Circular Economy: A Network Analysis of the Solid Waste Collection in the City of Rome (Italy)

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Abstract: Solid waste management represents a complex issue involving political, socioeconomic, institutional, urbanistic and environmental aspects. Separate collection of waste in the Municipality of Rome is a matter of particular interest due to the size of the city (with an urban area of 1,287 km²) and the considerable amount of waste produced (approximately 1,690,000 tons/year). In this context, this paper proposes an in-depth analysis with the aim of optimizing the delivery of waste to collection centres. The optimization focuses on several key elements, including the strategic distribution of collection centres within the city to make them easily accessible, particularly in densely populated areas or where waste production is higher.

Based on the data provided by the Municipality of Rome, the waste materials that should be advantageously recycled as part of the Life Cycle Assessment (LCA) have also been identified. This comprehensive approach can improve the city's waste management system, promoting the efficient use of resources and reducing environmental impact for greater urban sustainability.

Keywords: City planning, Urban networks, City of Rome, Municipal solid waste, Recycling systems, Collection centres.

1. INTRODUCTION

The current view of cities as complex systems dates back to 1960s, a topic period for urbanism worldwide: in United State of America cities were subject to massive infrastructural improvements, while in Europe there was a sharp increase of urban growth. Many of the major issues with cities today root in the transformations which took place at that time and the legacy of social and economic disparities and segregation ([1]).

In the United States, the perspective of cities as complex systems arose as a reaction to the pure urban renewal movement. The concept of "organized complexity" was stated by [2], but the first clear idea of cities as complex systems can be found in [3]. Her main point was that organized complexity is the key-element, that allows people to perceive the social and spatial "fabric" of large cities. She also proposed a methodology to gather how cities work, focusing on processes (rather than structure), which could induce analyses, researches and reflections on clues of a non-mean nature (to uncover overall properties from local ones).

In developing countries, the idea of complex systems took place from more practical problems, such as the growth of slums ([4]), the housing for poor people and so on, embracing all aspects of the city from health to education, from services to transportation. These new approaches were oriented towards the neighbourhoods' evolution, instead of previous practices which resulted in recurring problems ([5]).

The development of ideas about organized complexity led to what is now named as *complex adaptive systems*. There are many types of complex systems: natural systems and human social interactions certainly are, but it is possible to think of several others that are definitively to be considered in this group. When referring to them (especially for urban contexts), complex systems show at various degree five specific properties ([6]):

- *heterogeneity* refers to the nature of cities, generally very diversified. On the one had (positive aspect), this leads to many economic capabilities; on the other hand (negative aspect), it may generate (and it usually does) inequalities among different neighbourhoods. Cities are also very different in spatial terms: for instance, there are districts with several use (commercial, industrial, residential, etc.) rather than a

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prevalent one, or where public spaces (squares and parks) are used much more intensely than others and traditionally by different groups of people;

- *interconnectivity* highlights the close interdependence, as every possible change or action has consequences on other entities (activities, people, etc.), that in response undertake other actions that will affect again others and so on, in a sort of loop that returns to the starting point, which results of course modified. Moreover, fields apparently different result to be tied as well (issues of economic development or health are connected to physical places and to urban services, and these ones in turn to budgets at individual and municipal levels). This chain generates progressive modifications to the system, involving multiple layers (*i.e*. different environments), because complex systems are dynamical, with the outcome that changes (or, better, adaptations) move from a state to another;

- *scaling* indicates that the character of cities changes with their scale, which has a variety of possible measures (usually, but not always, the scale is related to population size). In larger cities, building density is generally higher than small cities and the need for infrastructures is higher, as well as waste production and collection (not to mention energy and environmental fall-outs), leading to a different structure of both advantages and costs;

- *circular causality* links cause and effect, showing that they are exchangeable. This rises a relevant challenge in planning interventions, as it is hard to obtain results in a given sector without generating unexpected fall-outs in other sectors of urban life. Urban planning capable to activate virtuous cycles is much more likely to be successful and sustainable;

- finally, any city (as other complex systems) is in constant *evolution* over time, as people and all the activities included develop: actions planed today should consider such a dynamical behaviour, in order to keep their effectiveness in the future, where conditions have changed. This emphasizes the idea of a city as a progressive process, rather than a static entity.

