

Tuscany Configurational Atlas: A GIS-Based Multiscale Assessment of Road-Circulation Networks Centralities Hierarchies

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Abstract. Digital thematic maps availability has increased with the diffusion of open-source Geographic Information Systems (GIS) suites, which also had important role in urban and regional sciences revamp throughout the late 1990's. These methodological innovations led to the conception of network-based data maps oriented to highlight urban scale road-circulation networks configurational properties, that supported comparative studies regarding cities' morphologies and their representation as complex systems. However, significant hindrances persist for the construction of very large road-circulation network datasets, such as those suitable to regional and supra-regional scale analyses. Owing to their sheer sizes, modelling these expanses require extensive processing times, which impact on research prospects. Data precision is a concern as well, since generalization processes, whereas can reduce computing complexity, oftentimes render comparisons amongst different scales inaccurate, due to certain road structures non-representation. Research requirements for a comparable and accurate multiscale database, suited to evaluate circulation networks configurational properties of centrality, prompted construction of the Tuscany Configurational Atlas as an experiment. Intended as a set of GIS-based digital thematic maps and data repository, it depicts *closeness* and *betweenness* centralities hierarchies of the Tuscan Region road-infrastructure in regional, provincial and municipality scales. This paper summarizes the scope and methodological steps to construct this Configurational Atlas, while reducing regional-wide dataset-related issues. Furthermore, it discusses its contribution as a spatial representation, and evaluates its prospects as an analytical instrument and database. Concluding remarks define forthcoming improvements to be done regarding usability, such as its implementation in a WebGIS suite.

Keywords: Geographic Information Systems · Configurational Atlas · Network analyses

1 Introduction

Geographic Information Systems (GIS) has been throughout continuous development and evolution during the past half-century, in which it made noteworthy contributions to mainstream geographic research [1, 2]. However, amidst much of this period, GIS has been secluded as a somewhat niche instrument, with its usage limited to

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cartographers and geographers, due to restricted-access software and a steep learning curve, even though, it demonstrated untapped potential applications to other disciplines. In that regard, GIS remained focused on organizing spatial information and establishing geographic rules [3], while seldom employed to explore geo-objects relationships.

Paradigms since then have shifted, as the diffusion of open-source GIS suites has democratized access to geoprocessing, increasing the spatial information acquisition, level of detail and overall production, all circumstances that contributed to the urban and regional sciences revamp throughout the late 1990's [4]. Gradual digitalization of topographical technical charts and the maturation of GIS-based regional and municipal datasets had a most significant role in these developments; further associated to methodological improvements on fields of configurational and network analysis [5], this led to the conception of datamaps oriented to depict urban scale road-circulation networks, supporting comparative studies regarding cities' morphologies and their representation as complex systems [6, 7]. From this standpoint, thematic maps based on network analyses became, over the past decade, important sources of information for urban design, set for describe local movement patterns, as configurational properties of these road networks – their *closeness* and *betweenness* centralities hierarchies – were unveiled as accurate predictors of pedestrian and vehicular movement [8].

Significant hindrances, however, are posed for the construction of very large road-circulation datamaps. Owing to their sheer sizes, modelling regions often require extensive computing times, impairing research prospects [9]. Data precision is a concern as well, as generalization processes, whereas can reduce computing complexity and time, oftentimes render comparisons among different scales inaccurate, due to certain road structures non-representation [8]. This last deterrent regarding data accurateness is not limited to spatial, but also to visual intelligibility. Thematic maps, by definition, should provide visual information regarding the spatial distribution of one or more phenomena, through a clear symbology arranged in hierarchies to illustrate the greater and lesser features about a variable, whilst also presenting specific information about its spatial location [10]. Hence, these maps should retain a *visual metaphor* component capable of evoke the relationships between symbols and the spatial context in which they are inserted [11]. Meeting these requirements may be problematic, above all, when working with interactive datasets with multiple variables set to be depicted both in small and large scales, due to overall data quantity and information overlap.

In that vein, proper organizations of spatial network analyses as thematic maps for open-access databases are quite limited[1], since urban analyses remain isolated as local case studies and regional analyses are not as imparted, due to aforementioned issues. From this perspective, significant urban-regional phenomena dimensions remain rather unexplored and unrepresented. Notwithstanding, research requirements for large configurational datasets, capable of assessing geospatial correlations amid infrastructure and movement, through dissimilar scales tend only to increase. These demands prompted the assemblage of a Configurational Atlas, both as a research phase and as an experiment for

[1] The most distinguished initiative in this aspect is the Space Syntax OpenMapping [12]. Created in 2018, it consists of an open data pre-processed spatial network model of Great Britain.

assessing the viability of a future project. Using spatial information from the Tuscan Region (Italy), this Atlas groups a series of thematic maps based on detailed spatial network models from diverse sections of the Tuscan road infrastructure. Their main objective is to illustrate road-circulation network morphologies, as well, to highlight the centralities hierarchies of *closeness* and *betweenness*, in order to represent magnitudes of movement potentials, organizing this information for several territorial extents in a same database.

