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METHODS, TOOLS AND BEST PRACTICES TO INCREASE THE CAPACITY OF URBAN SYSTEMS TO ADAPT TO NATURAL AND MAN-MADE CHANGES

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CONURBATIONS AND RESILIENCE. WHEN GROWTH MAKES US FRAGILE

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ABSTRACT

This paper is focused on the conurbations, extensive urban areas resulting from the expansion and coalescence of several neighbouring cities. Two theses underlay the research. The first is that, in the development of a conurbation, traffic has actually a role of '*maker and breaker of cities*', just to paraphrase the title of a well-known article by Colin Clark, focusing on the double role of roads and traffic in urban development: on a one hand, the making of a unique road network, encompassing the whole grid, actually allows movement and interaction all over the settlement, making possible the working of the conurbation as a wide urban system; on the other hand, the resulting pattern of movement concentrates its major flows on few roads connecting the original nuclei and the new development areas, actually bypassing the pre-existing urban fabric and diverting a significant amount of local traffic from the streets of the urban grid, what involves the loss of the fertilisation benefit the irrigation of through movement provides. The second thesis, complementary to the former, is that the merging of the nuclei and their embedding into a conurbation reduces the resilience of the whole settlement, in that it affects the capability of the system to adsorb accidental events and transformations without significantly changing its global behaviour.

The phenomenon of conurbations and the diachronic analysis of their resilience will here be observed from a configurational point of view, analysing by means of space syntax techniques the urban settlement of Florence, here assumed as an ideal case study. The results are expected to objectively describe the role of inter-urban roads in the making of a conurbation, and to appraise the extent to which their entanglement within the whole concur in transforming its inner geography and enhancing its global vulnerability. More in general, the configurational approach, suitable for appraising the urban grid as the interface between the physical city and the phenomena that occur along its paths, once again proves its usefulness in linking spatial issues and traffic questions, so as to bridge the traditional gap between urban design, focused on the morphologic features of blocks and buildings, and transport analysis, strictly concerned with the distribution of movement flows on the streets network.

KEYWORDS:
Urban sprawl, conurbation, resilience, configuration analysis

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城市圈与适应力。城市发展让我们更脆弱

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摘要

本文重点介绍城市圈，即几个邻近城市的扩张和聚集所导致的城市区域扩张。研究从两个方面入手。首先，在城市圈的发展中，交通实际上扮演着“城市创造者和破坏者”的双重身份，这里套用了 Colin Clark 的一本名著的书名，书中主要讲述了道路和交通在城市发展中所起的双重作用（Clark，1958 年）：一方面，建造一个四通八达的独特公路网，人们便可以相互来往，城市圈便可以像广域市那样发挥作用；而另一方面，主要人流集中在连接原先核心区与新开发区的几条道路上，实际上绕开了原有的城市干道，分散了城市街道的大量本地人流，与此同时还会因人口密集区的人流分流而导致经济损失。第二点，作为对上一条的补充，核心区整合为城市圈会削落整个居民区的适应力，反过来影响社会应对意外事件和改变的能力，但不会显著改变其整体行为。这里将从全局角度来研究城市圈现象及其适应力的历时性分析，而佛罗伦萨城市居住区被当成了理想的案例研究对象，对其进行了空间句法分析。结果将客观地描述城市圈建设中各城际道路的作用，并探讨在改变内部地理环境和加强整体危机防范方面的一致性程度。通常，顺理成章地将城市网视为连接实际城市及沿路景象之间纽带的全局方法，再次证明了它有助于在空间问题与交通问题之间建立联系，从而缩小关注街区和建筑的形态特征的传统城市设计与严密关注四通八达的街道中人流分布的交通分析之间的差距。

关键词：
城市扩张；城市圈；适应力；全局分析

1 INTRODUCTION

This paper is focused on the conurbations, extensive urban areas resulting from the expansion and coalescence of several neighbouring cities. A special attention will be devoted to the property of their resilience, assumed in relational terms and intended as the capability of an urban system, thanks to its own spatial features, to adsorb accidental events and transformations without significantly changing its inner geography and global behaviour. Such property is today to be considered a key issue, as related to the capacity of the system to continue effectively operating even in case of exceptional occurrences, and, in ordinary conditions, to the flexibility of the road network to adapt to the changing functional asset of the settlement.

Two theses underlay the research. The first is that, in the development of a conurbation, traffic has actually a role of 'maker and breaker of cities', just to paraphrase the title of a well-known article by Colin Clark, focusing on the double role of roads and traffic in urban development (Clark, 1958)': on a one hand, the making of a unique road network, encompassing the whole grid, actually allows movement and interaction all over the settlement, making possible the working of the conurbation as a wide urban system; on the other hand, the resulting pattern of movement concentrates its major flows on few roads connecting the original nuclei and the new development areas, actually bypassing the pre-existing urban fabric and diverting a significant amount of local traffic from the streets of the urban grid, what involves the loss of the fertilisation benefit the irrigation of through movement provides.

The second thesis, complementary to the former, is that the merging of the nuclei and their embedding into a conurbation reduces the resilience of the whole settlement, in that it affects the capability of the system to adsorb accidental events and transformations without significantly changing its global behaviour.

The phenomenon of conurbations and the diachronic analysis of their resilience will here be observed from a configurational point of view, by means of space syntax techniques, stressing the role of spatial relationships within the grid as the primary element of the effects of their development.

Several reasons suggest to assume the specific case of Florence as an ideal case study: the presence of a prominent and dense inner core, a wide recent urban development area, the presence of an important motorway that touches the conurbation so as to remain embedded into its local road network.

Fig. 1 The area of Florence: site plan

Since the beginning of this modern growth, in the post-war years, the presence of steep hills on the southern and eastern sides of Florence induced the development of Florence in a North-West direction, so as to determine the progressive urbanization of the so-called 'piana fiorentina' (literally 'Florentine plain'), binding together within a unique conurbation a number of pre-existing nuclei, namely Calenzano, Campi Bisenzio, Lastra a Signa, Sesto Fiorentino and Signa, up to the edges of Prato and Pistoia.
Over time, the urban congestion and the poor vehicular accessibility of the ancient inner core have gone inducing more and more prominent activities to shift towards this development area, which now houses the administrative departments of Tuscany Region, the regional hospital, the Penal and Civil Court, several departments of the University of Florence, the airport, several huge shopping centres, hypermarkets and department stores. As a result of such a dense concentration of activities, the Florentine plain is today one of the most attractive parts of the whole settlement, counterbalancing the traditional representativeness and the attractiveness of the historic centre of Florence, as well as the evocative strength it holds in the collective imagination.
The administrative fragmentation of the whole settlement, which overlaps the territories of 11 municipalities, prevented the provision of a global infrastructure development and an efficient public transport system all over the area; on the other hand, its local road network seems strongly supported by the national motorway A1, which touches Florence on its western side and actually works as a local road, internally connecting the conurbation.
The distribution of configurational values over time, as a result of the growth of the conurbation and according to the progressive transformation of its grid, will here be determined by means of a diachronic analysis since the beginning of XIX century and up to the present time. Such analysis is expected to provide some significant information on the transformation of the inner geography of Florence and its movement pattern with the making of the conurbation. The same results are also expected to pinpoint the role the motorway actually plays within the present pattern of urban vehicular movement, highlighting the degree to which it substitutes the connecting role of the local streets, what causes their impoverishment and decline: maker and breaker of cities, as stated.

