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Integration of Spatial and Descriptive Information to Solve the Urban Waste Accumulation Problem

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Abstract

The paper presents a general method to determine the location of garbage accumulation points on urban territories and sizing the number of bins. The position is set by taking into account the distance from the house of the citizens, while the number of bins is adequate to the amount of waste produced "locally". The solution is reached by integrating spatial and descriptive information.
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1. Introduction

"Managing solid waste (SW) well and affordably is one of the key challenges of the 21st century, and one of the key responsibilities of a city government" (UN-HABITAT, 2010). There are two major types of urban SW: residential and commercial. Households are the highest producers of domestic waste (EEA, 2013). Damghani et al. (2008) report that in Tehran, the capital city of Iran, the contribution of the household SW to the total municipal SW is around 62.5%. A similar estimation about the Americans' production of residential SW is reported in (US EPA, 2010).

Data show that municipal SW generation in the EU-27 has been stabilizing around 1.4 kg/capita per day since 2000 (EEA, 2013), similarly in the USA the SW generation per person per day in the period 1990-2010 kept

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substantially constant and equal to about 2 kg. These values give rise to a mountain of SW. For instance, in 2010, Americans generated about 250 million tons of trash (US EPA, 2010). Unfortunately, these values are intended to raise because of the rapid population growth.

The accumulation of the household SW is the first step in the chain of the municipal SW management. In Italy, at the present days, SW is accumulated using two complementary methods. From many years, the municipalities have spread on the major crossroads of the towns large-sized garbage bins (GBs). Daily, households put their SW in these containers, while cyclically municipality-owned machines take away the SW from the public containers. A more recent method consists in providing families with smaller GBs and the municipal workers collect the garbage door-to-door. In Italy, so far, the first method covers the largest waste disposal production. That is why the present study refers to such a scenario.

From the citizens' point of view, SW accumulation and collection are among the most visible urban services. If properly implemented, they contribute:

- to keep modern towns clean;
- to develop the culture of urban cleanliness;
- to protect municipal workers dealing with the collection and transportation of infectious waste materials (like syringes disposed from private homes in the same garbage bins storing common litter), (Miyazaki et al., 2007);
- to protect the health of pets (they regularly visit GBs looking for food residues, with the tangible risk of getting sick) and, therefore, they contribute to protect the health of residents;
- to keep high the market value of the apartments in the area;
- to get high residents' satisfaction. In fact, the effectiveness of garbage accumulation and collection is a variable largely used in studies that investigate the satisfaction of individuals living in the urban areas, e.g., (Felix & Garcia-Vega, 2012).

Unfortunately, as remarked for instance in (Parrot et al., 2009), the situation we are witnessing is quite different from what we might wish, in the sense that the spatial distribution of the garbage accumulation points (GAPs) inside towns often does not take the needs of all local residents into account in terms of quantities of waste produced and distance from their dwelling. The induced two side effects are, in sequence, that often the GBs are full and in those cases the citizens decision is to leave the bag of garbage outside of the GBs. While, the distance between houses and GBs turns out to be the primary factor, which affects citizens' waste disposal behavior. Parrot et al. (2009) found that when the average distance to the closest GB is long, there is generally a low percentage (37.4) of people who dump their waste in them. The long distance explains why households dispose domestic waste in open areas. Similar concerns about the not convenient location of the GAPs are expressed by Zia & Devadas (2008).

The objective of our study is to present a general method to come to a location of GAPs on the urban territory more rational with respect to the distance from the house of the citizens; moreover the application of the method makes it possible to adapt the number of bins in each GAP to the amount of waste produced "locally". The intention is to avoid both the drawbacks mentioned above. The solution given in this paper strictly refers to residential SW accumulation, but it can be easily adapted to the other two types (namely, commercial and industrial SW).

The remainder of the paper is structured as follows. Sec. 2 defines the residential SW accumulation problem inside modern towns, while Sec. 3, the kernel of the present contribution, focuses on two algorithms that together provide a general solution of the problem. Sec. 4 closes the paper.

