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RAPID CONFIGURATIONAL ANALYSIS USING OSM DATA:

Towards the use of Space Syntax to orient post-disaster decision making

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ABSTRACT

This paper addresses the problem of the growing exposure of contemporary cities to natural hazards by discussing the theoretical, methodological and practical aspects of using the configurational approach as a framework to perform a variety of spatial analyses to better orient disaster management. It claims that enabling a quick assessment of the evolving spatial functioning of the urban grid would effectively contribute to support strategic decision-making and to make post-disaster planning decisions more explicit among stakeholders, thus boosting wider understanding and participation among the public. The paper starts with a brief review of some relevant work done by the research community to date, which highlights emergent opportunities for urban morphology studies and Space Syntax theory to trigger effective innovations in disaster management practice. Next, the paper proposes to adopt a fit-for-purpose analysis approach with the aim to achieve a higher procedural flexibility in the analysis workflow. This issue is treated with a special focus on the necessities of relief organisations which need to integrate and overlap numerous layers of information and consider the feasibility of the analysis by evaluating time and costs. The proposal considers the economy of the construction of the map to be fundamental for ensuring the feasibility of a quantitative spatial assessment in data scarce contexts such as cities affected by disasters. Moreover, it recognises that the unicity of the map is likely to enable a better communication among different stakeholders following a BIM-oriented model of cooperation, while allowing a faster response in multi-hazards scenarios. Consequently, the proposal challenges the idea of the existence of a uniquely correct way to translate reality into a model, but rather suggests using a set of simplification techniques, such as filtering, generalisation and re-modelling, on a single crowdsourced map of the urban street network to generate suitably customised graphs for subsequent analysis. This brings together two themes: the first concerns the modelling activity per se and how certain technicalities that seem minor facts can influence the final analysis output to a greater extent; the second regards the crowdsourcing of spatial data and the challenges that the use of collaborative datasets poses to the modelling tasks. In line with the most recent research trends, this paper suggests exploiting the readiness of the Open Street Map (OSM) geo-dataset and the improving computational capacities of open GIS tools such as QGIS, which has recently achieved a wider acceptance worldwide. To further speed up the analysis and increase the likeness of the configurational analysis method to be successfully deployed by a larger pool of professionals it also proposes to make use of a state-of-the-art Python library named OSMnx. In the end, the consequences of using Volunteered Geographic Information (VGI), open source GIS platforms and Python scripting to perform the analysis are illustrated in a set of suitable case studies.

KEYWORDS

Space Syntax, Volunteered Geographic Information, Disaster Response, GIS, Python scripting

1. INTRODUCTION

Climate change coupled with the ongoing phenomena of rapid urbanization of the world's population has made many contemporary cities increasingly vulnerable to natural hazards and more easily subjected to disasters. Consequently, if no strategies are implemented to understand urban vulnerabilities and subsequently act to reduce them, new disasters will be likely to come at increasing social and economic costs. After the 2011 Japan earthquake and tsunami, the UNISDR (United Nations Office for Disaster Risk Reduction) published the Sendai Framework for Disaster Risk

Reduction 2015-2030, which indicates four priorities of actions, some of which concern the built environment directly. The document states that, to date, an enhanced understanding of the exposure of people and assets to hazards as well as better preparedness, which would ensure that capacities are in place for effective disaster response at all levels, are still needed. Additionally, the framework highlights that the recovery, rehabilitation and reconstruction phases represent critical opportunities to improve the resilience of cities, when actions are made to reduce their exposure to future risk. Because of their importance, these topics have since then triggered an intense academic debate which has involved many technical and humanistic disciplines concerned with the study of urban environments. Therefore, researchers have dedicated increasing efforts to develop sophisticated analysis models and techniques whose goal is to help professionals to better deal with hazardous events. Yet, to date, advances in disaster management practice rely largely on a trial-error approach and human guesswork. In the aftermath of a disaster, planners and policy makers work under the pressure of need and urgency, which contrasts the need for extensive situation assessments able to foster sensible and effective decision-making for the achievement of the best recovery strategy. As a result, many complex decisions – and often far-reaching in terms of their long enduring effects - are generally made quickly, based on partial information, most commonly available in form of text and tables. It is noted that these contingencies may ultimately prevent the realisation of the best possible outcomes in both design and planning and consequently hinder the achievement of the initial "build back better" goal. All this seems to suggest that further efforts need to be put in place to allow a more effective knowledge transfer between academia and practice. When developing an analysis method, it is necessary to consider the needs of the final users, the conditions in which they operate and their capacity to access quality information. This study seeks to addresses this challenge in the context of urban morphology studies, by setting the basis for the creation of an adaptable configurational analysis workflow. The paper is divided in three parts. The first reviews past research, showing the potential benefits of using the configurational approach to orient post-disaster decision making. The second discusses the diverse ambitions that stand behind alternative analysis models and supports the argument that a fit for purpose analysis workflow must be adopted in disaster contexts, which includes manipulating alternative data sources in a controlled way. The third uses two case studies to show how and to which extent the choices made during the modelling process ultimately affect the analysis results.

