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Urban Growth Control DSS Techniques for De-Sprinkling Process in Italy

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Abstract: This article relates to the concept of urban expansion reduction in limited areas, called "de-sprinkling districts", and methods of designation of their range, as well as modelling and management of their network. This concept was developed from research concluded in 2016, referring to 50 years of urban evolution in Italy, that investigated and diagnosed the forms of urban growth focusing on the Italian model. For this model, the authors of this paper proposed an alternative definition (urban sprinkling) with respect to the sprawl international standard. Certainly this urban model established in Italy during the mentioned years is due to an inefficient control of peripheral areas and new conurbations' development, both in forms and functions. The cause is to be searched for in the importance given to single towns' general plans and the minor role of strategic planning (province and region). The political and social assumption that urban development according to the extreme sprinkling model is no longer feasible is gaining ground. However, implementing de-sprinkling processes will not be easy. In this paper, criteria to create a decision support system (DSS) for administrators and municipalities is illustrated. These criteria aim at dealing, technically and politically, with sprinkling and planning medium-term containment.

Keywords: urban sprinkling; land take; urban–rural pattern

1. Introduction

The method illustrated here is based on research that showed the rate of land conversion into urban areas in Italy over half a century [1]. It provides a series of data, unprecedented for their level of detail, and it refers to the 1950s decade. This is a historical threshold, which acquired importance after being identified as the earth's entrance into the Anthropocene geological period [2,3]. For the first time, the true national scope of the land-take phenomenon, from post-WWII to present days, has been measured. Urban areas have increased by more than 350%, and buildings along Italy's mainland and island coastlines have increased by 10 km/year. Moreover, a quantitative similarity has been found between Italian regions and western Europe. They both have an average of 360 m^2/inhab, despite having had very different situations in the 1950s [4,5]. The research then highlighted the huge increase in the rate of plains' urbanization (from 3.3% to 12%) and more recently of hills' urbanization (from 1.2% to 6%), in addition to the threat of fragmentation of the national ecosystem's fundamental hubs (protected areas and Natura 2000 areas). However, the main result is the identification of a new urban configuration standard: sprinkling [6], considered different and alternative to the much more popular "sprawl" model [7]. The very same research underlined how this model has developed over time by means of a series of indicators. These indicators showed the model's correlations and differences with other social dynamics, such as demography, confirming similar conclusions achieved in other countries. There is little doubt that this model of urban distribution is a serious threat, with important consequences on social life quality, land economy, biodiversity conservation, climate change and ecosystem services' provision [8–15], but it is very hard to answer the question about this urban model's contrast and inversion perspectives.

Certainly this urban model established in Italy during the mentioned years is due to an inefficient control of peripheral areas and new conurbations' development, both in forms and functions. The new urban development has in fact almost never been carefully planned, with very rapid growths that have seen mixed neighborhoods and residential buildings with industrial and commercial areas, in rural matrices, with no drafted road networks or organic utilities framework. The cause is to be searched for in the importance given to single towns' general plans and the minor role of strategic planning (provincial and regional). As a consequence, the result of land transformation stems from the action of 8000 small municipality administrations. These decide within themselves with little large-scale interaction. Moreover, town administrations, to improve economic response and the people's consensus, and enforced through timeless and ess-strict regulations, have allowed community-led processes and contracts with private companies. This has led to a building surplus all over Italy. The National Institute of Statistics (ISTAT) measured this surplus in 2011, considering only residential buildings; the number measured was 12 million buildings (average of 1 per every 5 people); 816,000 of those buildings were built in the last 10 years (223 new buildings every day) with an enormous number of second houses (30% of the total; ISTAT).

The Italian government, throughout the years, has given little to no signals towards a reorganization of municipalities for a noticeable administrative fragmentation reduction, and on the contrary, provinces have been eliminated. The government used to draft strategic plans, which, as weak as they were, at least were an interpretation of a larger scale of land transformation and town activities coordination.

It is also true that the fast increase in the number of buildings has undoubtedly slowed for many years, compared to the situation in the 1980s, but it still continues with an appreciable rate. From 2000 to 2012, the satellite land monitoring service Corine Land Cover (CLC) showed a 12% loss of land to urban development, which was around 1650 km^2 (more than the metropolitan area of Rome) or 140 km^2/year and around 38 ha/day. Considering that for Italy, CLC monitoring data is inferior to the reality (which is at least 30% more), the comparison with the 80 ha/day measured between the 1950s and the 2000s shows that the phenomenon has still been powerful even in the last decade. In this light, the National Institute for Protection and Environmental Research (ISPRA) data show that between November 2015 and May 2016, Italy's land urban conversion average rate was still 28 ha/day [16].

Sprinkling is mainly caused by the following:

- Development plans that favour citizens' or businesses' requests. They request to improve the value of their properties, regardless of their location.
- Political trends that tend to maximize consensus by favouring the implementation of the development plan with "direct action".
- Speculation or necessity unauthorized development.

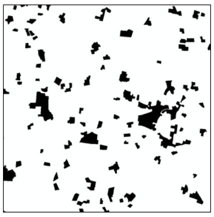
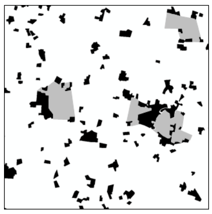
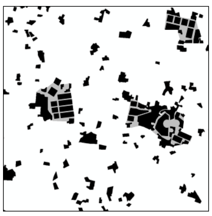
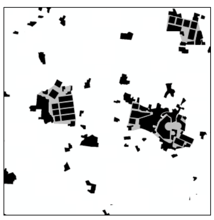
Which morphological structures will be affected by future phenomena? There is little doubt about this. Previous analyses [17] have evidently showed that the type of landscape that has been affected the most by urban conversion in the last five decades is the plain. However, the growing rate of hills being affected is evident, also as a result of plains' saturation and climate change-related hydraulic risks in the last few years.