2 BACKGROUNDS

Two main issues, variously crisscrossed, appear here interwoven. On the one hand, a wide issue is the growth of the urban settlement, which sprawls over time so as to form a conurbation, merging and binding together several pre-existing urban nuclei; such growth and merging involves the modification of the inner geography of the original nuclei and the shifting of the higher values of centrality towards the new development areas; accordingly, also the movement pattern is affected by these changes, which cause a different distribution of traffic flows. Another general issue is the matter of vehicular traffic in towns, the problems and the benefits it brings to urban settlements, as 60 years ago Clark pointed out; the presence of a motorway within the conurbation enriches the matter in the case study of Florence, thus extending the attention to the issue of the inclusion of motorways within the urban road network, and their use for local movements. Despite their evident connection, those two issues - urban morphology and dynamics, on the one hand, and traffic distribution, on the other hand - are generally approached from different points of view, as a result of a disciplinary division entrusted by a long-lasting traditional split.
The matter of the split between the treatment of roads as traffic channels and their assumption as streets - composing the public space of a settlement and narrowly connected with blocks and buildings - has been so far deeply investigated. The question of vehicular traffic in towns in fact dates back to the middle of the 20th century, when the increase of car traffic imposed the need for solutions, suitable for making the presence of vehicles compatible with buildings, pedestrians and urban life. The key idea of Modern Movement, explicit in

the Athens Charter and destined to widely affect town planning in the decades to come, was to split buildings and roads, liberating their own forms from each other, providing the urban roads with the unique role of circulation route and thus hierarchically classifying them with reference to traffic flow and road capacity. It is worth reminding that the split between urban roads and buildings necessarily involves the removal of traffic away from the building fronts, and hence the extinction of the street as intended so far: '*il faut tuer la rue-corridor*' (Le Corbusier, 1930) is the well known battle cry with such position.

Setting aside its effect on architecture and urban morphology, such traffic-driven approach was equated to a 'cataclysm' (Llewelyn-Davies, 1968) or even a real schism, definitely partitioning the two fields of traffic engineering and street (urban) design (Marshall, 2005). Since the middle of the 20th century, the main focus on the matter of vehicular traffic suggested the severe distinction between roads for traffic and access paths to buildings as well as their classification as 'entirely different and mutually antagonistic' (Tripp, 1950; p. 297), prelude to the subsequent hierarchical classification of urban roads by the Buchanan Report: '*basically, there are only two kinds of roads – distributors designed for movement, and access roads to serve the buildings*' (MoT, 1963; p. 44). Such distinction hence involved the assumption of the 'traffic conduits' as incompatible with the urban fabric and preventing them from approaching and giving access to buildings (Tripp, 1950); Oxford Street, London, is here cited as a very bad example of dangerous promiscuity, causing that '*on average, one pedestrian is injured by the traffic every shopping day*' (Tripp, 1950; p. 297).

The division between 'urban corridors' and 'urban rooms', represented by the metaphor of the hospital, whose departments are individually accessible and cannot be affected by through routes (MoT, 1963), as well as the paradigmatic planning of Radburn, in New Jersey, is well suited to represent this method, whose basic rule is to facilitate origin-destination movement and to repel through traffic: '*shopping, business and residential areas must be kept quite separate from all arterial and sub-arterial roads, and confined to local roads (…); the layout of systems of local roads must be such as will afford no short-cuts to through-traffic*' (Tripp, 1950; p. 310). On the whole, the result is what was said '*a division of traffic and towns into separate areas of priorities*' (Marshall, 2005; p. 48).

Relevant and recurring criticisms have long been raised against such approach - milestones, among others, Jane Jacobs and Christopher Alexander -, mainly complaining the impoverishment of the streets it involves, the weakening of social life and the shifting of accessibility from the historic centre towards the periphery (Jacobs, 1961; Alexander, 1966); yet the split between movement and urban space still persists nowadays, and the question concerning the road network and the accessibility to places and activities are mainly faced as mere infrastructural issues and a specific matter of traffic engineers, or, as it was said, '*from the traffic point of view*' (Tripp, 1950).

In light of the above considerations, it will be clear why a configurational approach was here selected for the present case study. In that it assumes the urban grid as the primary element in the distribution of movement, such approach allows to consider the configuration of the streets network as the key element in the patterns of human behaviour (Hillier, Hanson, 1984) and hence in most urban phenomena (Hillier, 1996b); what does not involve that a configurational approach can substitute any transportation model, nor it can provide the numeric amount of traffic flows. Nonetheless, in a configurational view '*the discovery that the spatial integration pattern of the street network shapes movement is more important that perfect prediction. It puts us in a position to design space for movement, and then assign the land uses to the right places according to their need to be close to movement*' (Hillier, 2005; p. 99); since '*in shaping movement*', the spatial pattern of the street network '*also shapes the patterns of human co-presence - and of course co-absence – that seems to be the key to our sense that good cities are human and social things as well as physical things*' (Hillier, 2005; p. 99). The matter is therefore not in movement itself, but in the relationship between movement and urban space; what is exactly the matter this research is concerned with, that is the dual phenomenon of the urban sprawl of Florence and the actual distribution of traffic flows.

Two wide issues appear therefore crisscrossing in the matter that is here concerned.

The first one obviously is the matter of traffic, due to the presence of a motorway, lapping the western side of the conurbation and arguably playing in this area, to some extent, also an urban role. The second issue regards the properties of the whole conurbation and its road network, with special reference to its resilience. And both issues can be usefully investigated by means of a configurational approach.

For what concerns urban movement, an amount of researches have been conducted in the last decades, in a wide range of directions: discussing the role and importance of 'natural movement', uniquely referred to the grid configuration (Hillier et al., 1993), discussing the capability of space syntax based models to reproduce the pedestrian flows (Jiang, 1999), demonstrating the strong relationship of the configurational values with the distribution of pedestrian flows (Cutini, 2001), proposing the use of space syntax to enhance the safety of pedestrians (Raford, Ragland, 2004), discussing the relationship between cycling routes and urban morphology (Raford, Chiaradia, 2007), showing the possible use of space syntax to support the planning of cycling routes (Dalton, 2015), or suggesting the applicability of space syntax to bicycle facility planning (McCahil, Garrick, 2008). All these researches agree that the integration value and the choice value are to be acknowledged as useful and reliable indicators of centrality. Different notions of centrality, in hindsight: while integration reproduces the to-movement potential of a spatial element as a destination (Cutini, 2005), choice measures the through-movement potential of an element as a piece of route (Hillier et al., 1993; Hillier, 1996a; Penn et al., 1998; Hillier, Iida, 2005).

Also for what specifically concerns the analysis and improvement of vehicular traffic in urban areas, the use of space syntax has already been variously tried and tested, focusing on several issues; among others, the use of space syntax in transport analysis (Pereira et al., 2008), the correspondence between planning choices and traffic (Giannopoulou et al., 2012), the use of space syntax as a traffic assignment tool (Barros et al., 2007), centrality measures for traffic (Scoppa et al., 2009; Kazerani, Winter, *2009*), traffic optimization (Zheng et al., 2008), car crashes (Dasanayaka, Jayasinghe, 2014), traffic noise (Dzhambov, 2014) and so on. Also different methods, using street-based representations for predicting traffic flows, have been proposed and successfully tested (Jiang, Liu, 2007). And interesting observations have stressed the strength of the law of scaling also with reference to vehicular movement, showing the street hierarchies as a good indicator for traffic flows (Jiang, 2008).