This paper summarizes the scope and methodological steps to construct the dataset and the models that compose the Configurational Atlas. With this framework in place, it is possible to emphasize characteristics of the GIS interface, as well, the adaptations made for configurational data intelligibility and usability. Furthermore, it will be discussed the Atlas contribution as a spatial representation and data repository, alongside with its prospects as an analytical instrument and future developments regarding data accessibility. Integrating models for geographic simulation and prediction is going beyond GIS' *information system* stage, and towards a dual-core stage, founded on geographic databases sharing and the diffusion of precompiled analysis models [13]. The Tuscany Configurational Atlas is intended as a step on this direction. By making spatial networks datasets available in an open-source geoprocessing-capable instrument, further simulations and correlations can be developed independently, hence, aiding in urban-regional related decision-making processes.

2 Datasets and Configurational Analyses Principles

The Tuscany Configurational Atlas is an outcome of experiments related to ongoing researches in network analyses, focused on the assessment of urban and regional road-infrastructures configurational properties. These were motivated by data requirements for a regional scale depiction of the Tuscan road-circulation network centralities hierarchies, a database to be correlated with other aspects of the built environment. Owing to long processing times entailed in modelling large regional networks, partial analyses using smaller territorial expanses were carried out in the meantime. Results were an extensive collection of original spatial datasets, arranged for consultation as GIS-based thematic maps. Its potential as an analytic instrument, as well as an information broadcaster prompted the Atlas assembly. The Configurational Atlas is organized and hosted as a project in the QGIS 3.10 [14] suite. Since QGIS is an open-source software, all created datasets are integrable to existent WebGIS platforms, therefore, this contributes to this Atlas future availability.

A common database is adopted to construct the Configurational Atlas and produce its network analyses datasets: the Tuscany Road Graph (*Grafo Viario della Toscana*) [15]; a Road-Centre Line (RCL) map that depicts the whole regional road-circulation network topology. This base graph is built based on a pair of regional technical charts

(*Carte Tecniche Regionali – CTR*)[2], scaled 1:10,000 and 1:2,000, hence, able to depict road-infrastructure at an urban quarter level of detail. Its vectoral layout is organized following the typical network structure, being composed by arches, continuous poly-line structures dubbed as "road-elements" (*Elemento Stradale*), and node structures, mid-points that establish the linkage between one or more road-elements defined as "road-junctions" (*Giunzione Stradale*) [16].

The base graph is further sectioned, in order to represent the road-infrastructure of the following territorial divisions: region (*regione*), provinces (*province*) and municipalities (*comuni*). Individual datasets were created through an intersection, employing as a frame structure the Tuscan Administrative Limits, which were included in the Atlas as auxiliary maps [17]. From each individual limit, buffers (1 km for provinces; 300 m for municipalities) were used to preserve road-circulation network continuities during sections[3]. Any road-elements that remained disconnected were removed in the graph revamp[4]. A total of 302 unique graph datasets were created[5], corresponding to all Tuscan Region mainland and archipelago[6] continuous road-infrastructure, being subdivided in: region (1), provinces (11) and municipalities (290).

All the Configurational Atlas datasets share an equal coordinate reference system (CRS): Monte Mario/Italy Zone 1 (EPSG:3003); default projection of the Tuscany Road Graph [16] and the Tuscan Administrative Limits maps [17]. It is important to remark that this CRS projection and the WGS 84/Pseudo Mercator (EPSG:3857), often used by satellite imagery repositories, such as Google Maps [18], have parameter values close enough to be considered identical within the accuracy of the transformation. Google Maps satellite imagery was used as a locational reference during the project but will be substituted by the Tuscan Region orthophotos [19] for a future release version.

Prior administrative limits section, the base road-circulation graph was submitted to a generalization process, which employed the Douglas-Peucker simplification algorithm (*v.generalize*) [20] in order to reduce network complexity. Nevertheless, a very

[2] While OSM data is available for the Tuscan Region, the CTR data provides a homogeneous dataset that requires less of accessory data generalization. This graph is also used to ensure compatibility with the Tuscan Region Ambiental and Territorial Information System (SITA)

[3] Buffers are set within those threshold radiuses as greater extents collected many discontinuities, due to Tuscany fragmented territorial division, especially at municipality scale.

[4] It is important to remark that sections are not territorially strict, as for network analyses the graphs natural continuities ought to be respected over administrative limits to ensure system wholeness. Hence, road-elements were conserved whenever removal would cause a network gap, even when comprised in a neighboring territorial unit. This adequation was used mainly were road-elements had small segments in another municipality territory.

[5] Some municipalities had to be sectioned in two distinct areas due to network discontinuity, as consequence of the Tuscan fragmented territorial division.