The political and social assumption that urban development according to the extreme sprinkling model is no longer feasible is gaining ground. However, implementing de-sprinkling processes will not be easy.

This work illustrates a decision support system (DSS) to detect key areas mentioned in Table 1, point 2. In the scientific literature, a DSS is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning at strategic levels and help politicians to make decisions about problems that may be rapidly changing and are not easily specified in advance. DSSs can be either fully computerized, human-powered or use expert-based processes [18].

In the following paragraphs, criteria to create a support system for administrators and municipalities are illustrated. These criteria aim at dealing, technically and politically, with sprinkling and planning medium-term containment. In summary, the aims and scope of this article are (1) the presentation of the concept of urban expansion reduction in limited areas, called "de-sprinkling districts" (DSDs), (2) elaboration methods of designation of their range, and (3) modelling and management of their network.

Table 1. Possible steps in the Italian de-sprinkling process.

De-Sprinkling Process					
Step	**Methodologies/Goals**	**Pattern**	**Action**	**Tools**	**Time Horizon**
1	Slackening, up to the interruption, of the phenomena of further land take according to traditional dynamics, so as not to further burden the current conditions. It is an action reasonably falling within the Regions' strategic responsibilities. In this sense, the laws pertaining to "land consumption," with which several Regions have already complied, seem to be the main solution for setting regulatory-fiscal regulations aimed at containing the behaviours of Municipalities and private subjects as to further forms of uncontrolled use of territorial surfaces.		Stopping urban sprawl/ sprinkling	regulatory intervention/ tax deduction	short term
2	Identification and reorganization of "key areas" in which to carry out localization interventions of infrastructures, services and polarizing productive functions, with the intent to reorganize a macro urban fabric with its central areas and its reclassified road system. It is a key step in the de-sprinkling process, as it requires an almost paradigmatic reformulation of the current planning modalities. The aim, in fact, can be achieved by inverting the plan reduction trajectory, giving it a more incisive compulsoriness		Prioritised functional ranking	strategic plan/ operational plan	mid term
3	Densification intervention of the urban fabric so as to satisfy the future needs of land take increase, but especially to guarantee efficient public utilities, optimizing the users' accessibility and threshold volumes. The key areas host all the functions that in time become indispensible to guarantee the qualitative and supply improvement of the territorial ambit (housing, utilities, industrial, commercial, managerial) systematically using the tools of equal distribution/compensation of land.		Densification/ infilling	Operational planning/ urban projec	mid term
4	Incentives or managerial interventions negotiated in phase of equal distribution/compensation (for example, through the acquisition of public patrimony areas) aimed at the gradual removal of built/urbanized areas, with local projects of re-establishment/restoration of the landscape-environmental-pedological state of the areas and of the original use of the land, with increasing of urban density		Shrinking	regulatory intervention/ tax deduction	long term

2. Study Area

In the key study areas, projects of urban area structuring are implemented. Necessary functions for its future structures are concentrated in a few suitable land portions, without continuing until now with the extreme expansion model implemented.

The urban expansion reduction process should be implemented in limited areas, the DSDs. DSDs must be defined at the operational planning detail [19–21] by those authorities that have the greatest decisional power on land transformation; as already addressed, in Italy, these are the municipalities. Therefore, in a municipal area, DSDs can be numerous and require an accurate technical and monitoring phase, leading to their definition.

In the experiment illustrated in this paper, the study area (DSD) is located in a North Italian plain–low hill area, distinguished by the extreme dispersive urban model, sprinkling (Figure 1).

For the DSDs subject to works, a minimum set of data is necessary. These data will enable the implementation of the method mentioned and are the following (Figure 2):

- urbanized soil by type (residential, services, and production);
- volume of buildings by type (residential, services, and production);
- built-up land by type (residential, services, and production);
- population by type (residential, services and production workers) referring to each urbanized soil and volume of buildings.

The data set refers to the individual urban areas within the DSDs. It is a set of data that can only be implemented at a town level; however, in Italy, municipalities that can provide such detailed information on single urbanized soils are very few. The most common datum is that on "census sections", which is normally used to manage political and administrative elections.

Therefore, the de-sprinkling process has the serious issue of implementing municipal land data-gathering systems. These types of data are not always easy to gather with maps, and therefore they need monitoring and measuring inspections, which are very expensive in terms of resources and personnel.

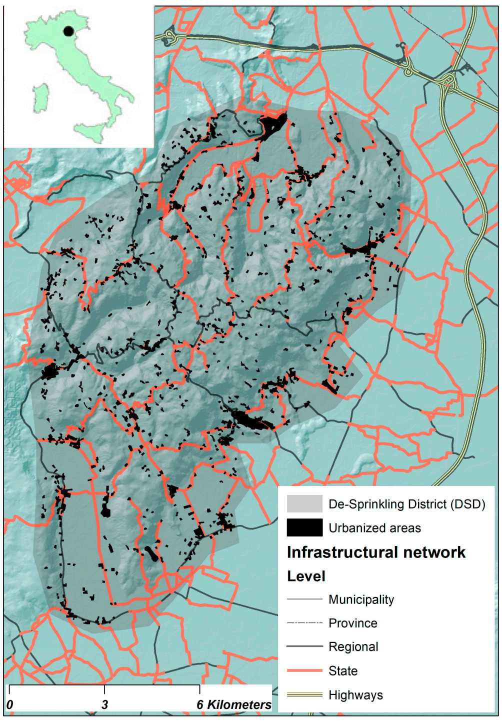


Figure 1. Study area (de-sprinkling district—DSD).