It is not the purpose of this paper to discuss on the most reliable method for narrowly approximating traffic and thus predicting the distribution of its flows. It will rather addressed the matter of the relationship between traffic and urban fabric, discussing the way the distribution and pattern of traffic change with the sprawling growth of the settlement, as the whole grid goes so far as to encompass and include extra-urban roads. In such cases those roads frequently seem to remain entangled within the conurbation so as to work as local traffic distributors, mainly operating between the single urban nuclei that have gone generating it. Here issues of urban dynamics and matters of traffic go combining and intertwining, influencing each other and causing several problems, both in urban and infrastructural field. And here, therefore, a configurational approach, aimed at connecting and integrating those aspects, can actually play its part.

Closely linked to the matter of traffic is the further issue of urban resilience, which is increasingly regarded as a key property of urban systems and has been variously declined in order to indicate and reproduce different features. A relational notion of resilience, to be called 'network resilience' will be here taken into account, assumed as the capability of an urban system, thanks to its own spatial features, to adsorb accidental events and transformations without significantly changing its inner geography and global behaviour (Cutini, 2013); and, when it comes to vehicular traffic, it is clear which kind of events or transformations are here mainly concerned: car accidents, road disruptions, traffic jams, traffic regulations. What in particular makes network resilience strongly related to traffic issues is that fundamentally it is appraised as a result of the diffused richness in alternative paths from any origin to any destination; while, on the other hand, resilience clearly affects traffic, as related to the vulnerability of the road network to any turbulence, as well as its flexibility and capacity to adapt to different functional assets.

With reference to the network resilience, three main indices have been so far introduced and tested (Cutini, 2013): the mean connectivity value of the grid (suitable for roughly reproducing the density and variety of paths connecting each line to all the others of the axial map), the frequency value (suitable for reproducing the degree to which the shortest paths are diffused all over the grid) and the synergy coefficient (reproducing the strength of the correlation between the distribution of integration values at different scales). In this paper a further parameter will be introduced and discussed with reference to the case study of Florence, aimed at appraising the degree of polarization of the movement flows distribution, to be regarded as clue of vulnerability of the system.

3 METHODOLOGY

As hinted above, a configurational approach was here selected as a tool for the analysis of conurbations. What suggested this choice is its assumption of the urban grid as the primary element in the distribution of movement and hence in determining the patterns of human behaviour (Hillier, Hanson, 1984): mainly movement, which is oriented and leaded by the visual perception of the spatial layout, and through movement, also the location of activities, land value and so on. At the root of the configurational approach is the assumption that an urban grid contains, due to the spatial relations between its elements, an intrinsic vocation for attracting movement flows (Hillier, 1996); which is liable to drive movement-seeking activities towards the most crowded spaces and to address the movement-avoiding ones towards the most segregated and deserted. Several operational techniques – encompassed under the denomination of space syntax - have been so far developed, differing from one another in respect of the way of reducing the grid into a system, and hence on the single spatial element composing it: the line in axial analysis (Hillier, Hanson, 1984), the vertex in visibility graph analysis (Turner et al., 2001), the segment in segment analysis (Turner, 2005), the road-centre line in road-centre line analysis (Turner, 2007), the mark point in Ma.P.P.A. (Cutini et al, 2004). Despite these differences, still all those techniques share the same conceptual basis sketched above; and all provide each element of the grid (either line, vertex, segment, road-centre line or mark point) with a set of parameters suitable for reproducing different urban aspects. Among those parameters, integration and choice value are acknowledged suitable for describing the changes in the inner geography of the settlement. Integration is the normalised value of the mean depth of an element with respect to all the other elements of the grid (Hillier, Hanson, 1984), and should describe its accessibility, that is how easy it is to get to from all other elements; concretely, in fact, it was proved suitable for narrowly reproducing the actual density of the located activities, and hence the distribution of attractiveness, or the vocation of a place to work as an appealing location (Cutini, 2005). Choice, defined as the frequency of a spatial element on the shortest paths connecting all pairs of other elements, is suitable for measuring how likely an element is to be passed through: in fact, several studies attest a strong correlation of choice with the distribution of movement flows (Hillier et al., 1993; Penn et al., 1998; Hillier, Iida, 2005). In other words, while integration reproduces the to-movement potential of a spatial element as a destination, choice measures the through-movement potential of an element as a piece of route (Hillier, 2012).

With reference to the network resilience, three main indices have been so far introduced and tested (Cutini, 2013). A first parameter is the mean connectivity value of the grid, which measures the density and variety of paths connecting each element to all the others. High values of connectivity are likely to guarantee a dense presence of alternative paths and hence the capability of the urban system to absorb a material grid transformation without significantly modifying its relational state (Cutini, Rabino, 2012). A further index takes into account the distribution of shortest paths: being resilient the systems that are provided with a widespread presence of shortest paths all over the grid and, on the contrary, vulnerable those that are characterized by their dense concentration through a small number of spatial elements. On such basis, an indicator of resilience was introduced (Cutini, 2013) as the ratio of the highest choice value and the maximum frequency a spatial element could present, what would occur if it were located on all the shortest paths between any couple of the other elements. In a system of n elements, this index, called frequency index, is expresses as follows:

$$v = choice_{max}/(n^2/2 - 3/2\ n + 1)$$

The frequency value obviously varies from 0 to 1, increasing as the resilience of the system decreases. In the extreme case, should a line be located on all the shortest paths connecting all the couples of lines (v = 1), the system would result vulnerable to its highest degree, in that each of its paths will share (and depend on) that single line.

A further parameter, called 'synergy coefficient', reproduces the strength of the correlation between the distribution of integration values at different scales (local versus global). Since integration was proved suitable for reproducing the distribution of urban centrality at different values of radius, a strong correspondence of global and local integration can be assumed as a clue of steadiness of the system. Those three parameters can hence be used as tangible indicators of the network resilience of the whole system and to reproduce its trend over time.

The configurational technique named axial analysis was applied to the case study of Florence and to the Versilian conurbation; in both cases the actual grid consistency at different dates was analysed in order to obtain the respective configurational state and hence its diachronic trend during the making of the conurbation.

4 THE CASE STUDY

As presented above, this research is applied to the case study of the Florentine conurbation, which has gone growing on the northern side of the historic core of Florence since the middle of the 20th century. This paper aims at using space syntax in order to reconstruct the diachronic genesis of the configuration of this whole system, from the date preceding the modern growth of Florence, up to the present point in time. Given the strong relationship that correlates the configurational indices with traffic flows, the analysis of the grid configuration at different dates (before and after the north-western growth) will allow appraising the actual role of the motorway A1 within the urban grid, since its first encompassment within the whole area of the conurbation and up to the present date. The present configurational state will then be cross-referenced with the available vehicular traffic data, in order to evaluate the actual degree of inclusion of the motorway within the urban system of Florence and its likely influence in the distribution of local traffic flows. On this regard, those data can be preliminarily presented, in order to describe the general matter of the motorway traffic in the area of Florence.

The motorway A1, opened in 1964 and thereafter subject to upsizing works, was actually reached by the sprawling Florence in the first '70s and then swallowed within the conurbation at the end of the century. In the Florentine area, the motorway is provided with 5 gates for entrance and exit (namely, from south to north, Firenze Sud, Firenze Impruneta, Firenze Scandicci, Firenze Nord and Calenzano); in addition, the settlement hosts two other motorway gates, that is Prato Est and Firenze Ovest, on motorway A11. The traffic data of the motorway A1 (light vehicles) in 2014 around the gates of Florence is here represented in figure 2, which allows to easily notice the sharp rise of average traffic volume as soon as the motorway enter the Florentine area.