[6] The Tuscan archipelago islands are referred as independent networks, even when partake to another municipality administrative limits. Spatial data regarding some islet's road network, absent in Tuscan Region Graph, were incorporated to the database. Elba Island continuous road-circulation network is represented at provincial scale due to its size, even though it is comprised in Livorno administrative limits. All Tuscan provinces (10) and municipalities (273) are represented, apart from Ca' Raffaello exclave, located in Badia Tedalda municipality (Arezzo Province), which is discontinuous from Tuscan territory, being positioned inside the province of Rimini (Emilia-Romagna Region).

small tolerance value (0.1) was applied during the generalization, with the intent to only diminish excessive numbers of polylines vertices in roundabouts and highway accesses, while preserving their road geometries (Fig. 1).

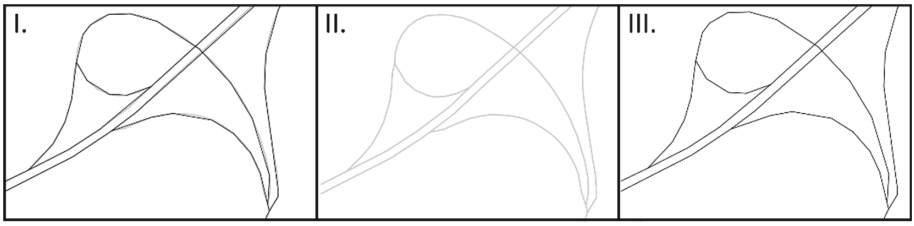

Fig. 1. Comparison (I.) between non-generalized (II.) and generalized (III.) road-circulation networks from Tuscan Region Road Graph – source: Regione Toscana – Grafo Iternet.

Albeit a minor reduction on the road-elements absolute number (1.06%) (Table 1), mostly due to post-generalization clean-up, the process had substantial impact in vertices count. Hence, this led to a substantial decrease in processing times (Table 2) for when RCL graphs are converted to angular segment maps through DepthMap X 0.5 [21], a network analysis software. This conversion step is required to assess *closeness* and *betweenness centralities* hierarchies in road-circulation networks through Space Syntax' Angular Analyses [22].

Table 1. Comparison between non-generalized and generalized Tuscan Road Graph number of road-elements prior and after angular segmentation.

	Road-elements prior Angular Segmentation	Road-elements after Angular Segmentation	Δ% Road-elements
Non-generalized	393.660	4.657.114	1083,02%
Generalized	389.477	1.251.610	221,35%
Δ% Generalization	1,06%	73,12%	–

Table 2. Average approximated modelling processing times of region, provinces and municipalities for non-generalized and generalized networks converted in Angular segment maps[7].

	Region	Province	Municipalities
Non-generalized	≈7,5 Months	≈23–72 h	≈2–8 min
Generalized	≈2,5 Months	≈7–18 h	≈0,5–3 min

Developed by Turner during the 2000's [22–24], Angular Analyses comprehend a set of methods conceived for evaluating spatial network properties and predict movement potentials on road-circulation networks constructed as dual graphs, such as RCL datasets. These methods require conversion of RCL graphs into angular segment maps,

[7] Processing time values for an overclocked Intel i7–8700 k (4.7 GHz); 16 GB of RAM.

in which the network *j-graph* is weighted according to the angle (in radians) amid each connected pair of vertices (in dual graphs, the road-elements), attributing to them a correspondent angular coefficient. System depth is obtained from the shortest *angular* path among all origin-destination pairs of vertices in the network, therefore, this angular coefficient corresponds to a weighted topological step, permitting measurement of *closeness* and *betweenness centralities* hierarchies. Whenever there are angle variations amid a road-elements pair – including any t-intersections or crossings between two roads – the RCL original continuous polyline will be segmented in two (angular segmentation), and the attribution of a corresponding angular value to each individual road-element will ensure, thus, curvatures with many nodes will result in many segments. Continuities will perdure when no interruption or direction change happens.

Closeness centralities analyses are drawn from Space Syntax' Normalized Angular Integration (NAIN) [25]. An algorithm equivalent to mathematical *closeness*, angular integration calculates (sums) the average angular costs of travelling over the shortest path, from each road segment *i* to all other possible destinations in the network. Hence, it depicts the to-movement potential of a road segment *i*, or its *relative accessibility* – how central its position is when related to all other positions in the network. The normalization of angular integration measures proposed by Hillier, Yang and Turner [25] ensure that systems' *integration* values are related to the urban average, through the division between node count (NC) and angular total depth (ATD) values regarding a determined segment *i*, formalized as following:

$$NAIN = (NC)^{\wedge}1,2/ATD \tag{1}$$

This adequation intend to standardize overall angular integration values, reducing the sums absolute number to proper established ranges[8]. This allows better comparisons amongst centralities hierarchies of different sized cities (with non-identical depths) or of diverse scaled road-circulation networks within a same urban settlement.