2. FACTORS OF URBAN EVOLUTION

Urban transformations are the result of many factors influencing the life of cities, both external and internal, and derive from multiple reasons: historical, political, economic, social, geographical and environmental. They act at different speeds, depending on the forces prevailing in a given historical moment, determining demographic and socioeconomic growth and territorial expansion. These factors (which are, therefore, the “engines” of evolution) can be of global or local nature: the first are responsible for the development guidelines of a city and a territory, determining their changes; the second ones lead to city's structure arrangements and internal relations. Among these many factors, we want to highlight only a few.

Lately, big cities present an *undifferentiated space* ([7]), where everything is achievable and traceable everywhere. The ease to access the single parts, abandoning the idea that only the city centre can offer certain services, leads to the identification of space as an opportunity to find resources and products; there is no longer a link with a specific function, but a space where everything can be done. This concept, which is not necessarily a negative aspect, changed the conception of urban organization in citizens: at the local level, it is allowing the development of neighbourhoods as they are perceived today (*self-containing* areas), where it is possible to find most of the products and services necessary for the ordinary life of people without moving to other places (this is the *functional mixité*, [8]).

Two other relevant phenomena are worth mentioning here: *competition* and *cooperation*. Although apparently contradictory, these two situations coexist reaching a balance between them, assuring their own growth and a large scale cooperation that involves several realities (it is the so-called *coopetition*, [9]). The concept of competition applied to the city is based on the same principles used in economics and is therefore undergoing the same evolutions. Competition between cities can be defined as the ability of a single city to attract initiatives and investments by competing with other cities of similar rank ([10]). This formulation is based on the hypothesis of the indifferent space, where the location of activities is independent of the territorial space, relying only on the criterion of competitive advantages, which can be expressed in terms of socio-economic variables (work, costs, etc.) and urban quality, with a dual significance: corporate (with reference to business and administration services) and personal (with reference to the quality of

life). In common perception, urban quality is strictly intertwined to several properties such as good administration, safety, infrastructure provision, social and recreational facilities, as well as environmental quality, energy efficiency and sustainability.

The interactions are fundamental in terms of the organization of a metropolitan area and contribute to the tendency to aggregate and structure of the territory. In a network, as it will be showed below, cities or parts of the city (in the case of metropolitan realities) are considered as nodes, which develop long-distance (global) and short-distance (local) relationships; they contribute to structuring the system of the city and the urban territory, conferring an organizational structure and certain properties.

3. NETWORKS APPLICATION TO CITY PLANNING

The representation of a city with a network allows, beyond the type of graph in use, to simultaneously consider multiple relationships and study strengths and weaknesses of reality through the analysis of the model. In general, the choice of modelling implies risks of error and propagation of them. The construction of a database is, therefore, essential for the development of a sufficiently reliable and verifiable model.

Currently, the use of network models is widespread in urban studies for analysis purpose, but recently is also gaining ground in planning. On the one hand, it is, in fact, certainly suitable to represent a situation concisely but comprehensively; on the other hand, it is now possible to continue to exploit the model also for planning purposes, because network tools have reached a level of development that guarantees reliable predictions on the results of any interventions studied on the model and only subsequently implemented in the real world.

For planning examples we refer to the literature available; but we choose to reproduce here one of the significant drawing of Rome City Masterplan (Figure **3.1**), as we will take this city for a specific application analysis in the waste organization. The new plan (2008) led to a new different image of the city and the role of the parts. The idea of centralities becomes dominant, notwithstanding the presence of an predominant historical city centre and of the Vatican, which tend to obscure any other pole. Nonetheless, managers and planners opted for a revolution in the idea of the city, moving towards a new future balance within the parts and the exchanges among them.