2. CONFIGURATIONAL APPROACH AND DISASTER SIMULATION

The adoption of the configurational approach as a framework to conduct a variety of disaster simulation studies seems to offer novel opportunities for enhancing the dialogue across the numerous scientific disciplines involved in disaster management. For instance, transportation and telecommunication engineering, social studies and economics, already share with urban configuration studies a network-shaped model of reality, besides relying on Graph Theory to derive useful insights (Barabási, 2014). Additionally, past research has demonstrated that using configurational analysis it is possible to connect other complementary pieces of information and effectively help decision-makers to better understand, plan for and respond to a variety of challenges posed by natural hazards to cities at different moments in time. For example, Srinurak et al. (2016) propose to use the configurational analysis to develop an integrated urban disaster prevention and mitigation strategy, while Mohareb (2011) suggests to apply it to refine current evacuation simulation models. Moreover, Chang and Lee (2018) utilises the configurational analysis to evaluate the suitability of emergency sheltering to effectively respond to the needs of the evacuees and Penchev (2016) uses it to develop a strategy of hierarchical interventions after a disaster, aimed at minimising indirect economic losses and fostering the continuity of the economic activities in the disaster affected urban areas. Next, it is worth mentioning the pioneering work of Cutini (2014), Koch and Carranza (2013) and Esposito and Di Pinto (2014). These authors were the first ones in the Space Syntax community who have addressed the problem of describing urban resilience from the perspective of its relational meaning; starting from the assumption that space is the ruling factor over which other mechanisms of resilience - social, economic and environmental – are then superimposed. In particular, Cutini (2013) has shown that a Space Syntax analysis in the context of a disaster would help to:

1) Highlight abrupt changes inflicted by the disaster to the morphology of a city (situation assessment and emergency management);
2) Quantify the dynamic changes in levels of centrality and attractiveness in time (monitoring);
3) Predict some of the long-term effects of recovery plans with respect to reconstruction claims and housing supply (disaster relief and post-disaster reconstruction);
4) Foster the assessment of the inner resilience of a given spatial system (preparedness).

In line with these principles, many recent Space Syntax studies have targeted different natural hazards ranging from hurricanes (Carpenter, 2013), flooding (Abshirini et al., 2017; Gil and Steinbach, 2008), landslides (Castillo, 2013) and earthquakes (Sari and Kubat, 2012, Heitor et al., 2000).

The studies mentioned above have shown the relevance of two Graph Theory measures of centrality, named as 'Closeness Centrality' and 'Betweenness Centrality' in disaster applications. In Space Syntax analysis equivalent metrics are known under the names of 'Integration' and 'Choice' and are used to quantify 'to-movement' and 'through-movement' respectively. 'Integration' measures the level of accessibility of a street and it is higher for the segments that are more central and lower for the ones that are more segregated, that is on an average more distant from all the others in the correspondent dual graph representation. A higher 'Integration' level usually corresponds to a higher density of commercial activities and pedestrian presence. 'Choice', on the other hand, describes where the flows concentrate or similarly where peoples' paths overlap as it measures the number of times a certain street (or a part of it) falls into the shortest route connecting every origin to every destination. Specifically, past studies have suggested to use 'Choice' to inform strategic decisions about infrastructure reconstruction and logistics and 'Integration' to assess the accessibility of relief resources and services. In addition, to 'Integration' and 'Choice', Cutini (2013) uses a third metric to measure the configurational resilience of cities, namely mean 'Connectivity', which counts the average number of spaces that are immediately connected to any space in the graph. In fact, mean 'Connectivity' describes in a simple way the level of "hyperstaticity" of the urban system, i.e. the redundancy of its connections. Table 1 reports the frequency of Space Syntax metrics' use in the previously cited studies. Based on it, this paper focuses on the analysis of the five following attributes: local Integration (calculated using a radius of 800 meters from each node, equivalent to a 10 minutes' walk); global Integration (radius n); local Choice (radius 800 meters); global Choice (radius n) and Connectivity.