Betweenness centralities analyses derive from Space Syntax' normalized angular *choice* (NACH), an algorithm based on Angular Analysis [25]. Angular *choice* corresponds to mathematical *betweenness*, as it counts (sums) the number of times each individual road segment *i* is traversed when travelling, crossing through the overall shortest path, towards all potential destination segments, from all possible origin-destination pairs within the network. In this regard, this measure represents the road segment *i* through-movement potential, or the probability of its use as a system *preferential route*. Without normalization, *betweenness centralities* absolute values are conditioned to the network size – thus, to its depth. Concerning this, the quantity of *betweenness* acquired by a road segment *i* is related to its *integration/segregation* and its relative position within the system, with *segregated* designs adding more total and average *betweenness* to the network than *integrated* ones. Hence, angular *choice* measures highlight only the segments with the highest absolute *betweenness centrality* values – the main *preferential route* – while disregarding the remainder of road-circulation

[8] Hillier et al. [25] theorical tests demonstrate that NAIN ranges innately differ, depending on node count and total depth proportions. Therefore, there are no exact ranges for NAIN comparisons, but only approximations between top and bottom values depending on the urban settlement structure.

network *preferential routes* hierarchies' due to a high amplitude amid top and bottom *betweenness* sums, resulting in an insufficient representation of through-movement dynamics. Hereof, angular choice is not suited to comparisons amongst different systems or scales. The normalization method devised by Hillier et al. [25] mitigates this purported "*paradox of choice*" by weighting the calculated centralities values (angular *choice* – ACH) by the corresponding angular total depth (ATD) of a segment *i*, as following:

$$NACH = \log(ACHi + 1)/\log(ATDi + 3) \quad (2)$$

Through this relation, centralities values are adjusted according to the angular total depth of its correspondent segment *i*, hence, the depth component is distributed along the network. In this sense, greater the network *segregation*, the more reduced angular *choice* absolute values will be, by being divided by a higher angular total depth value. Normalization will then render visible the lesser *preferential routes*, by attributing to them a relative positional weight within the network hierarchy. The inclusion of a logarithm base standardizes NACH relations in a power law, restricted between 0 and 1, 5+[9] deeming possible comparisons between road-circulation networks with different depths, thus, non-identical sizes and scales, as absolute *betweenness centrality* values are now brought to an equivalence.

Angular Analyses models are exported from DepthMap X 0.5 as MapInfo datafiles (.mif), compatible with QGIS 3.10, then, converted in GIS to ESRI shapefiles (.shp). These models do not include normalized measures, though. While NAIN and NACH could be calculated for each individual graph directly through DepthMap X 0.5, due to the substantial amount of datasets, the use of a Microsoft Excel [26] macro was opted to accelerate the process. This macro imputes the normalization functions in the Excel database sheets (.xlsx) obtained from shapefiles, by creating two columns and normalizing each road-segment (rows). Another macro was used to reconvert these database sheets to a comma-separated values (.csv) file for further remerge with their respective original shapefiles in the GIS-based dataset. This procedure was made for 301 datasets, apart from the regional map, calculated through DepthMap X 0.5 since its road-elements quantity exceeded the Microsoft Excel memory for rows.

3 Tuscany Configurational Atlas Interface, Thematic Maps Data Discussion and Their Usage Prospects as Analytical Instruments

At this stage, datasets and spatial models approaches set, it is possible to emphasize the organizational fundaments applied in the course of the Tuscany Configurational Atlas construction, such as its GIS interface features, and thematic maps' visual adaptations made with data intelligibility in mind.

[9] Hillier et al. [25] theoretical tests state that *betweenness centralities* values can sometimes surpass the 1.5 threshold in specific cases, such as systems that exhibit ample differences between mean and total depth.

As mentioned, two parameters – NAIN and NACH – are employed for depicting the Tuscan road-circulation networks' movement potential distributions. Since these parameters are modelled for the 302 road-graphs, 604 individual datasets[10] were produced. To reduce overall files' quantity, both models were imbedded in a same shapefile, which was then classified in GIS to exhibit the desired parameter. Those datasets are organized in a multi-group hierarchical structure, labeled according to the administrative limit that is correspondent to the model extent, therefore, the municipalities (*Comuni*) are set inside their respective provinces (*Provincia*), that are, in their turn, placed in the regional group (*Regione*)[11]. All models can be accessed, shown or hidden through a drop-down list. NAIN and NACH parameters have their values discriminated in graduated legends. The Atlas interface also contains the depiction of the Tuscan road graphs (*Grafi Stradali*), divided in continental network and archipelago networks and corresponding administrative limits (*Aree Amministrative*) (Fig. 2).