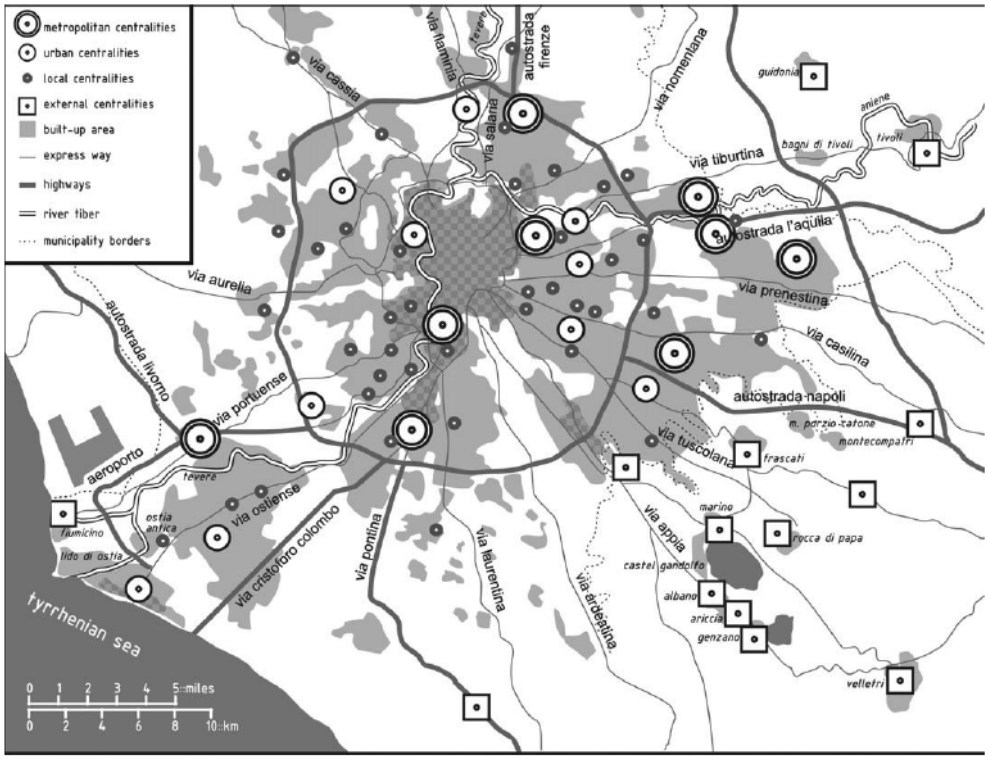


Figure 3.1: Rome City Plan (2008).

4. MUNICIPAL SOLID WASTE COLLECTION: DATA AND ANALYSIS

Consolidate data regarding municipal solid waste production refer to the year 2019 (AMA, 2022) [11], even if scattered and incomplete data relating to 2022 are available, however substantially similar to those of 2019.

During the year 2019, within the Municipality of Rome, 1,690,303 tons of waste were collected, corresponding to a production per capita of 590 kg/habitant. Waste collected separately during this year amounted to 764,493 tons, corresponding to a percentage of separated waste collection equal to 45.2%. Of the total amount (764,493 tons) of waste sorting: 9% was collected via door-to-door, 32% through street collection, 20% from third party providers at non-domestic user and 10% at collection centres. The remaining 29% is represented by fractions sent for recovery with charge borne by third parties.

The distribution of the quantities and types of municipal solid waste collected during 2019 is reported in Table **1**.