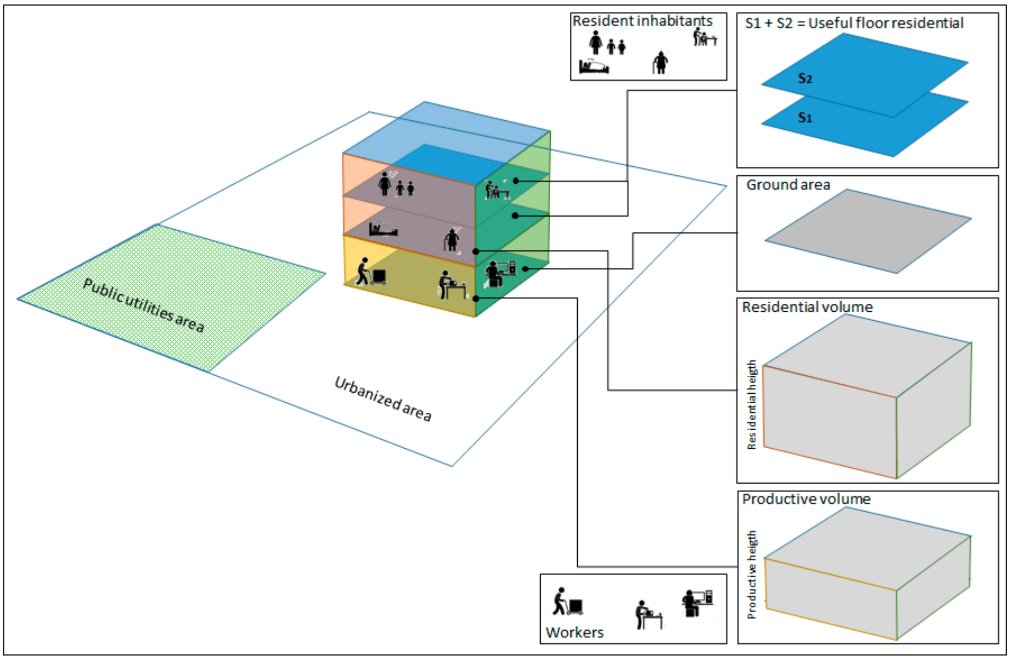


Figure 2. Basic data for the de-sprinkling process implementation.

3. Method and Results

Table 1 summarizes a possible containment and reorganization process for the sprinkling model, which covers a long timespan of 30 years overall. The procedures to be implemented and the goals to be achieved gradually should be included in a timetable involving the use of several tools one after the other, as part of a politically robust and supported long-term policy (long-term planning). Incentives and tax relief will have to be coordinated with planning and project-related activities at various stages and levels but whilst being aware that this is an extremely difficult issue that requires tools to be tested ex novo in part. It will be necessary to involve public bodies (municipalities, regions and the State) for the implementation and management of transfer development right (TDR) tools [22,23], which will be essential to apply long-term balancing and offsetting techniques and rules. It will not be possible to achieve substantial and ongoing results over time without putting in place processes to involve entrepreneurs, social stakeholders and non-profit associations: a world that is very sensitive to this issue even today.

On the other hand, as Italy is a highly advanced country technologically and culturally, it can tackle this issue despite the huge difficulties. In light of these remarks, the systematic implementation of plans to reorganize urban areas to help reduce differences in the typology and distribution typical of present-day expansion models, that is, the achievement of the mid-term goals up to item 3 in Table 1, would already be a great result in itself, given the present-day situation.

Regarding the data used, urbanized soils were retrieved from the regional land-use map (LUM) update in 2006 on a scale of 1 cm to 100 m, using the following definition of urbanized soil [24]: land used for urban functions, involving the replacement or retention of natural soil includes built-up land and land used for ancillary settlement functions, such as public and private gardens, sports facilities, unpaved roads and other service areas, either permeable or impermeable to water.

However, data listed in Table 2 were not available at the municipal scale. To be able to develop the method of the de-sprinkling process, the set of input parameters was retrieved with a geographical information system (GIS) technique. This technique generates random values from an input range. A range of values, consistent with the sprinkling model recurring standard, was fed into the system.

Other parameters, relating to demography and building density and population (Table 2), were derived from primary data.

Table 2. De-sprinkling district (DSD) data obtained with random technique.

		Indicators	km^2	m	m^3	m^3/m^2 N.	Inhab/km^2	%	m^3/inhab
Primary data	Urbanization data	De-sprinkling district (DPX-D)	135.3						
		Urbanized areas	7.45					0.055	
		Mean urbanized area	1.15						
		Public utilities	0.053					0.007	
	Building data	Floor area (residential)	2.95						
		Floor area (productive)	0.3						
		Total residential volume							
		Total productive volume				18,658,651			
		Mean heigth residential buindings			6.32	1,760,550			
		Mean heigth productive buindings			5.9				
	Demographic data	Resident inhabitants					39731		
		Workers to the productive sector					15308		
Secondary data	Urban/building densities	Urban density						0.055	
		Cover Ratio (residenzial)						0.3959	
		Cover Ratio (productive)						73154	
		Land Utilization Index (residential)						0.04	
		Volumetric density (residential)				2.5		0.83	
		Volumetric Standard (residential)							
		Useful floor (residential)	6.19						180
	Demographic densities	Demographic density					293.65		
		Worker density					113.14		

The method used is a comparative type. It highlights urbanized areas which, as a result of functions' layering and concentration, already function as central hubs for their hinterland. In other words, this means selecting those hubs in which urbanization should be intensified. This is to detect urban functions (residence, services, and production structures) that the DSD will need in the future.