Type of disaster	**Space Syntax Metric** Integration	Choice	Connectivity	**Purpose in disaster management**	**Disaster phase**	**Author(s)**
Earthquake and tsunami	X		X	New urban layout assessment	reconstruction	Heitor et al. 2000
Flood	X	X	X	Street network and flood risk	preparedness and emergency	Gil et al. 2008
Not Applicable	X	X	X	Evacuation	emergency	Mohareb 2011
Earthquake	X	X		Evacuation	emergency	Sari et al. 2012
Landslide and flood	X		X	Informal settlements vulnerability	preparedness	Castillo 2013
Earthquake	X	X	X	Street network resilience	recovery	Cutini 2013
Hurricane	X		X	Social resilience and the built environment	recovery	Carpenter 2013
Flood		X		Street network and indirect economic losses	recovery	Penchev 2016
Not Applicable	X			Street network classification	preparedness	Srinurak 2016
Flood	X	X		Street network resilience and flood risk	preparedness and emergency	Abshirini et al. 2017
Not Applicable	X			Accessibility of emergency shelters	preparedness	Chang et al. 2018

Tab 1. Use of Space Syntax metrics in previous disaster-related studies.

Space Syntax metrics are measurable outputs that describe complex socio-spatial phenomena as a result of a process of analysis, visualisation and interpretation. Past studies share the belief that, by limiting the use of intuition, the 'discursive nature' of the configurational approach may effectively support decision-making in all phases of the disaster management cycle. Thus, the quantitative outputs of Space Syntax analysis could improve judgements under uncertainty (Kahneman, 2011), which is a typical condition in which disaster decision-makers operate (Gomez and Baker, 2019).
Besides that, Space Syntax studies have been progressively enriched with other types of spatial information expanding possibilities of using the configurational analysis method in wider applications. The work of authors like Jiang and Claramunt (2002), Jguirim Ines et al. (2015) and Gil et al., (2015) aim to better integrate Space Syntax analysis within GIS systems. The integration with GIS enables a multidimensional study of urban street-networks as different layers of information can be combined within the same platform; highlighting different aspects of the functioning of the urban

system. These ideas are further explored in the following paragraphs, which present some preliminary results of an ongoing research project whose main goal is the improvement of design decision-making in disaster relief practice.

3. A FIT-FOR-PURPOSE SPACE SYNTAX ANALYSIS

While assuming on the one hand the importance to adopt a configurational approach to guide post-disaster decision-making, this paper highlights, on the other hand, that the issue associated to the plurality of existing modelling approaches in this domain needs to be carefully considered (Marshall et al., 2018). This study seriously questions the necessity to look for a ’one size fits all’ way to interpret reality and convert it into a model. It attempts to prove the analysis workflow should be fit-for-purpose / custom-based, considering the contingencies and context of the disaster situation. Specifically, the analysis method needs to be flexible enough to allow the choice of alternative workflows. It claims that failing to consider the feasibility of the analysis, i.e. evaluating the ability and likelihood to complete it successfully considering all the relevant factors, could lead practitioners to abandon the decision to use the configurational method in real-life applications, losing its potential benefits.

3.1 Space Syntax analysis methods

Adopting the most classical Space Syntax analysis, namely the Axial Analysis as defined in Hillier and Hanson (1984), is likely to prove extremely challenging if not impossible in the aftermath of a disaster, when planners must take numerous decisions within a short time and without the possibility to engage in lengthy modelling processes. In fact, the Axial Map is a highly specialised type of representation which, due to its distinctive features, it is not commercially available. In his famous critique Ratti (2004) attacks the process of the manual construction of the map (traced by hand starting from the longest lines that connect the fattest convex spaces) showing that it presents issues of methodological objectivity and reproducibility, which ultimately affect the reliability of the results. Even when the operator uses an automated computational method to build the Axial Map (Batty and Rana, 2004) the process still presents challenges in large scale disasters because it becomes computationally intensive and time consuming. Moreover, the Axial Lines ignore the presence of public open spaces in urban areas, which represent points of special interest for relief operations. Finally, the Axial Map is hard to integrate with external data because of the difficulty to find direct correspondences between the Axial Lines and the segments composing urban street-networks in the common cartographic representations of cities.