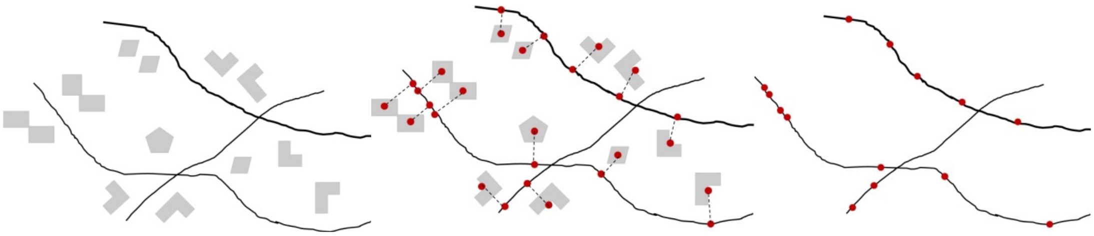
2. The solid waste accumulation problem

The SW accumulation problem (SWAP) inside modern towns can be formulated as follows: given the set of houses and public roads (*spatial information*) being part of an urban area (Fig.1a), the goal is to compute the location of the GAPs on the area as well as sizing their number of bins. Further relevant data of the problem (they all together give rise to the *descriptive information*) relate to the type of waste to be stored in the GAPs, the capacity of the GBs, the frequency of emptying of the GBs of the various types, the number of inhabitants in each house of the area to be served, and their per capita daily production of SW.

For long time the scientific community has ignored the SWAP. The few works that have studied this problem, starting from 2006, are mentioned in (Ghiani et al., 2012). They share the common objective of solving the problem of locating the GAPs on the urban territory to be served in order to: a) contain the initial cost for buying the GBs, b) reduce the overall collection time, and, finally c) limit the negative visual impact due to the presence of the GBs near by the residential buildings. The present paper is ideally linked to (Ghiani et al., 2012), with two major differences: in our work the accumulation/collection of the municipal SW is sorted, moreover, while they start from a given set of GAPs located at known position inside the city, in our approach the GAPs may be located at any point of the city roads and their number and position is the outcome of the elaboration of the method decided according to the "urban geography" of the dwellings to be served. Obviously, the problem of positioning and sizing the GAPs in urban areas is of primary interest to the municipalities but, to date, they are lacking in "robust" solutions because of the delay with which the scientific community has tackled the problem. In the meantime, what we can observe browsing the network is the proposal of miraculous solutions of this problem.

In our paper, the SWAP is solved under the following constraints:

- the GAPs have to be placed on public roads;
- every house must have at a distance (measured along the public roads) not greater than a predetermined value at least a GAP;
- the number of bins of the different types of waste in each GAP must be sized according to the potential daily production of household waste by the residents of the district, in order to prevent the saturation of the capacity of the GBs before they are emptied by the municipal workers.



(a) (b) (c)

Fig. 1. A scene of roads and houses (a); the original scene plus the centroid of each house and the projection of the centroid on the reference road (b); the roads and the projection of the centroids of the houses on the roads (c).

3. A strategy to solve the SWAP

Hereafter the following notations are used:

$\mathfrak{District}$ is the urban area to be served with GAPs,

$\mathcal{R}$ ={r_1, r_2, …, r_R} is the set of public roads crossing the $\mathfrak{District}$. The generic element of $\mathcal{R}$, r_j, is a triple <*id*, *name*, *the_geom*> whose values, in sequence, denote the unique identifier of the road, its name, and the geometry modeling its shape,

$\mathcal{H}$ ={h_1, h_2, …, h_H} is the set of houses located inside the $\mathfrak{District}$. By house we mean a building having a certain shape at ground. We do not care about the number of floors composing each building, while the number of people living in it is relevant. The generic element of $\mathcal{H}$, h_j, is defined by the tuple <*id*, *road_id*, *num*, *density*, *the_geom*, *the_geom_c*, *the_geom_h*> whose values, in sequence, denote the unique identifier of the house, the unique identifier of the reference public road (that is the road that specifies the building's address), the house number, the number of occupants the dwelling, the geometry of its layout (i.e., a polygon), the simplified geometry of the dwelling (i.e., the centroid of the polygon), the geometry of the projection of the centroid of the dwelling on the public road of reference. Fig.1b shows the geometry of the layout of the houses, their centroid and the projection of the centroid on the reference road. From here on, when talking about dwellings always it shall be deemed to refer to the projection of their centroid on the reference road, therefore, the scene of Fig. 1a is substituted by that of Fig.1c,