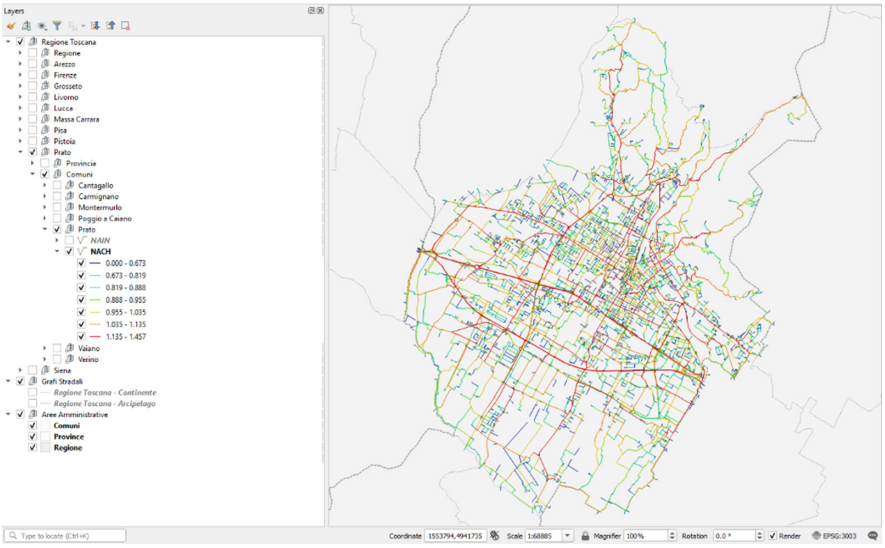

Fig. 2. Tuscany Configurational Atlas GIS project interface and thematic maps organization structure – source: Regione Toscana – Grafo Iternet

Groups were set to be mutually exclusive, thus, when one parameter is set active, the other will be automatically hidden, circumventing thematic maps data superimposition, undesirable from a visual coherence standpoint. Superimposition among different

[10] Total size of the Tuscany Configurational Atlas thematic maps datasets, auxiliary maps and original road graphs is 23 GBs.

[11] Groups were created as such to facilitate further incorporation of other regions' datasets in the Atlas database.

scales, however, is made possible, as this can be used to compare how movement patterns and centralities hierarchies are set over dissimilar territorial dimensions.

From a data provider and cartographer perspective, rendering spatial information intelligible in territorial expanses and scales as dissimilar as those intended for a Configurational Atlas ought to be a major concern. In this sense, proper adaptations had to be made to map symbology regarding the vectors' representation and, above all, to the color ranges that individuate *closeness* and *betweenness* centralities hierarchies in the datasets. While issues regarding vector representation where simple to solve, by setting variable line widths in proportion to scale dimension, color range issues were not so trivial, requiring further adjustments. DepthMap X 0.5 [21], where models are first processed, differentiates spatial data through a spectral blue-cyan-yellow-red (bcyr) color band, split in seven gradient intervals that span from dark-blue (lesser values) to dark-red (greater values). Tuned to highlight cyan-yellow mid-range transitions, this spectral gradient distinguishes, through contrast, gradual variations in road-circulation network centralities hierarchies' values. Although QGIS 3.10 [14] possesses a bcyr color range (ctp-city), comparable to DepthMap X 0.5, its blue-cyan and orange-red gradients are predominant over cyan-yellow transitions. Hence, the green gradient remains in a narrow range, in such form that cyan appears to transition directly to yellow (Fig. 3, II.), rendering mid-range centralities data difficult to read in the map.

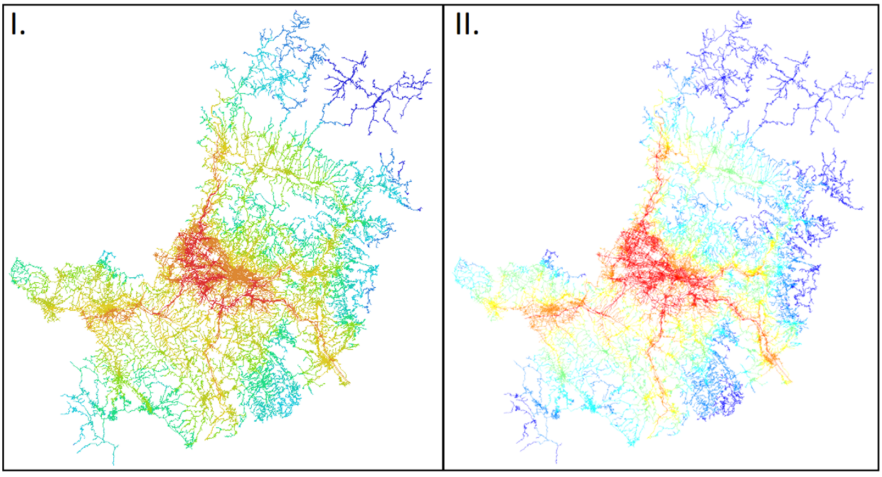

Fig. 3. Comparison between DepthMap X 0.5 (I.) and QGIS 3.10 (ctp-city) (II.) bcyr color ranges for NAIN in the Firenze Province dataset – source: Regione Toscana – Grafo Iternet (Color figure online)

This issue prompted a revision of the QGIS 3.10 [14] bcyr ctp-city color range, and the development of a suitable gradient, capable of highlighting the cyan-green-yellow transition without squandering thematic maps' data intelligibility concerning highest and lowest values for centralities hierarchies (Fig. 4).



