. In countries like Italy the demolition of IBs is the unique way to discourage future infringements of the law.

Metric $S3$ can be used either alone or as part of a set of criteria selected for computing a "robust" ranking about IBs to be demolished, in the well-known general framework of "multicriteria problems". A similar approach has been adopted, recently, by Forte et al. [6]. Their proposal was inspired by a preliminary version of the DDL S.580-B (Disposizioni in materia di criteri per l'esecuzione di procedure di demolizione di manufatti abusivi) approved by the Italian Parliament on March 2018.

Unauthorized building is a rapid phenomenon. There are many cases of dwellings built in a few days. It is, therefore, unrealistic to assume that there are up to date data available from institutional sites. But, because the IT tool we plan to develop becomes really effective, it is necessary that the set $\mathcal{B}$ is updated frequently (let say every three months). A way of obtaining updated data about land use consists of the following steps: (a) acquisition of satellite raster data; (b) their processing through some of the known methods for automatic building detection (of high-resolution remote sensing images); (c) transformation of the raster into a vector (the set $\mathcal{B}$) by using a GIS software (for instance, QGIS). Use this dataset to update the *buildings* table of the Geo-DB. It is also opportune stimulate the citizen participatory sensing (by means of awareness campaigns) to report suspicious cases via social media (Twitter on all).

The future work will take place in four steps: (a) creation of the Geo-DB of Sect. 2.4 and tables loading with the input data of the problem; (b) implementation of the proposed metrics, as SQL queries; (c) sperimentation of the method on a case study concerning the Abruzzo region (Centre of Italy); (d) validation of the results through checks on the field.

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