$\mathfrak{GB}$ ={gb_1, gb_2, …, gb_{GB}} is the set of the different types of GBs that are part of each GAP. In our study we take into account the following five types: *glass* (gb_1), *plastic* (gb_2), *paper* (gb_3), *organic* (gb_4), and *unsorted* (gb_5), but the solution method is general, so it can be easily adapted to work under different assumptions. The generic element of $\mathfrak{GB}$, gb_j, is defined by the tuple <*id*, *type*, *capacity, collection*> whose values, in sequence, denote the unique identifier of the GB, its type, its capacity (m^3), and the frequency of collection (days) from municipality's workers. For example, the tuple <1, glass, 1.8, 7> specifies that the GB of type glass has id 1, capacity 1.8 m^3, and weekly frequency of collection,

$\mathfrak{GAP}$ ={gap_1, gap_2, …, gap_{GAP}} is the set of GAPs to be dislocated in the $\mathfrak{D}$istrict. The generic element of $\mathfrak{GAP}$, gap_j, is defined by the tuple <*id*, *the_geom*, *road_id*, *glass*, *plastic*, *paper*, *organic*, *unsorted*, *rs, hs*> whose values, in sequence, denote the unique identifier of the GAP, its coordinates, the id of the public road where gap_j is located, the number of GBs for glass, plastic, paper, organic, and unsorted, and, lastly, the total number of residents and houses that the GAP is able to serve,

housesServedBy_aGAP[] is an array of sets data structure having a number of components equal to the cardinality of $\mathfrak{GAP}$. The component housesServedBy_aGAP[k] stores the (sets of) ids of the houses served by the GAP having id equal to *k*,

dailyGlass, *dailyPlastic*, *dailyPaper*, *dailyOrganic*, and *dailyUnsorted* denote, in sequence, the per capita daily generation (in m^3) of the five different types of SW we refer to in the paper,

distance: denotes the value of the maximum distance between each house and the closest GAP.

All identifiers are positive integers starting from one. Moreover, in the algorithms we are going to present we use, for brevity, the notation "*record_name.field_name*" of programming languages, linking a composite variable (*record*) to one of its parts (*field*). Therefore, h_j.*density* denotes the number of people leaving in dwelling h_j, and so on.

The solution of the SWAP is obtained in two stages via the algorithms *LocatingOfGAPs* and *SizingOfGAPs* to be invoked in sequence

Algorithm **LocatingOfGAPs**

Input: $\mathfrak{H}$, $\mathfrak{R}$, *distance*

Output: $\mathfrak{GAP}$ and housesServedBy_aGAP[]. The generic tuple of $\mathfrak{GAP}$ has value: <id, the_geom, road_id, NULL, NULL, NULL, NULL, NULL, NULL, NULL>

Method:

1. **Set** $\mathfrak{GAP}$ to the empty set
2. **Set** each component of array housesServedBy_aGAP[] to the empty set
3. **Copy** $\mathfrak{H}$ in Hcopy
4. **FOR EACH** *r* in $\mathfrak{R}$
5. Let H_r be the set of houses in Hcopy having *r* as the reference road
6. **DO**
7. Let *h_first* be the house in H_r closest to the beginning of *r*
8. Let *extremeRight* be the point on *r* away from *h_first* of the value 2**distance*
9. **IF** in the stretch of road *r* delimited by points *h_first* and *extremeRight* there is at least a second dwelling
10. **THEN**
11. Let *h_last* be the centroid of the house in H_r located between the points *h_first* and *extremeRight*, fulfilling the property of being the house nearest to *extremeRight*.
12. **Set** gap.the_geom to the position of the mid-point between points *h_first* and *h_last*.
13. **ELSE**
14. **Set** gap.the_geom to the position of the *h_first*.

15. Let gap.id be the id of the GAP identified. **Set** gap.road_id = r.id. **Set** to *NULL* the remaining values of the record about *gap*
16. **Add** *gap* to $\mathfrak{GAP}$
17. **Add** the ids of the houses in H_r located between *h_first* and *h_last* to the set housesServedBy_aGAP [gap.id]
18. **Remove** from Hcopy and H_r the dwellings located between *h_first* and *h_last* because they are served by *gap*
19. Let H* be the set of dwellings for which it is not true that the_geom_h falls on *r*, but anyway they are distant from gap.the_geom at most equal to *distance*
20. **Add** the ids of the houses in H* to the set housesServedBy_aGAP [gap.id]
21. **Remove** from Hcopy the dwellings in H*
22. **WHILE** there exist dwellings in H_r
23. **END FOR EACH**