With the method used, an urban hubs' ranking has been generated, as the sum of dimensional and qualitative features related to their "urban ranking". Urban ranking is defined as the ability to attract flows of users and people interested from the hinterland, on the basis of the functions' availability and concentration (services, residential, production, and commercial).

A few attempts at a classification have been made, on the basis of two statistical functions: natural break (Jenks) and quantile. Clearly, the two results are similar when the value distribution is even and very different when the distribution is uneven (Figure 3). However, the goal is a "soft" selection of possible future urban hubs to support DSS processes; therefore taking only dominant and extreme values is avoided. For this, each parameter taken into account was distributed on a six-quantile base, and the urban ranking index (URI) was obtained with a multi-parameter procedure, as follows:

$$\text{URI} = \sum q_i\, \alpha_i \qquad (1)$$

where q_j is the quantile value (1–6) for each jth parameter; α_j is the weight of the jth parameter category considered in defining urban attraction.

In relation to the number of quantiles, the work proposes an experimental approach based on a closed-scale comparative assessment between the various urban nuclei. The number of quantiles is relatively unimportant, as the applied method serves to make it clear which urban areas are most equipped to support in the future a function in the aggregation of new buildings with different purposes. In this sense, with an expert-based process, six classes have been chosen, as they are a good compromise to highlight the main differences between the nuclei and also to produce a non-dispersive grouping of the same nuclei useful for their final ranking.

The parameters taken into account to measure the urban ranking of each urbanized soil are indicated in Table 3.

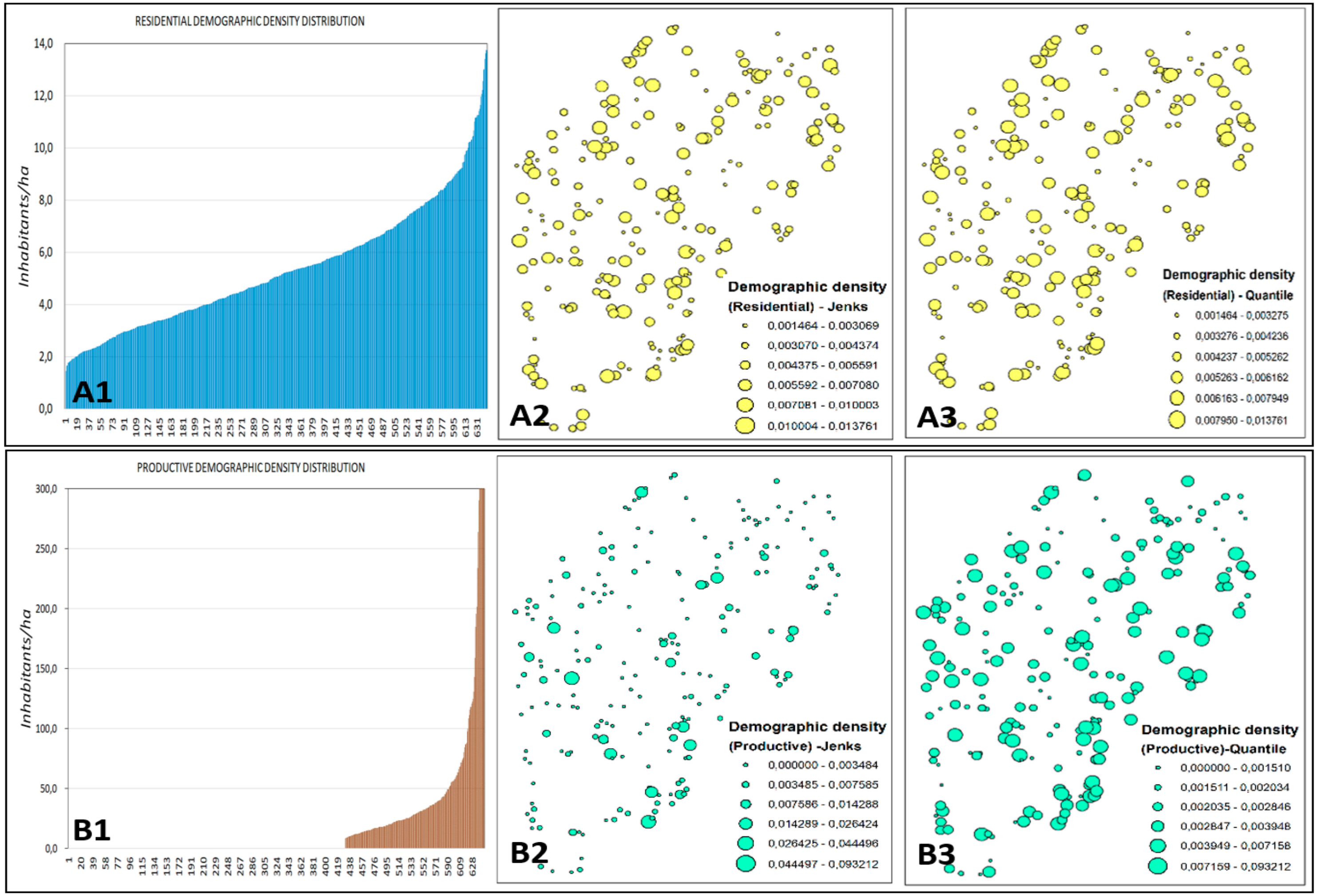


Figure 3. Data distribution of residential demographic density (**A1**) and productive demographic density (**B1**). Comparison of classification results: natural break (Jenks) (**A2**,**B2**) and quantile distributions (**A3**,**B3**).