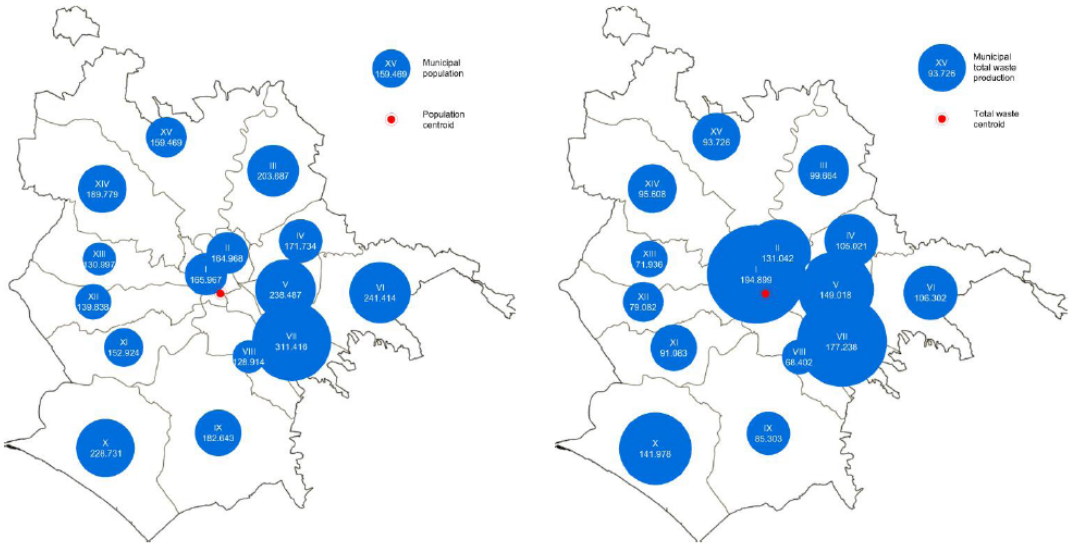
Furthermore, in Figure **4.1** is reported the urban population for each municipality, while Figure **4.2** shows the total quantity of waste from separate collection in the different municipalities. The bowls in Figures **4.1** and **4.2** are located in the geometric centroids of the fifteen sub-municipalities (the individual geometric centroids have been calculated with the continuous system's formula).

The collection centres are specifically dedicated areas with yards and containers, open to the public for the collection of separated waste, which is then sent for recovery or, in case of hazardous waste, for inspection and appropriate disposal. In 2019 the collection service of the city of Rome had only 12 waste collection centres located irregularly across the territory: in five Municipality there were no collection centres (see Figure **4.3**).

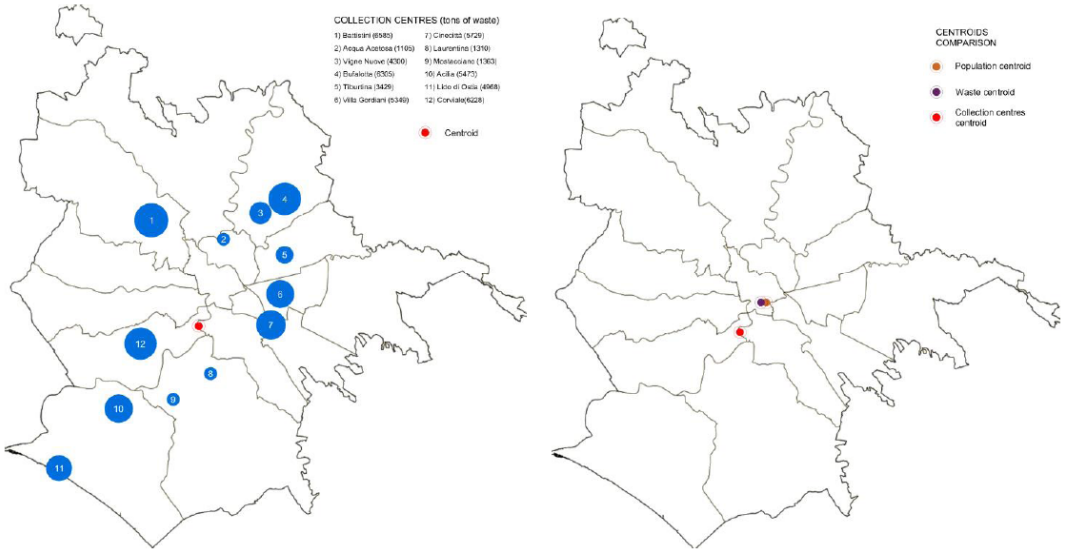
Finally, the analysis proceeds with the calculation of the centroids (using the discrete system's formula) of the total population, the separate waste collection and positioning of collection centres, overlapping them in the same map (Figure **4.4**). Although a minimum distance can be considered physiological, especially in