Remarks about *LocatingOfGPAs*

LocatingOfGPAs takes as input the sets $\mathfrak{H}$ and $\mathfrak{R}$, and the value of *distance* and returns the set $\mathfrak{GAP}$ and the data structure housesServedBy_aGAP[] used to keep the algorithm *SizingOfGAPs* simple. H_r collects the houses having *r* as the reference road (Line 5). For those dwellings it happens that the point *the_geom_h* belongs to *r*. For example, Fig.2 assumes that there are eight houses having *r* as reference road. In the figure, h_j (j=1, ..., 8) is a shorthand of *the_geom_*h_j of the houses having *r* as reference road.

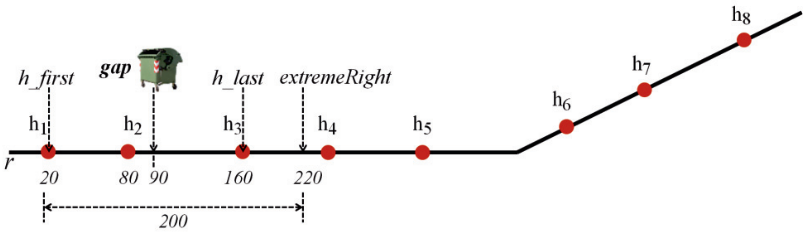
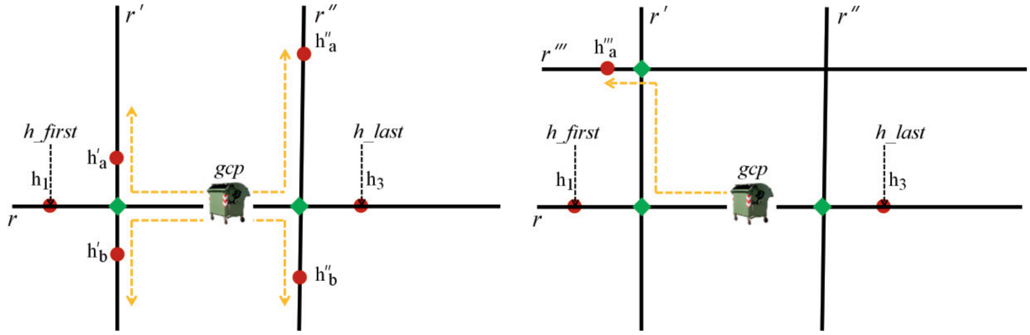


Fig. 2. Road r plus the (eight) houses having it as reference road.

The notion of first house (Line 7) on road *r* descends from the assumption of the existence of a travel direction on *r* that, hence, allows us to distinguish between the start and the end point of *r*. *h_first* denotes the house in H_r having *the_geom_h* closer to the beginning of *r*. *extremeRight* is the point on *r* away from *h_first* by a quantity equal to 2**distance* (Line 8). (Remember that the distances are calculated along the roads - Sec.2.) The IF-THEN-ELSE portion of the algorithm (Lines 12-14) sets the geographic position of the GAP (the first in the example of Fig.2). The computation is done by distinguishing two cases: besides *h_first* there is at least another house (*h_last*) along the stretch of road *r* before reaching *extremeRigh* or, alternatively, *h_first* is the only house in the stretch of road *r* delimited by the points *h_first* and *extremeRigh*. Line 12 (or alternatively Line 14) calculates the position of the first GAP (let us denote it as *gap*) on road *r*. While, Line 15 calculates its id, and, finally, associates *gap* to the road *r* assigning to the field *gap.road_id* the id of *r*. Fig.2 shows the location of *gap* (schematically represented by one of the GBs being part of it) under the assumption that *distance* is 100m. Line 16 adds element *gap* to $\mathfrak{GAP}$. The meaning of Line 18 is obvious. The purpose of Line 19 is to identify further houses (if any) that do not have *r* as reference road, but that can be served by *gap* since it is distant less than *distance* from those dwellings. There are two possible situations to be investigated.. The first one (Fig.3a) is that of houses that lie on roads that intersect *r* near to the point where is positioned *gap*. In the figure, *r* is intersected by roads *r*' and *r*'' at the points marked as (green) diamonds. By hypothesis, H*={h'_a, h'_b, h''_a, h''_b}, i.e., the dwellings h'_a, h'_b, h''_a and h''_b are considered to be served by the GAP *gap*. The second situation (Fig.3b) is that where the houses lie on roads different either from *r* o from the streets that intersect *r*. In Fig.3b, by hypothesis, house h'''_a, located on the road *r'''*, is distant less than *distance* from *gap* and, therefore, it can be served by such a GAP. In summary, $H^*=\{h'_a, h'_b, h''_a, h''_b, h'''_a\}$. The purpose of Lines 17 and 20 is to copy the ids of the dwellings served by the GAP *gap* in the set housesServedBy_aGAP[gap.id]. With regard to the examples of Fig.2 and Fig.3, we have that: housesServedBy_aGAP[gap.id] = $\{h_1, h_2, h_3, h'_a, h'_b, h''_a, h''_b, h'''_a\}$. This information will be exploited by algorithm *SizingOfGAPs*. If H_r is not empty (Line 22), then a new iteration will be started whose practical effect is the advance along *r*. In fact, at the new iteration (the second in the case of the example of Fig.2), the algorithm identifies (Line 7) the dwelling h_4 as *h_first*, since houses h_1, h_2, and h_3 have been removed from the set H_r. And so on. When H_r becomes empty, then the algorithm proceeds to consider a new road between those in ℛ.