Table 3. Parameters taken into account to measure the urban ranking of each urbanized soil.

J Parameter	Quantile (1–6)	*J* Weigth
Urbanized soil (m^2)	qUS	αUS
Residential volumetric density (m^3/m^2)	$qRVD$	αRVD
Productive volumetric density (m^3/m^2)	$qPVD$	αPVD
Residential demographic density (inhab/ha)	$qRDD$	αRDD
Productive demographic density (Inhab/ha)	$qPDD$	αPDD
Part of urbanized soil for public utilities (Public utilities %)	qPU	αPU
Road proximity (km)	qRP	αRP

Quantiles were assigned by using the related GIS function, and only to infrastructures, the six levels were directly assigned, according to the following criteria:

- 6 for areas $\leq$ 3 km away from a motorway toll booth or train station;
- 5, 4, 3, and 2 for areas within 200 m respectively of national roads, provincial roads, >6 m wide municipal roads, or <6 m wide municipal roads;
- 1 for all the other areas.

As for weights α_j, these must be the result of a discussion with the town administration, taking into account the administration's needs: services and transport optimization, and the willingness to favour particular types of economies of scale, that is, public services (or some of them), industrial production, or craftsmanship, without excluding the residential aspect [25–27]. Choosing one or the other changes the weight assigned for planned urban centralization. In theory, a higher value should concern public services, then residential volumetric and demographic density, then productive density, and finally road proximity. The weighting is necessarily derived from a comparison between the team of technicians that elaborates the plan and the establishment of the municipal administration. This is a shift in territorial policy supported by an adequate public participation process. In the case study illustrated, category weights were all evened at 1.

A database with each urbanized soil's centroid, found in the DSD with all the six values for each of the analyzed parameters, was then implemented (Figure 4). The related URI was then assigned to each centroid as a variable sum from a maximum of 42 to a minimum of 7. On this database, a kernel density estimation was carried out to classify the levels of centralization potential (Figure 5).

Figure 6 shows the collocation of higher kernel density values corresponding to urbanized patches that, in view of the multi-parameter estimation, have location advantages and functions that classify them as more convenient for building concentration (services, public, residential and production areas), which will be planned in the future. It is likely that DSDs should be reorganized in a multi-center way in the future, thus reinforcing their specialized central nature, avoiding redundancies: public services and equipment, administrative and economic headquarters, residences, and industrial production/craftsmanship infrastructures.

Clearly, planning the road and transport networks again will be necessary, favouring transport by rail and taking into account land morphology, to vastly improve exchange between centres.

To reorganize infrastructures, urban configuration and aggregation, optimization methods for transports, and public services are very important. Much has been written about this in international scientific productions. These methods are based on neural networks, cellular automation, and brownian agents [28–32].

The entire process was designed with a visual programming language for building geoprocessing workflows. With the open source Q-Gis software, it is possible to implement the automated geoprocessing models (processing modeller) and document the spatial analysis and data management processes represented as a diagram that chains together sequences of processes and geoprocessing tools, using the output of one process as the input to another process (Figure 7).