Fig. 4. Default QGIS 3.10 bcyr color range (ctp-city) (I.) and revised bcyr color range (II.) used to highlight *closeness* (NAIN) and *betweenness* (NACH) centralities hierarchies (Color figure online)

Comparisons with DepthMap X 0.5 [21] color range demonstrate that QGIS 3.10 revised bcyr can individuate clearer transitions among mid-range values (cyan-green-yellow), which was the main problem regarding QGIS 3.10 ctp-city bcyr [14], and, as well, remark subtle transitions between mid-range and the top-bottom values for centralities hierarchies, absent in the DepthMap X 0.5 gradients (Fig. 5).

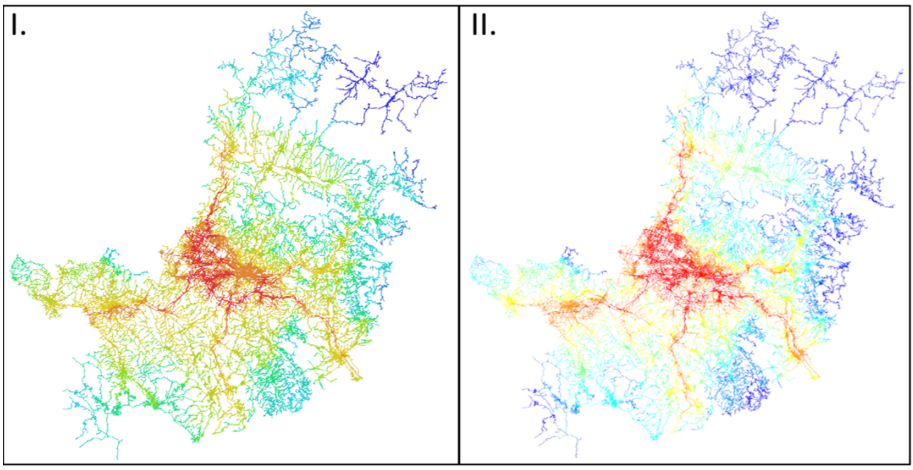

Fig. 5. Comparison between DepthMap X 0.5 (I.) and revised (II.) bcyr color ranges for NAIN in the Firenze Province dataset. – source: Regione Toscana – Grafo Iternet (Color figure online)

Data visualization in the Configurational Atlas interface is further improved through changing the NAIN and NACH color ranges rendering order, so higher valued road-elements (centrality cores) are rendered on top. While this setting is enabled by default on DepthMap X 0.5 [21], it must be manually set on QGIS 3.10.2 [14].

Another issue that had to be taken in account was the innate bcyr issues concerning data intelligibility in grayscale. Even though a minor problem in digital environments, since color bands may be unrestrictedly reproduced, this can be a hindrance when paperback publication or reproduction is considered. While not ideal, the revised bcyr tries to minimize this issue by adopting a darker hue for all gradients, with emphasis in the green gradients that, when converted into grayscale, can mark the point where the transitions from cyan to green and from green to yellow happen (Fig. 6), individuating top middle and bottom centralities hierarchies.



Fig. 6. Default QGIS 3.10 bcyr color range (ctp-city) (I.) and revised bcyr color range (II.) when converted to grayscale. (Color figure online)

Regardless that bcyr color ranges are considered far from ideal representations for scientific data [27], requirements of a broad range of graduation that denotes configurational models' values hierarchies make its usage inevitable. These proposed revisions acknowledge and try to minimize bcyr problems and can be used as guidelines for other GIS-based datasets with similar requirements concerning data distribution.

Visual metaphors issues circumvented, the digital framework in which the Tuscany Configurational Atlas datasets are included, and how being in this context can have influence on the Atlas overall prospects as an analytical instrument may be discussed.

Set in a GIS-based environment, the Atlas project permits the apposition of several spatial information layers to its precompiled thematic maps. Being in this context, grant that the configurational models, which depict road-circulation networks movement potentials dimensions, can be visualized alongside other variables that may or may not be affected or interact with these dimensions. From a visual standpoint, this simple juxtaposition can already evoke some aspects about a determined spatial relation that could not be perceived otherwise, therefore, indicate possible correlations. A practical example of this prospect can be observed when a productive built-structures density [28] datamap is layered to the Pisa Municipality NAIN model thematic map, focused in its central urban area (Fig. 7):