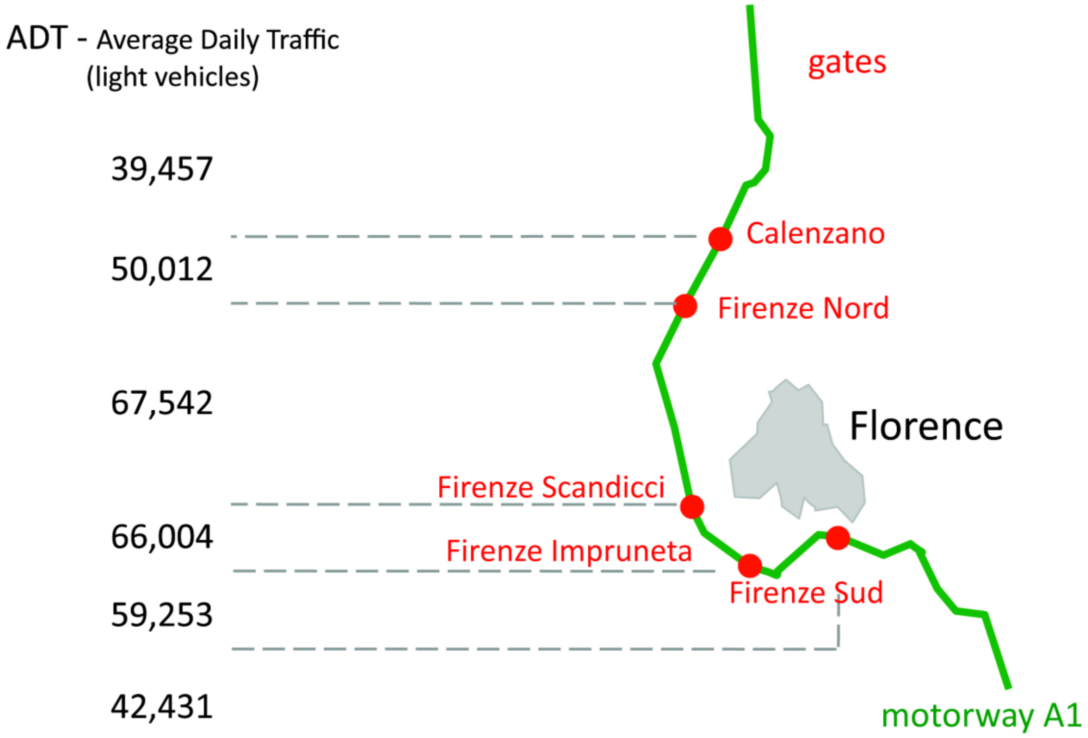

Fig. 2 Traffic data (light vehicles) of motorway A1 in 2014

It hence appears clear that traffic on motorway A1 is strongly increased by local traffic, that is car movements with both origin and destination within the Florence urban area. In other words, the difference between the average values within the Florence area (50,000/67,500 light vehicles) and the values outside (around 40,000 light vehicles) can be clearly considered just as urban traffic. If we then focus on the Florence area, and observe only the vehicles that in 2014 passed through the local gates of the motorway A1, their traffic data, provided by Autostrade per l'Italia S.p.a., operator of the motorway, are here shown in tables 1 and 2.

destination origin	Calenzano	Firenze Nord	Firenze Scandicci	Firenze Impruneta	Firenze Sud	Firenze Ovest	Prato Est	Total
Calenzano	-	252,756	839,648	426,949	513,567	188,070	32,946	2,253,935
Firenze Nord	428,050	-	136,699	391,774	342,737	19,051	46,453	1,364,764
Firenze Scandicci	925,831	82,256	-	798,686	1,463,240	225,205	864,720	4,359,938
Firenze Impruneta	406,377	59,541	671,864	-	1,387,202	475,406	361,514	3,361,904
Firenze Sud	474,631	52,495	1,458,769	1,452,646	-	372,237	435,636	4,246,414
Firenze Ovest	76	46	127	167	149	-	3,312,974	3,313,539
Prato Est	32,202	30,388	836,452	373,474	486,617	3,211,232	-	4,970,365
Total	2,267,167	477,481	3,943,559	3,443,696	4,193,512	4,491,201	5,054,243	23,870,859

Tab. 1 Vehicular flows in the Florence area in 2014 (source: Autostrade per l'Italia S.p.a.)

Destination Origin	Whole Florence area	Total	Percentage Florence area
Calenzano	2,253,935	3,556,668	63.4 %
Firenze Nord	1,364,764	2,800,640	48.7 %
Firenze Scandicci	4,359,938	7,149,299	61.0 %
Firenze Impruneta	3,361,904	4,922,532	68.3 %
Firenze Sud	4,246,414	6,950,527	61.1 %
Firenze Ovest	3,313,539	6,677,345	49.6 %
Prato Est	4,970,365	7,075,529	70.2 %
total	23,870,859	39,132,540	61.0 %

Tab. 2 Vehicular flows in the Florence area in 2014 – total data

The data reported in the last table are specially clear and highly impressive: over 60 per cent of the total vehicular movements locally entering the motorway actually has a local destination, confined inside the Florentine area, values that go as high as 70 per cent in some of the gates: a significant amount of the motorway traffic in the area of Florence is hence actually local – that is urban – traffic, going on top of the heavy vehicular traffic running down the peninsula and making the Autostrada del Sole a very crowded motorway, with high percentage of troubles, traffic jams and car accidents. Conversely, a large amount of vehicular traffic to and from locations within the Florentine conurbation does actually use the motorway, preferring it to the urban grid, despite the toll payment its use involves. As a matter of fact, the seven motorway gates appear mainly working as urban network nodes, rather than extra-urban movement terminals. The question is whether this traffic assignment is to be acknowledged as influenced by the structure of the settlement; or, in other words, if is it possible to find any clue that the grid configuration itself is the primary element addressing the route choice towards the use of the motorway. In order to answer this questions, a configurational analysis of the settlement was carried out, beginning from a diachronic analysis, aimed at reconstructing the genesis over time of the grid configuration, and then focusing on the present state of the system.

As for the diachronic analysis of the settlement, nine significant dates have been selected, suitable for identifying as many epoch-making moments in the modern growth of Florence. The first one is 1825, date of the Lorraine cadastral registry, reliably reproducing the layout of the city in 1:1,250 scale just before the beginning of modern urban growth. Apart from few punctual transformations, such state appears fundamentally unchanged with respect to the golden era of the Renaissance. The second date is 1858, just the year before the annexation to the Kingdom of Italy. The third date is 1867, representing the 6 years when Florence was the capital of Italy, and, above all, reproduces the transformation works carried out for such role; among them, in particular, are to be mentioned the demolition of the ancient townwalls, their substitution with a ring boulevard and the realization of the first extra-moenia residential developments. The forth and fifth date are 1910 and 1938, witness dates of the progressive consolidation of the radial growth out of the inner core. The sixth date is 1955, reproducing the saturation of the flatland towards south and east, as well as the beginning of the unidirectional growth towards north-west, which appears developed at the following date, 1970; the conclusion of this growth is attested by the cartography at the eighth and ninth dates, respectively 1990 and 2015, with the progressive merging of the north-western urbanization with the surrounding settlements and the making of the present conurbation, swallowing and including the layout of the motorway. The grid corresponding to each of the dates above was analyzed by axial analysis.