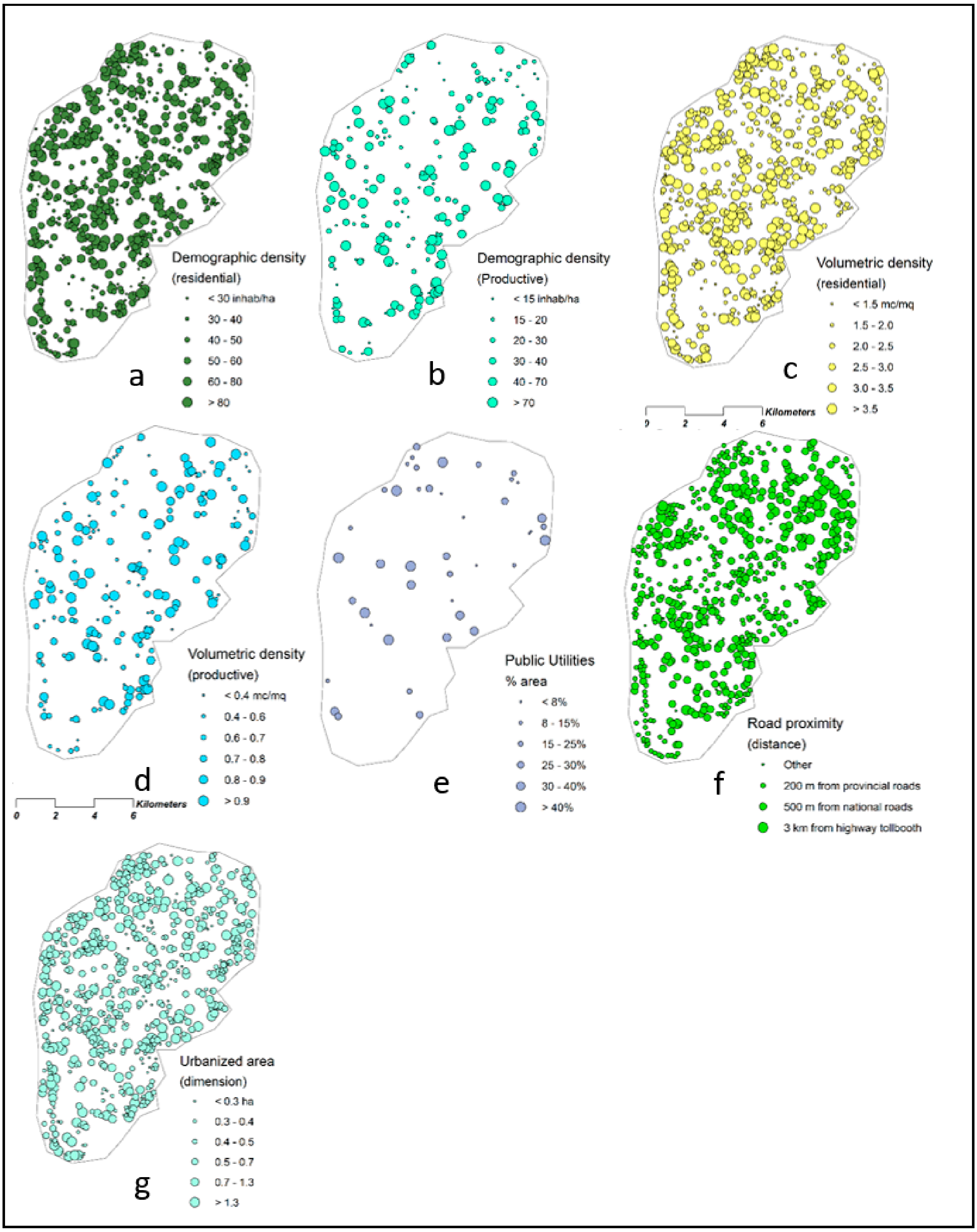


Figure 4. Quantile value distribution related to urban ranking's single indices: RDD (**a**), PDD (**b**), RVD (**c**), PVD (**d**), PU (**e**), RP (**f**), US (**g**).

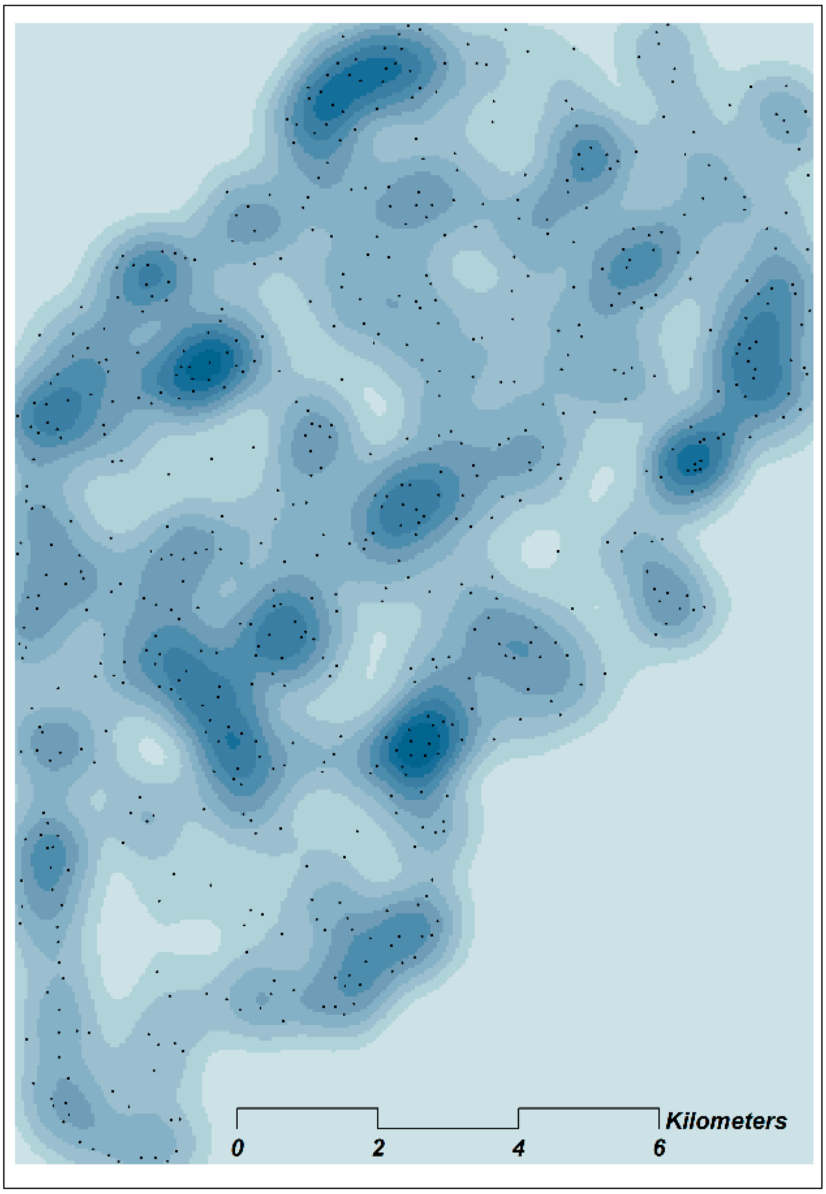


Figure 5. The ranking selection (urban ranking index—URI) with kernel density of possible centres on which future actions of urban concentration could be implemented. The darker colour tone corresponds to a greater concentration of urban elements and hence a higher level of "centrality" potential.