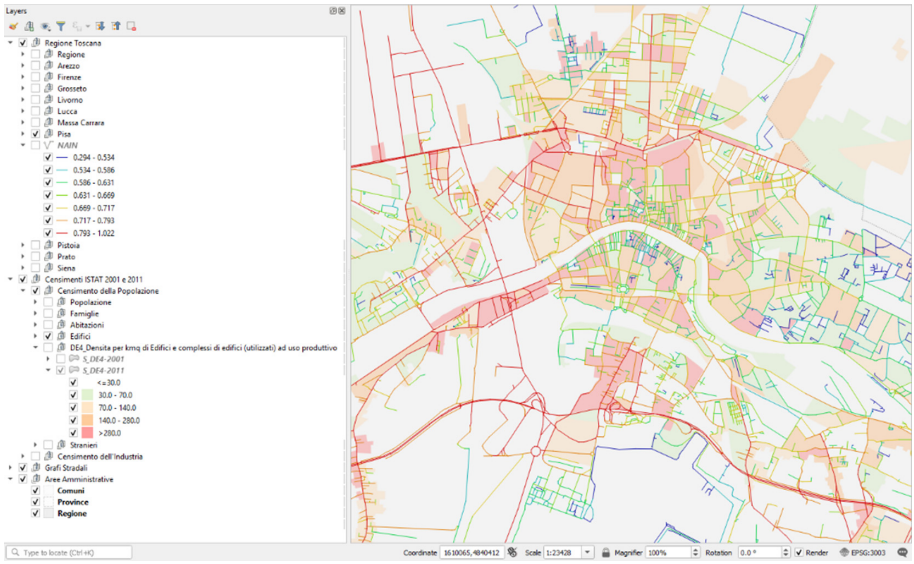

Fig. 7. Productive built-structures density for km2 apposed to Pisa Municipality NAIN dataset – source: ISTAT – Censiamento Generale 2011; Regione Toscana – Grafo Iternet.

The ISTAT datamap [28] depicts the density of buildings or building complexes that have productive – retail, industrial and services – usage throughout the territory. It can be observed that, the productive structures density tends to be generally higher on the areas close to the city center (centered on the map). Outside this case, however, the productive structures density tends to be greater near areas with high to-movement potentials (indicated by NAIN orange and red lines), which are predisposed to gather more pedestrians and vehicles. From a locational economics perspective, this visualized relation explains a known empirical logic, since retail placement tend to be associated to pedestrian and vehicular movement [29] due to customer attraction and presence demands that these activities have.

Even though data juxtaposition can already reveal some aspects about geo-objects spatial relations, these are generally restricted to the initial purpose and characteristics of the precompiled datamaps. However, GIS-based digital environments enable these visual comparisons to be taken one step further, as the datasets can be manipulated. In this sense, GIS' geoprocessing instruments allow the creation of new sets of variables based on the existing data and enable proper geospatial correlations to be set, expanding the possibilities regarding the spatial analyses. This prospect can be exemplified in the following instance, that juxtaposes productive areas data, generated from the Tuscan Land Use and Cover 2007-2016 dataset [30], to the Livorno Municipality NAIN model thematic map (Fig. 8):

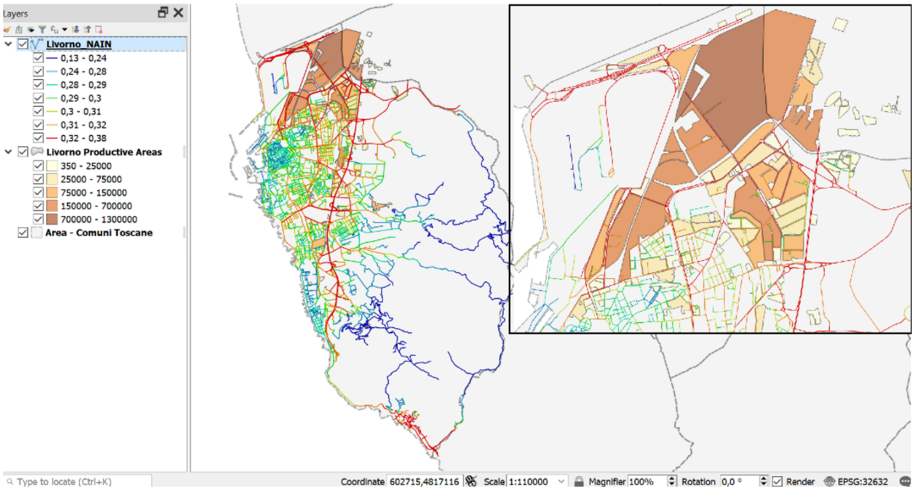

Fig. 8. Productive areas data apposed to the Livorno Municipality NAIN dataset – source: Regione Toscana – Grafo Iternet; Regione Toscana – Uso e Copertura del Suolo 2007 – 2016

Producing original spatial information from a precompiled dataset opens quite a few possibilities regarding spatial analysis. In the example, enacting a sphere of influence associated to density estimation values provided by the heatmap enable statistical correlations between built-structures position, agglomeration and their

nearness to network centralities hierarchies. This can yield more detailed and robust results when compared to the previous example (Fig. 7), which is based only in a visual analysis.

Outside shown applications, oriented to juxtapose the spatial datasets to the road-circulation network thematic maps, proper analyses of Configurational Atlas models themselves can, as well, reveal intriguing network dynamics. These can be considered as research topics for further studies to be developed in the fields of theorical and applied mathematics, informatics and cartography.