The diachronic trend in the distribution of integration value in Florence is here summarized in figure 4. As the system has gone greatly increasing over the years (as can be seen in figure 3), it was here preferred to use here different scales of representation, in order to maintain a full view on the whole system and clearly describe the distribution of values and their trend over time.

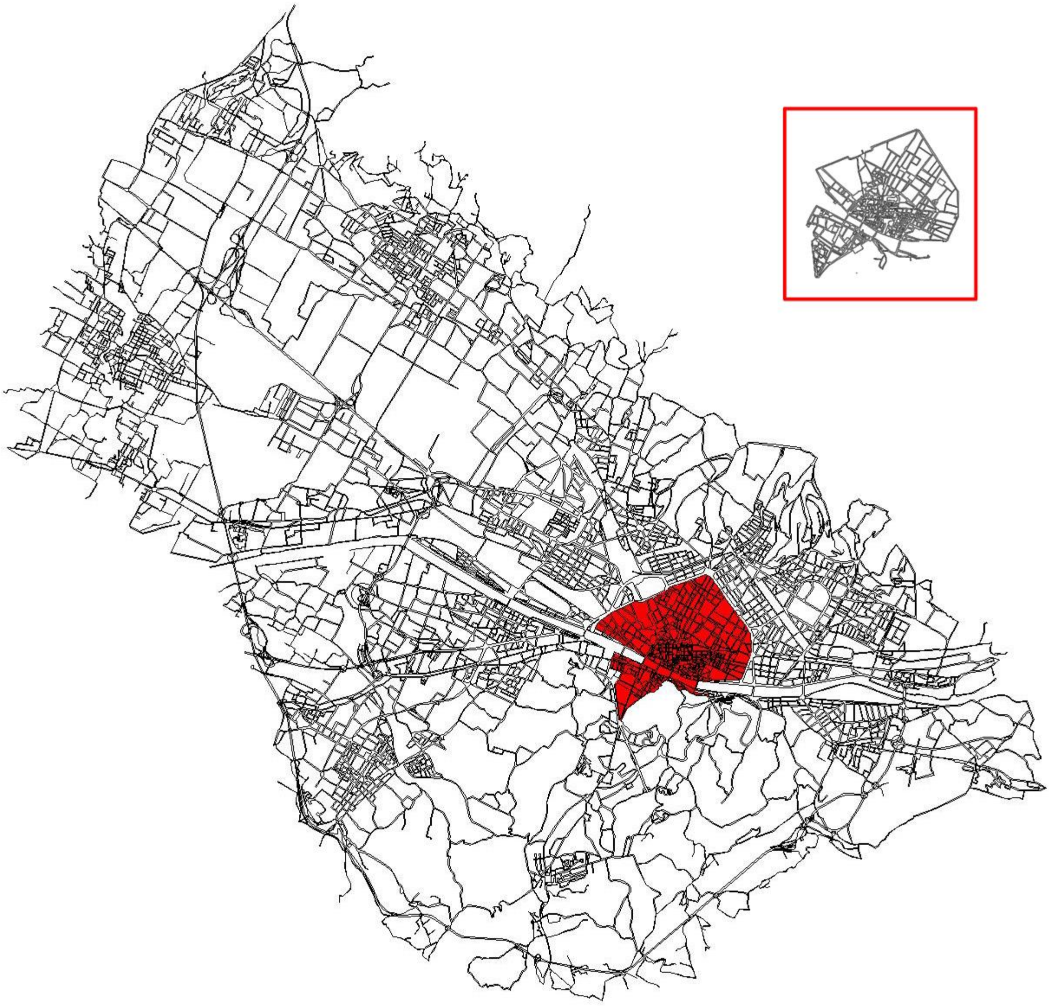

Fig. 3 The grid of Florence at the present date and (above and highlighted in the box) at 1825

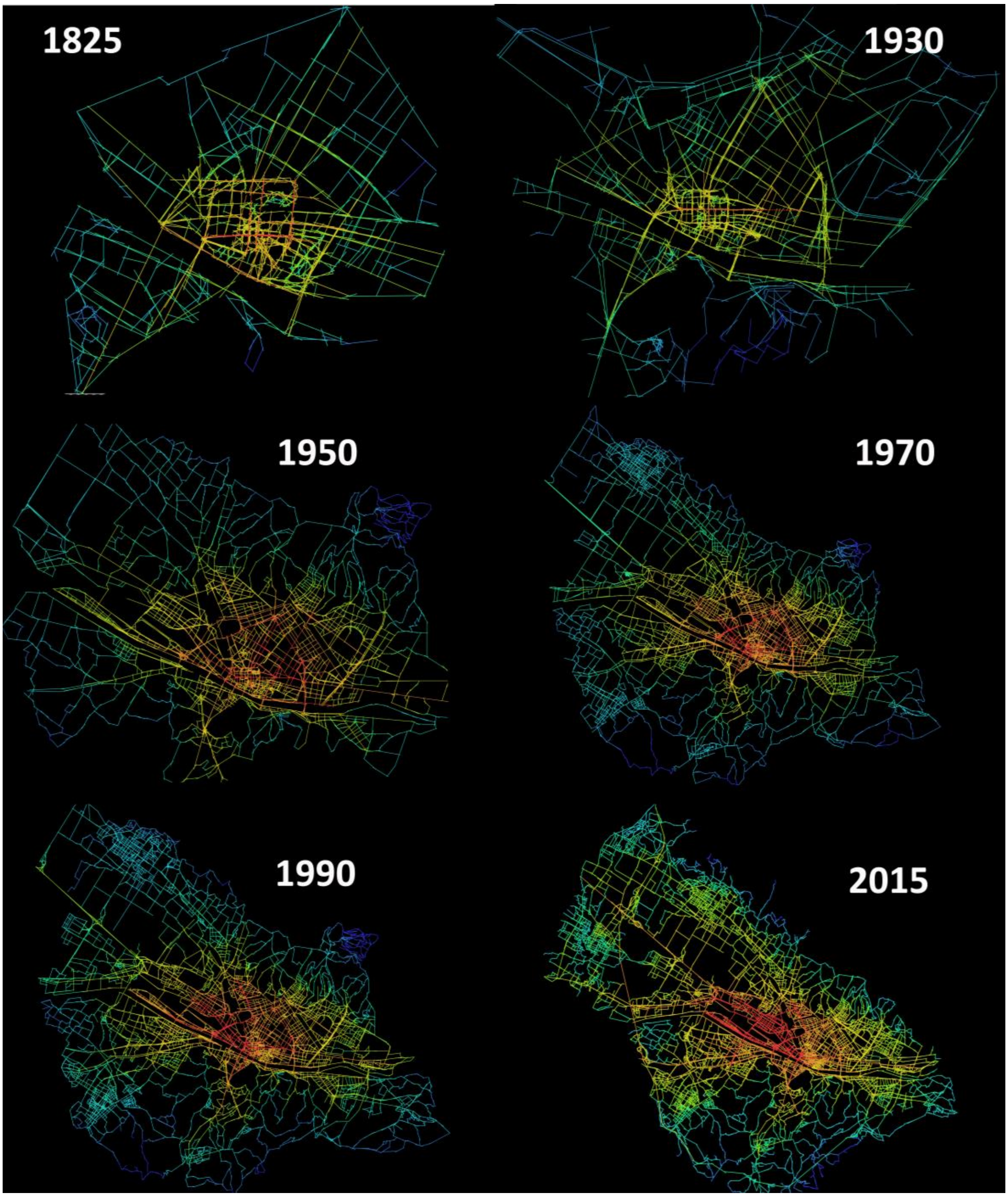

Fig. 4 Distribution of global integration in Florence 1825-2015

Some considerations easily arise from the observation of those results. First, a progressive shift of centrality, from the geometric centre of the inner core towards the external radial developments, is clearly shown in figure 5: while in the first three maps of the 19th century the strongest integrators appear to steadily persist coinciding with the cardus and decumanus of the original Roman layout of the city, in the very heart of Florence, since the early twentieth century the outer ring appears gaining more and more attractiveness. The making of the conurbation, in the last decades of the century, appears to involve the clear orientation of the integration core towards north, up to the last state, at 2015, showing it steadily anchored between the ancient townwalls and the recent north-western developments.