Table 1: Production of Municipal Solid Waste and Recovery

	Waste		Sorting		Recovery	
	(tons)	(%)	(tons)	(%)	(tons)	(%)
Paper / cardboard	246,989	14.61	245,285	32.09	220,980	33.25
Plastics	242,873	14.37	77,151	10.09	37,414	5.63
Textiles	132,326	7.83	6,823	0.89	6,618	1.00
Glass	128,071	7.57	75,391	9.86	73,006	10.98
Wood	50,525	2.99	20,495	2.68	19,880	2.99
Ferrous cans	38,419	2.27	10,748	1.41	10,675	1.61
Non-ferrous cans	9,411	0.56	1,249	0.16	1,249	0.19
Green	118,535	7.01	83,212	10.88	79,330	11.94
Organic	365,672	21.63	166,699	21.80	139,206	20.94
Under-sieve	51,813	3.06	0	0	0	0
Bulky waste	49,907	2.95	29,724	3.89	28,554	4.30
Inert	28,267	1.67	18,449	2.41	18,449	2.78
WEEE	17,342	1.03	8,917	1.17	8,917	1.34
Sweeping	18,183	1.07	18,183	2.38	18,183	2.74
Others	191,970	11.38	2,167	0.28	2,167	0.33
Total	1,690,303	100.00	764,493	100.00	664,628	100.00
% of total	100%		45.2%		39.3%	



Figures 4.1 (left) and 4.2 (right): Population and waste production of sub-municipalities of Rome (2019).



Figures 4.3 (left) and 4.4 (right): Collection centres and centroids overlapping (2019).

a city like Rome, the overlap shows a significant distance between collection centres and waste production.

The reduction of such distance and a distributed system across the territory is the objective that, in our opinion, must be pursued in the coming years as the results of our analysis confirm a lack of homogeneity in the provision of collection services, due to an unequal use of resources and planning [12]. Moreover door-to-door collection was extensively developed in areas (suburbs with low population density) that do not lend themselves to this collection method [13]. These neighbourhoods for their territorial and urban characteristics are not suitable to this mode, yet no specific separate waste collection system as an alternative to door-to-door is provided. The city of Rome chose in the design a model of “decentralized network” and, therefore, it is necessary to plan a new model of “distributed network” waste collection, re-engineering services and systems. On this path, the opening of seven new centres is planned by 2026 and their distribution should greatly improve the current situation, investigated and shown in cited Figures.

5. CONCLUSIONS

Unlike traditional linear economic model based on a “take-make consume-throw away” pattern, a circular economy is based on sharing, reuse, repair,

refurbishment and recycling, in a closed loop, where products and materials contained in the devices are highly valuable. So that waste collection in an urban system upstream of their disposal constitutes an important part of the circular economy. This is expressed through careful planning of separated waste collection, the study of the location of the collection centres, the search for optimal routes for the delivery of waste to collection centres and the development of efficient collection methodologies (for example door-to-door).

The waste collection system in the municipality of Rome is not optimized, in particular the collection centres are located in semi-central areas but they are not evenly distributed across the urban territory without providing an overall homogeneous coverage.

The separate waste of the urban solid waste stands at a value of 45,2% (2019), with and effective recycling amount of less than 40%: such values are far from both Italian (61,3%) and European averages (47,2%), according to Eurostat data [14]. Finally, whilst the recovery of the organic fraction and green cuttings is at good level (33%), the recovery and collection of plastics is far from acceptable values (5,63%).

If the municipality of Roma wants to reach collection levels comparable to those of Europe or even only Northern of Italy, the collection system has to be reorganised, rethinking it at local as well as at global level. Probably to optimize the collection system a very widespread door-to-door collection should be organized in the central areas of the city.

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