A group of network phenomena that was observed concerns the *visual similitude* of *betweenness centralities* (NACH) throughout the scales. Regarding this, the found logic is that centralities hierarchies tend to remain largely unaltered in the same places along the network, despite variations of network size (scale), that ought, at least, to change its general hierarchies' distribution. Hence, the Regional model for *betweenness centralities* hierarchies tend to remain substantially simile to Provincial models and Municipality models, which in their turn display similarities between themselves, when considered the same stretches of the network, as highlighted in the example (Fig. 9) between Firenze Province (I.) and Firenze Municipality (II.)

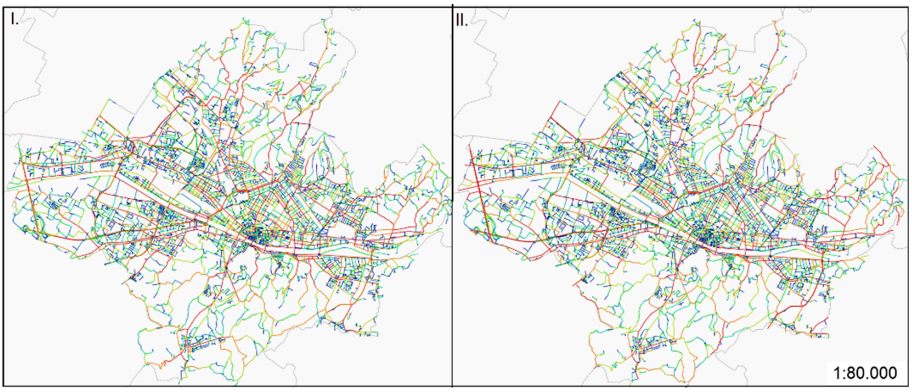

Fig. 9. Visual similitude between Firenze Province (I.) and Firenze Municipality (II.) NACH models - source: Regione Toscana – Grafo Iternet

Without the conception of the Configurational Atlas models and thematic maps, these network phenomena might not have been observed, nor their repetition pattern amid different scales.

Overall, the Tuscany Configurational Atlas has demonstrated stimulating potentials as an analytic instrument. The versatility of the GIS-based digital environment and the availability of geoprocessing instruments enables diverse kinds of data to be apposed and analyses to be developed. Data completeness is an important aspect in decision-making processes, as it helps policymakers to think beyond the single dimensions of the territory, empowering a broader vision of the territorial potentialities.

4 Concluding Remarks

Continuous GIS development implies a transcendence from the *informational systems* stage, towards an instrument that combines geographic databases sharing and analysis models diffusion. Concerning this matter, GIScience progress ought to be oriented for shortening the gap amid informational demands and datasets availability that perdures in several disciplines, urban and regional sciences included. From this perspective, it is expected that, for the near future, digital data repositories constructed in GIS-based environments will have significant roles in setting these transformations in motion, functioning as outsets for the integration of databases and analysis models.

This paper summarized the principles behind a Configurational Atlas construction, describing its data sources, technicalities of its GIS project, and methods used to conceive the configurational models responsible for outline the road-circulation networks movement patterns, main parameters to be exhibited on the repository. In the discussion, some aspects were addressed regarding the Atlas map sets organization on GIS interface, and the amendments devised with intent to avoid information overlap when manipulating the datasets. Another step discussed were the adequations made to circumvent issues concerning the Atlas' *visual metaphors*, and the improvements made to symbology with thematic maps data intelligibility in mind required as part of the incorporation of DepthMapX 0.5 models into GIS. These considerations can be used as construction guidelines for other GIS-based interactive configurational datasets.

Even though constructed as an experimental project, the Tuscany Configurational Atlas has demonstrated potential to go beyond its original purpose as a data repository for consultation. Set in a GIS-based environment, the Atlas permits the apposition of several kinds of spatial information, such as the presented examples from census and built-structures datasets, to the precompiled thematic maps representing the configurational models. From a visual standpoint, this can undoubtedly evoke some aspects about geo-objects spatial relations, yet, since the Atlas' thematic maps can be manipulated, these visual comparisons can be taken one step further, as the configurational datasets may serve as sources for formal spatial correlations using GIS' geoprocessing instruments. As the Atlas allows configurational models representation through several scales with the same level of detail, this consented to visualize intriguing network logics that are reproduced in different scales, and ought to be explored in further studies, such as the mentioned *visual similitude* of *betweenness centralities*.

Forthcoming improvements are in course regarding the Configurational Atlas availability and usability, the most important, being its integration to a WebGIS suite. This is intended to be done through the Tuscan Region Ambiental and Territorial Information System, (SITA - GEOScopio) in hope that more comparative studies are developed, but also, to improve governmental access to spatial information, giving further dimensions to be considered in the decision-making processes. Another possible research course consists in expanding the Configurational Atlas to include other Italian regions, in order to make a comprehensive analysis of the Italy's movement potentials logics throughout the territory.

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