The images in figure 5 represent the correlation of local integration versus the global one, whose coefficient was mentioned above as 'synergy value', accounting for the extent to which local centralities depend on the whole pattern of centrality. This index can be assumed as an indicator of the degree to which the different scales of the settlement are actually correlated, so as to concur in synergy to the global working of the city, which is commonly acknowledged a vital property in urban areas: in case of a strong correlation, local integrators are also prominent integrators at a global scale, thus creating a stronger and perceivable interface between the whole settlement and its single parts. The diachronic trend of synergy coefficient, since 1825 up to the present time shows a clear weakening of the correlation in the second half of the twentieth century (from R^2 = 0.92 to R^2 = 0.55), as a result of the sprawl of Florence and the growing of the conurbation.

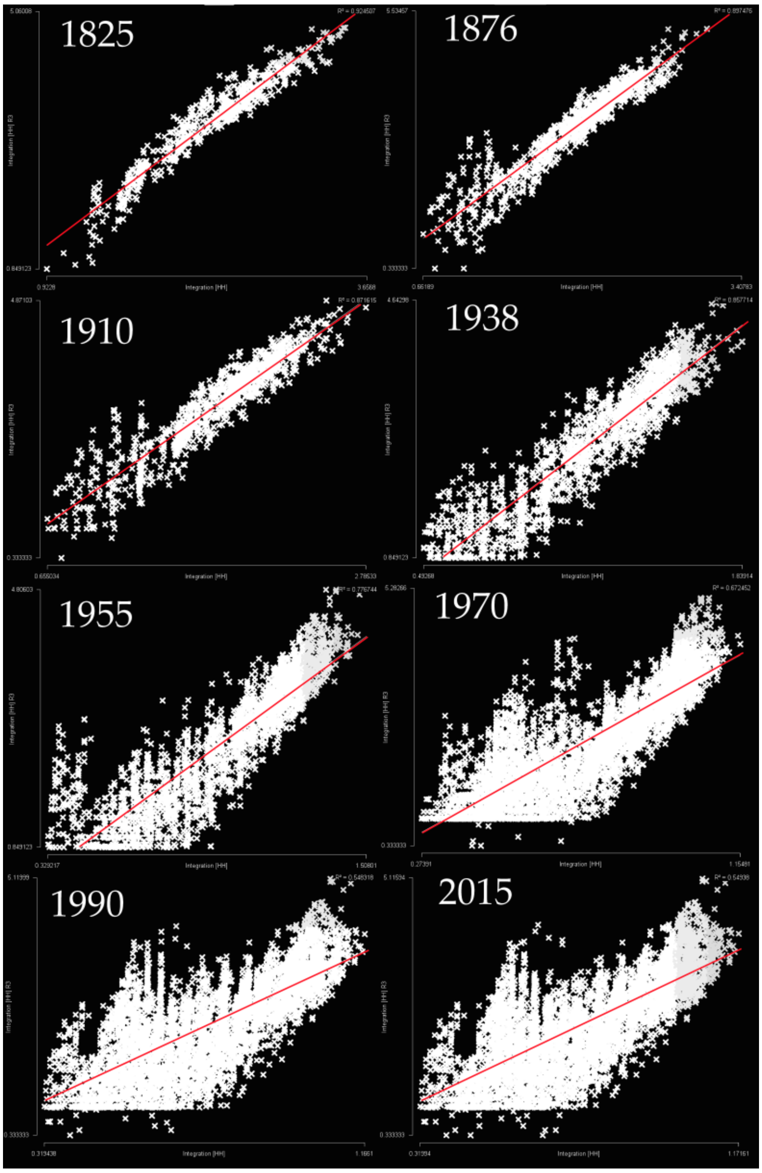

Fig. 5 Correlation local (R = 3) vs. global integration in Florence 1825-2015

The figure 6 summarizes the diachronic trend of the three resilience parameters in the period 1825-2015, highlighting the recent increase in the spatial vulnerability of the system. In fact, the decrease in the mean connectivity value stands for the decrease in redundancy of connections, what is commonly acknowledged as a fundamental element of urban resilience (Salingaros, 2005), as well as a precious source of urban life (Dupuy, 1991). Moreover, the decrease in synergy value stands for the weakening of the spatial relationship between the whole settlement and the local centres, which are scattered around and drift away, detached from the global spatial structure. Furthermore, the sharp rise of the frequency value stands for the strong polarization of the network structure around a limited number of road axes. Just like the tree-like pattern described by Christopher Alexander, a tree whose major trunk is here the motorway, distributing movement flows to the neighbourhoods scattered around: 'Whenever we have a tree structure, it means that within this structure no piece of any unit is ever connected to other units, except through the medium of that unit as a whole' (Alexander, 1965; p. 50).

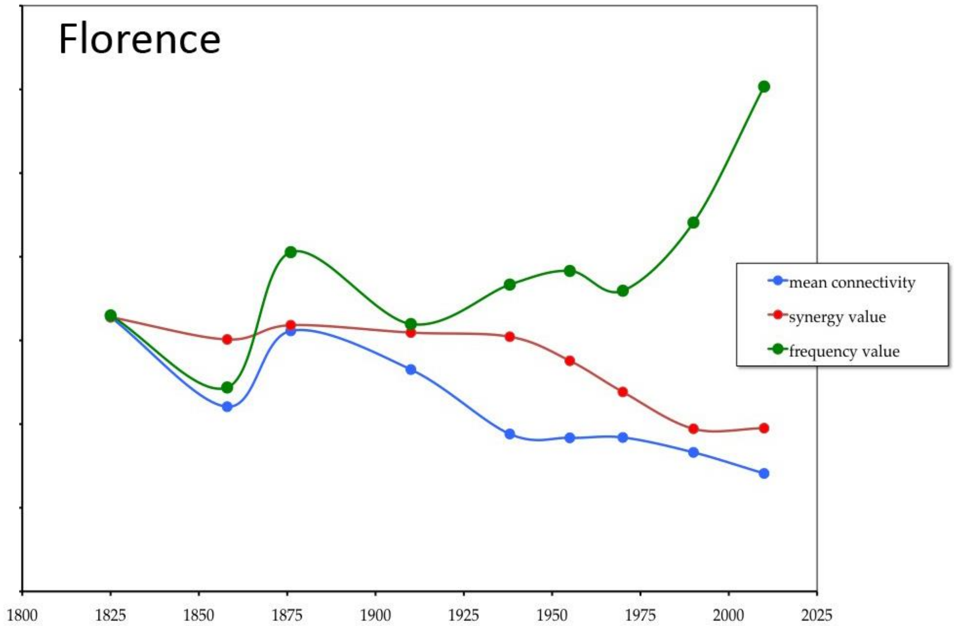

Fig. 6 The trend of resilience parameters in the grid of Florence in the period 1825-2015

All those phenomena appear attested in the grid configuration corresponding to the first '70s, and can be easily referred to the making of the conurbation and the embedding of the motorway within its grid: at present, the whole settlement actually appears highly depending on a handful of distributor roads, and above all on the motorway itself, provided with the highest values of choice: should any perturbation affect this road (as it is likely to occur, due to possible car accidents or traffic jams, unfortunately so frequent in this crowded section of road), the whole urban system would be at risk of globally collapsing.