(a) (b)

Fig. 3. Dwellings close to the GAP gap located on road r, but having as reference road one different from r.

Algorithm **SizingOfGAPs**

Input: ℋ, 𝒢ℬ, 𝒢𝒜𝒫, housesServedBy_aGAP[], *dailyGlass*, *dailyPlastic*, *dailyPaper*, *dailyOrganic*, and *dailyUnsorted*

Output: 𝒢𝒜𝒫 updated

Method:

1. **FOR EACH** *gap* in 𝒢𝒜𝒫
2. **Copy** housesServedBy_aGAP[*gap*] into HS
3. **Set** *gap.rs* equal to the sum of values h_j*.density* (j=1, 2, …, |HS|), where h_j belongs to HS
4. **Set** *gap.hs* to |HS|
5. **Compute** the number of different types of GBs that make up the GAP *gap* by taking into account:
   a) their capacity (i.e., *gb.capacity*),
   b) the daily per capita generation of SW of the different typologies from the *gap.rs* residents, and
   c) the periodicity of waste collection of the different typologies (i.e., *gb.collection*)
6. **UPDATE** the fields *glass*, *plastic*, *paper*, *organic*, *unsorted* of *gap*
7. **END FOR EACH**

Remarks about *SizingOfGAPs*

SizingOfGAPs completes the job of the previous algorithm by updating the values of the records of the set 𝒢𝒜𝒫 relatively to the fields left to **`NULL`** by *LocatingOfGPAs*. The algorithm repeats for each GAP in 𝒢𝒜𝒫 the following steps. Let *gap* be the generic GAP. Initially the content of the set housesServedBy_aGAP[gap], i.e., all the dwellings served by *gap*, is copied into the variable HS (*HouseServed*). Then (Line 3), it is calculated the total number of citizens that *gap* can serve by adding the number of inhabitants in each of the houses present in HS. Line 4 set the field gap.hs to the value of the number of houses served by *gap*. The next step (Line 5) computes the number of GBs of the five types took into account in our study. For example, the number of GBs for the glass is calculated as follows:

gap.glass= (gap.rs*dailyGlass*glass.collection)*0.85 / (glass.capacity).

Set gap.rs=165, dailyGlass=0.005 m^3, glass.collection=7, and glass.capacity=1.8 m^3, it follows that gap.glass = 2.73 that is rounded up 3. The value 0.85 introduces a margin of caution in estimating the number of GBs. Obviously, this threshold can be changed as desired or eliminated altogether. The final step of the sizing algorithm consists of updating the fields *glass*, *plastic*, *paper*, *organic*, *unsorted* of *gap*.

4. Conclusions

When a software tool based on the algorithms introduced in the present paper is put into operation, it will be easy for people in charge of managing the household SW to fix, on the territory of a district, the location of the GAPs and sizing the number of GBs to be put in them. A pilot study implementing such an approach may be found in (Di Felice, 2013).

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