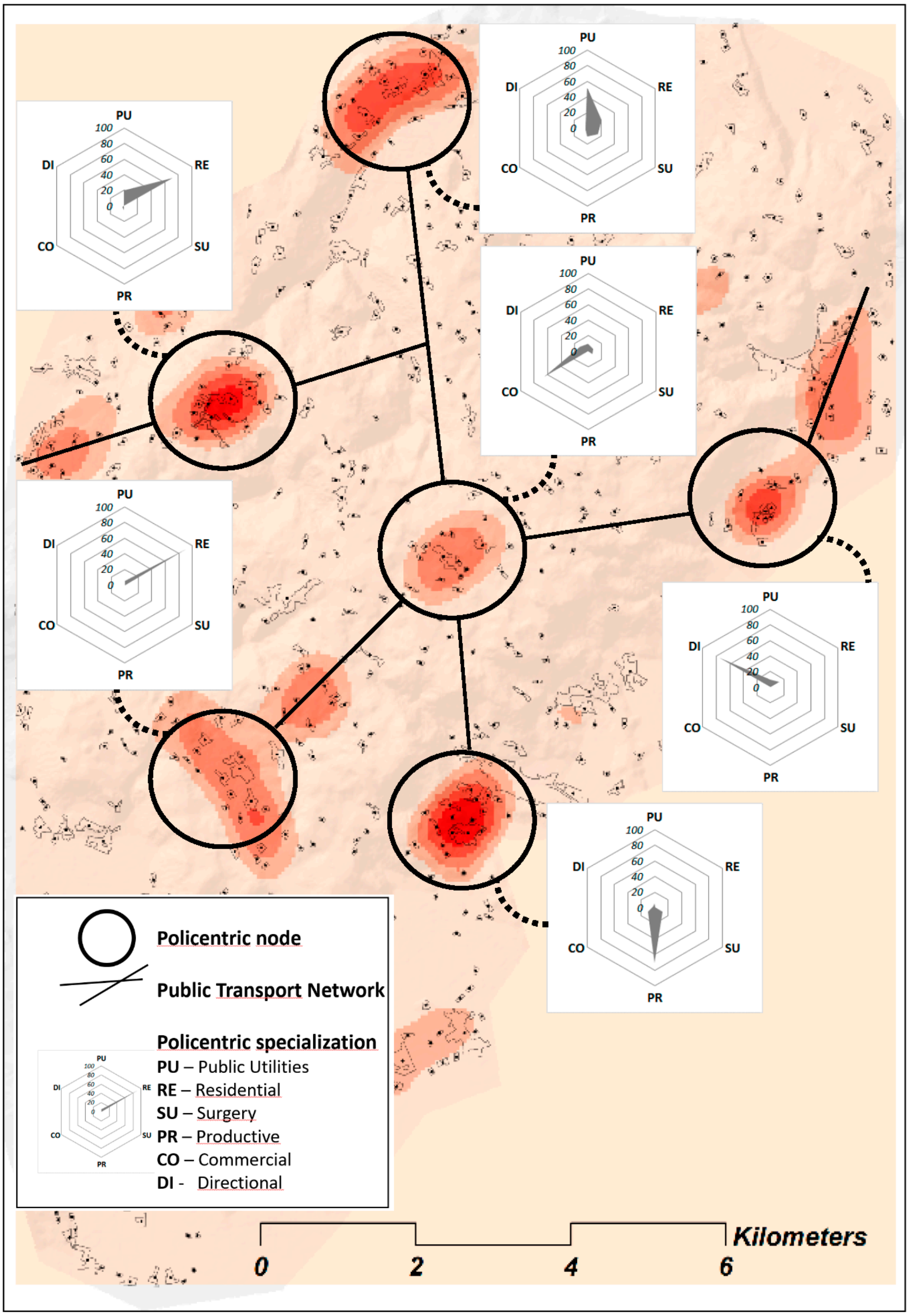


Figure 6. Example of de-sprinkling districts' (DSDs') specialized multi-centre organization.