A qualified literature on the issue (Penn et al., 1998; Hillier, Iida, 2005; Iida, Hillier, 2005; Turner, 2005) suggested to use angular segment analysis, according to different values of metric radius, in order to determine likely patterns of movement. Such analysis was therefore applied to the present grid of Florence, with radius varying from 400 m up the highest value of 15,000 metres in order to encompass the whole conurbation. Obviously the lowest values of radius are expected to provide the likely pattern of pedestrian movement, while the highest are suitable for reproducing the distribution of vehicular traffic.

The results of these analyses, for what concerns the distribution of choice values, are summarized in figure 7 and reveal that the distribution of pedestrian movement (R= 400/800 metres) mainly involves the streets of the inner core, making to clearly emerge the orthogonal grid of the ancient Roman city; on the other side, the vehicular traffic flows (R= 15,000 metres) are particularly intense outside the historic centre, towards the northern edge of the conurbation.

A further, appropriate refinement in the representation of vehicular movement pattern would then result from the clearing of the limited traffic zone out of the urban grid. As a matter of fact the streets of this zone, which at present approximately covers the area encircled within the ancient townwalls, do not actually concur to the road network of the settlement. As a result of the cancelation of those streets, the distribution of choice values, with a radius of 15,000 metres, appears as shown in figure 8.

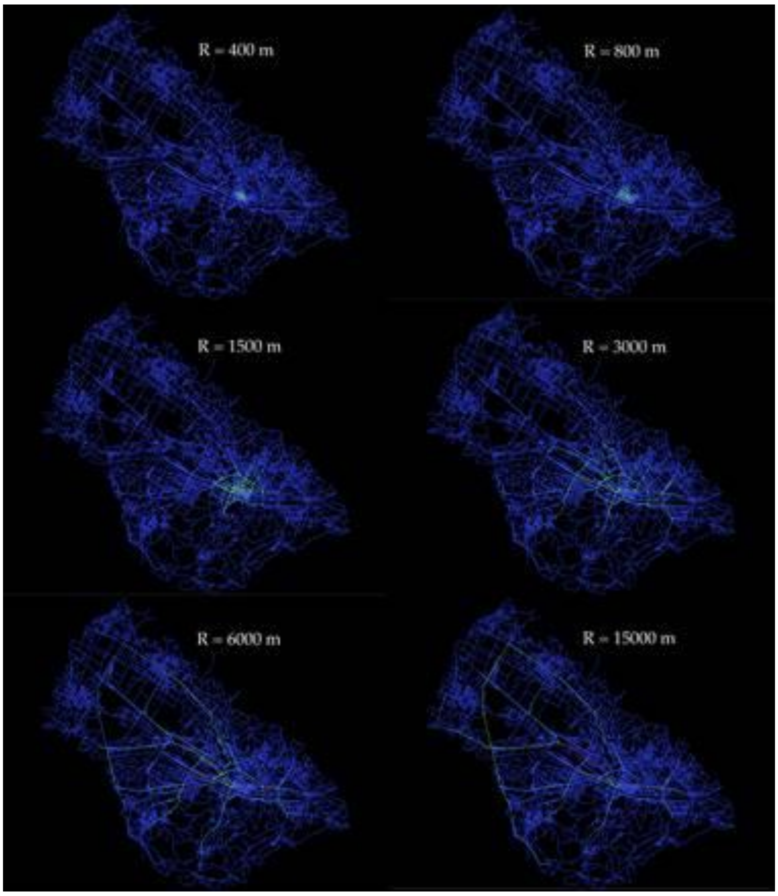

Fig. 7 Distribution of choice value in Florence for different values of metric radius

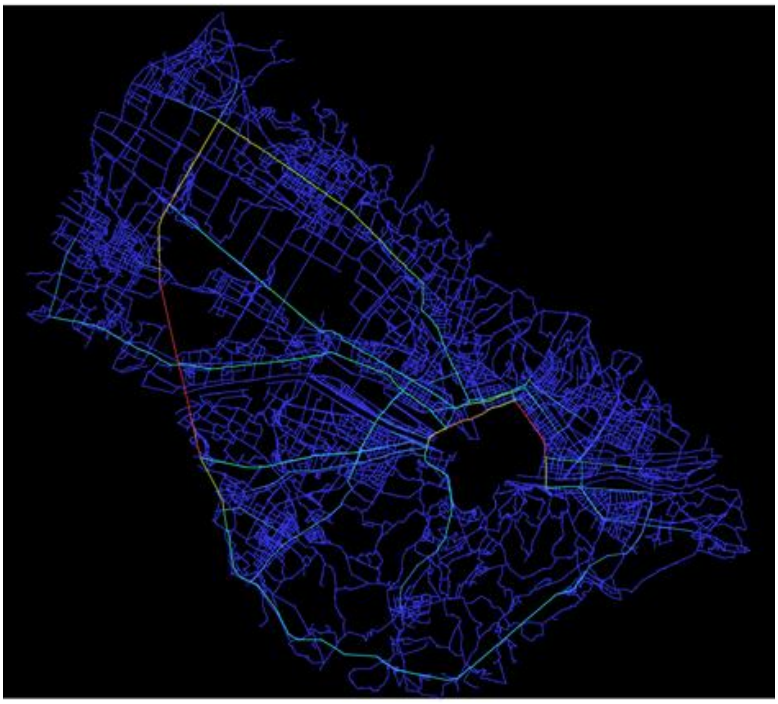

Fig. 8 Distribution of choice value in Florence (R= 15,000 m), net of the limited traffic zone

The figure above highlights two major traffic distributors, as provided with the highest choice values: the road segments composing the ring route surrounding the historic centre – the so-called 'viali', which in 1865 substituted the pre-existing townwalls; and the Florentine section of the motorway A1, appearing an outer ring on the western side of the conurbation. This result appears to exactly correspond to the actual phenomena of traffic congestion in the area of Florence, as it is perceived in the common sense as well as objectively measurable by direct survey. But it also appears to clearly materialize the traditional classification of traffic engineers in '*roads to be built as traffic conduits*' (here in green and red) and '*roads to be built for the needs of the local communities to give access to their homes*' (here in blue) (Tripp, 1950; p. 297) that was mentioned above. Two aspects are worth highlighting. First, the motorway appears to divert a significant amount of traffic from the streets of the urban fabric, thus depriving them from the precious by-product of origin-destination movements (Hillier, 1996b). Moreover, on the traffic side of the matter, it has to be noted that, while the few large scale movement arteries mostly run on the edge of the settlement, the short range movements, suitable for pedestrian movement, are exclusively encompassed within its inner core and hence are practically non existent all over the wide conurbation. The hierarchical sequence traffic distributors / local traffic roads / pedestrian paths traditionally established by the manuals of traffic engineering for the efficient distribution of urban movement here appears broken and incomplete in most of the settlement, mainly due to the absence of a much finer scale structure outside the historic centre, suitable for receiving and distributing local traffic: a serious deficiency, since cities, as Hillier wrote, quoting John Peponis, '*in a sense, are interfaces between scales of movement*' (Hillier, 1996b; p. 56).
This evidence induces to deeply investigate on the hierarchy of configurational values, observing the change of the frequency distribution of choice values in 2015 and in 1930, before the merging of the conurbation (fig. 9). It can be seen that over 95% of values is today under the 5th percentile, while in 1935 such percentage was around 83%. The choice values appear hence to follow a Paretian distribution: few lines (2% in 1930, 0.2% in 2015) take the overwhelming majority of the shortest paths between any couple of the others, and the slope of the function gets steeper with the progressive making of the conurbation.

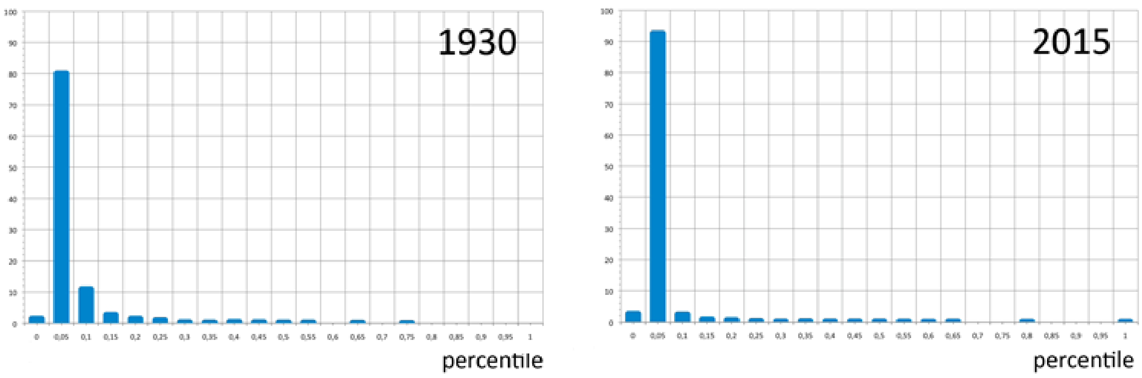

Fig. 9 Frequency distribution of choice values in the axial map of Florence at 2015 and 1935

The decrease of choice values appears so steep as to suggest representing their distribution by means of log-log rank-choice diagrams, having on x-axis the logarithm of rank (ordered by decreasing values of choice) (fig. 10). Those diagrams appear to narrowly correspond to a typical Zipf's function

$$ß \log R_i + \log Ch_i = \log Ch_1 = constant$$

up to a cut-off threshold, after which such correspondence sharply weakens and choice values rapidly drop.

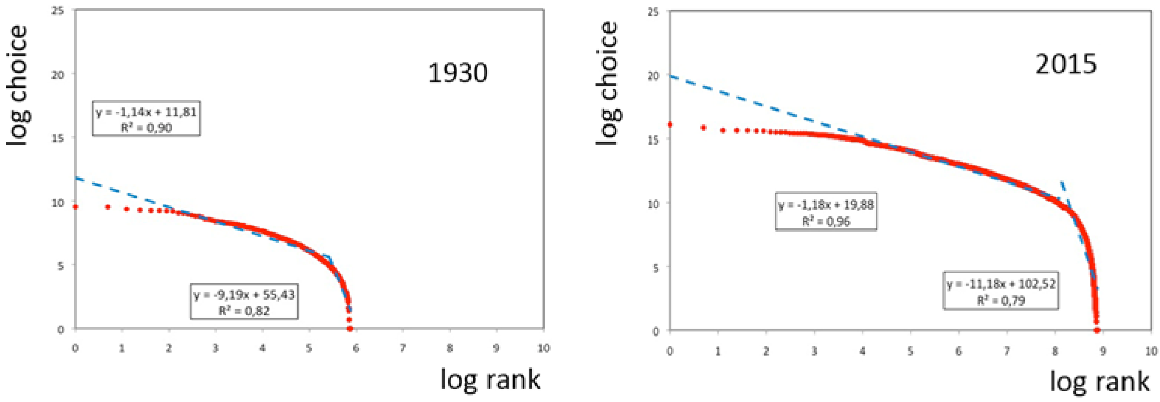

Fig. 10 Log-log rank-choice values in the axial map of Florence at 2015 and 1935

The distribution represented in figures 9 and 10 certifies that the merging of the conurbation has determined a strong polarization of the movement flows along a very limited number of spatial elements, hosting the vast majority of traffic. Conversely, an increasing number of lines (over 95% in 2015) appear excluded by the through movement all over the grid. Comparing such findings with the actual distribution of choice values represented in fig.8, we may easily observe that the very heart of this phenomenon of polarization is the motorway, while the suburban fabric appears almost entirely segregated from the major traffic flows.

5 CONCLUSIONS

The results sketched above allow certain conclusions to be drawn on the effect of the making of the Florentine conurbation. First, the diachronic analysis of its configurational state confirms the actual progressive shifting of centrality from the original inner core towards the north-western development area. Besides, the resilience of the whole system appears weakening as a result of the recent growing of the conurbation and to the strong polarization of the network structure around a limited number of road axes; among them, the motorway A1 in particular, lapping the urbanized area on its western side, appears to polarize most of the whole traffic within the conurbation. Moreover, a large amount of internal movement bypasses the urban grid of the conurbation, moving from an urban origin to an urban destination through the motorway, even at the cost of the toll payment: the vast majority of the accesses to the motorway through the gates of the Florentine area actually corresponds to local (that is internal) movement. Furthermore, the motorway A1 appears supplementing the urban streets, thus improperly concurring in supporting the working of the system; what obviously involves a local worsening of its traffic condition, heavy in itself because of the heavy traffic running down the Italian peninsula. Yet, apart from this effect on traffic, the local role of the motorway also diverts a significant amount of vehicular traffic flows from the streets of the urban grid, involving the loss of the fertilisation benefit the irrigation of through movement provides. And each of these aspects appears worth highlighting, as they clearly affect both the inner geography of the settlement and merely traffic issues, linking them and making evident the mutual influence of one on the others.

More in general, leaving aside the case of Florence, two aspects deserve a special focus.

The proposed method can be applied to the general issue of motorways in metropolitan areas, in order to evaluate the relationship between the motorway and the urban road network and the actual entanglement of inter-urban roads within the system of the conurbation: a widespread phenomenon, commonly resulting from the growth of the urban settlements and their sprawl into the surrounding areas.

Even more in general, the configurational approach, suitable for appraising the urban grid as the interface between the physical city and the phenomena that occur along its paths, once again proves its usefulness in linking spatial issues and traffic questions, so as to bridge the traditional gap between urban design, focused on the morphologic features of blocks and buildings, and transport analysis, strictly concerned with the distribution of movement flows on the streets network.

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IMAGE SOURCES

Fig. 1: Google Earth

Fig. 2: Autostrade per l'Italia S.p.a

Fig. 3, 4, 5, 6, 7, 8, 9, 10: elaborated by the author

AUTHOR'S PROFILE

Valerio Cutini as a researcher in Town Planning in the University of Pisa, since 1996 Valerio Cutini teaches Urban Planning at the School of Engineering of the University of Pisa. His main interests and studies are in the areas of the analysis of urban settlements, aimed at focusing on their development and the diachronic transformation of their morphology and functional consistency.