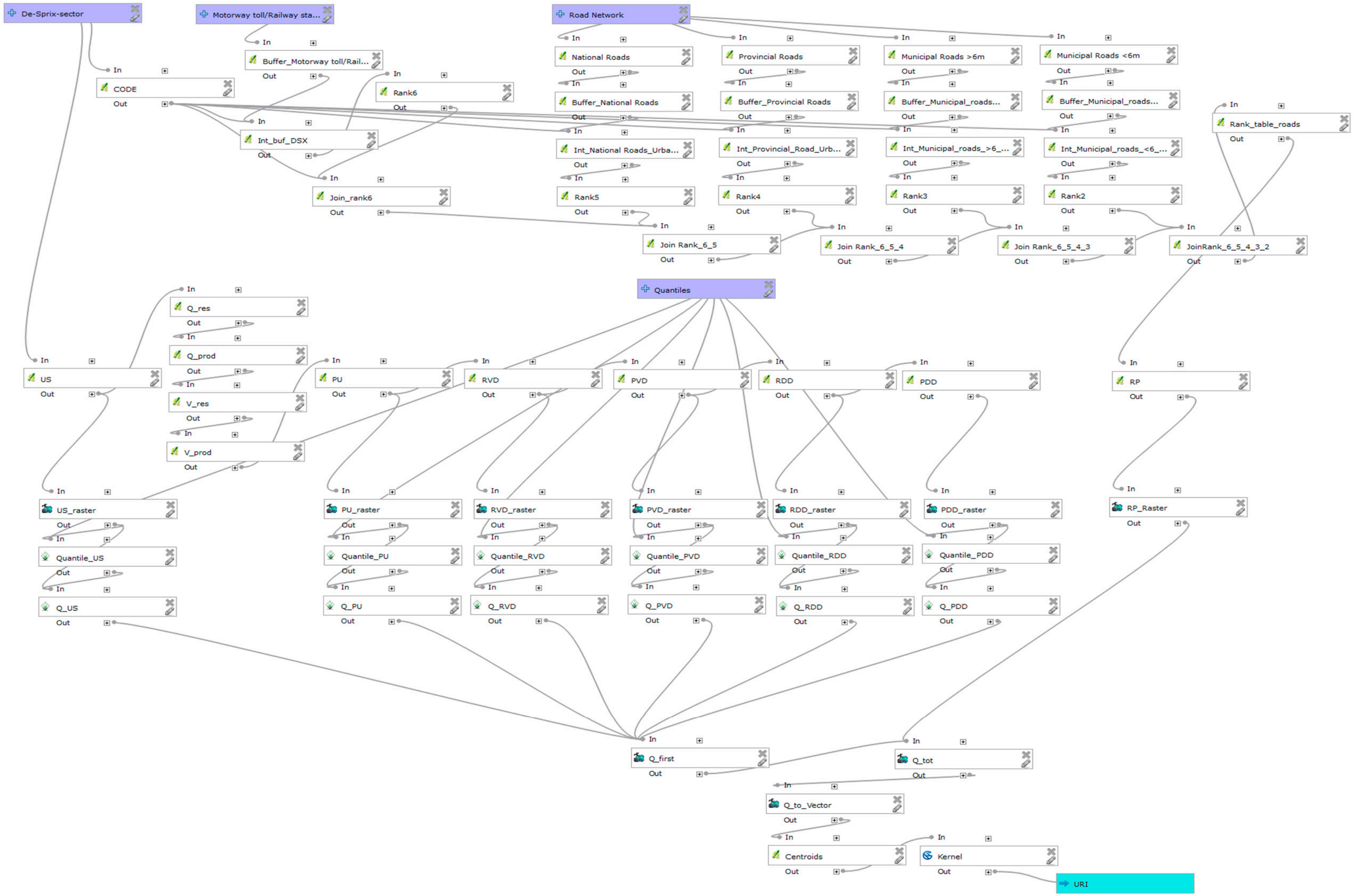


Figure 7. The de-sprinkling algorithm with processing modeller of Q-Gis software.

4. Discussion

The illustrated process, realistically, covers a period of around 30 years. Processes to implement and goals to achieve must be included in a timeline chart. The use of many instruments, within a strong long-term political planning programme, must be also included. Fiscal actions and incentives must be coordinated with planning stages, with the knowledge that this is not easy and there is a need to experiment with brand-new devices [33]. The help of public bodies (municipalities, regions and the government) will be necessary to design and manage transfer development right (TDR) instruments [22], which will be fundamental to implement an equal distribution and long-term compensation rules and techniques. To obtain sizable and continuous results over time, private companies, social representatives and charities, who are already aware of the issue, must be involved. Italy, being technically and culturally advanced, can face this challenge, despite the difficulties.

The illustrated de-sprinkling process uses a set of data that is hardly retrievable in Italy. The availability of detailed information is a real issue of resources and needs awareness for municipalities. Therefore, local administrations willing to invest in continuous monitoring are very few [34]. All regions have had a general development plan for relatively few years, and at any rate, they are far from the type and level of detail of data used for this research. Technologies available to municipalities could enable them to retrieve this kind of data, but the level of awareness and finances for this purpose are still too low.

De-sprinkling techniques should be implemented in the operational plan after detecting DSDs in the structural plan, but reading these plans is extremely hard, because of differences between urban instruments of municipalities and map legends and the lack of operational information (buildings, urbanized soils, infrastructures, etc.). Moreover, concentration areas should be more widely monitored. Besides the mentioned morphology, they can also be overmapped with limitations in force and natural ranking (protected areas, high value habitats and ecosystems, landscapes, etc.) and endangered (seismic microzonations, ecological values, hydraulic risks, etc.) areas. This kind of information is often available only partially or with little detail and cannot be used with municipalities' prescription or descriptional maps.

5. Conclusions

The global economic crisis and building excess have surely damaged the building industry. Its GDP (Gross Domestic Product), for the first time after post-WWII, has stopped growing and fallen, worrying national governments. Many measures have been proposed to improve this sector, but strategic plans have never been developed. Currently, a vast amount of buildings is available in the free market, with very high average prices (around 100 times an average Italian monthly salary), while social housing, for free or with low prices, is lacking. In years to come, the increase in migrant flows, for social protection and balance sakes, will call for the government to construct new affordable buildings, taking lands away from farming.

That illustrated in the introduction and discussion sections shows that, when strategic planning at a high level is lacking, it is hard to manage complex processes, such as de-sprinkling, which generally affects intermunicipal districts. A notable operational efficiency in analyzing and managing this issue could be given by GIS instruments [35], which, along with others, can be an effective consolle to check and control programmes and changes. These can also manage numerous sets of indicators on vast areas, even in real-time (fast monitoring).

Moreover, municipal development plans are shifting towards sustainability and innovative topics, such as soil balance (including de-sprinkling), ecologic networks, climate adaptation and energy improvement. All of these need strategic environmental estimation's advanced management devices and changes' fast monitoring, as well as an exchange between towns. There is the need to quickly register and classify general development plans' programmed contents and their progress. Today, this seems the only way to provide regional decision-makers with real-time information about the condition of land structure, determined by municipal actions within the multi-objective framework outlined here.

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Author Contributions: B. Romano and L. Fiorini conceived the model and analyzed the data; F. Zullo and A. Marucci processed the data; F. Zullo implemented the Q-Gis modeller.

Conflicts of Interest: The authors declare no conflict of interest.

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