Among the alternatives, the Angular Segment Analysis (ASA) has been widely used in Space Syntax studies, showing an improved capacity to highlight nuances in configurational variations when compared to the Axial Analysis. Initially, it was common practice for researchers to perform the ASA on Axial Segment Maps generated from classic Axial Maps, by firstly segmenting the axes at the crossings and then cleaning the small stubs. However, the Axial Segment Maps obtained by following this process seem to present some distorted angular qualities (Krenz, 2017). Later, because of the problems encountered in using the Axial Segment Map, some researchers have started to use Road Centre Lines (RCL) to create alternative segment maps. The use of RCL in Space Syntax analysis has firstly become popular to study vehicular flows (Turner, 2007) because the model resulted in a better correlation with the observed traffic than the axial one but later their use has been extended to the analysis of a variety of urban phenomena.

On the one hand, RCL representations are widely diffused and can be outsourced when required. They help to overcome likely difficulties in distinguishing between the public (and shared) and the private space (not freely accessible) in rural areas or in cities of the Global South, where such distinction is hardly neat and varies according to local cultural factors. On the other hand, using RCL requires to explicitly consider the issue of converting the map into a graph consisting of nodes and edges prior to the analysis. Some studies fail to report in detail the decisions made in the process of constructing the graph for the analysis, which makes it harder to replicate results and perform theoretically sound analysis comparisons. This study describes the spatial characteristics of RCL maps obtained from different data sources and presents the underlying reasoning behind principles used for their conversion into graphs for ASA, considering the implications of this reasoning in spatial representations and results.

3.2 Data sources for RCL Maps

In general, official RCL data may come from different sources such as city, region and national data repositories or from private companies such as Tom Tom and Google. With a few exceptions (e.g. the ITN dataset in the UK or TIGER in the US), these data are not open for free public use. Official RCL

may present differences, due to their scattered production in time and space and the presence of different mapping standards across the various mapping bodies; which must be acknowledged to avoid issues of consistency in the representation that may arise when the analysis is conducted on an area that crosses multiple administrative boundaries. Official RCL maps tend also to have a coarse-grained classification of streets and their availability in post-disaster contexts is extremely limited as their production can be relatively resource-expensive and time-consuming.
The use of Volunteered Geographic Information (VGI) seems to represent a valid alternative to the use of official data. Several web-based platforms for collaborative crisis geo-mapping have started to appear in recent years as a bottom-up initiative to foster mutual support among communities affected by major natural disasters. One of the first and most famous cases was the mapping effort undergone by the volunteers of the Red Cross after the 2010 Haiti earthquake, with was followed by a series of humanitarian mapping campaigns coordinated by the HOT team ("Humanitarian OpenStreetMap Team" n.d.) as part of the Open Street Map (OSM) project. In particular, Imi et al. (2012) show that after a disaster occurs, it is reasonable to expect a sensible increase in the local production of geo-data within popular platforms such as OSM. The OSM mapping coverage is reaching a considerable extent worldwide and because of interest and support from NGOs operating in the field, it seems particularly appropriate to attempt exploiting such a valuable - yet sometimes imperfect – emerging resource. The idea of bringing OSM RCL data into the Space Syntax analysis pipeline is not entirely new, see studies from Dhanani et al. (2012), Krenz, (2017) and (Kolovou et al., 2017) for relevant contributions in this respect.

3.3 Angular Segment Analysis workflow and modelling decisions

Figure 1 compares the Axial Segment workflow with the RCL workflow for the ASA. Modelling-related decision-making points are presented in light blue boxes.
The RCL workflow offers flexibility to cope better with limited time and resource availability and opens the possibility of iterative refinement. The critical steps of the proposed workflow are the initial sourcing of the RCL map and its subsequent conversion into a (simplified) graph as those are likely to influence the final analysis results. In principle, any alternative route on the workflow is considered "correct", as far as:

(i) It proves good enough to respond to its contextual needs;
(ii) The embedded choices are transparently presented and
(iii) Its limitations are previously anticipated.

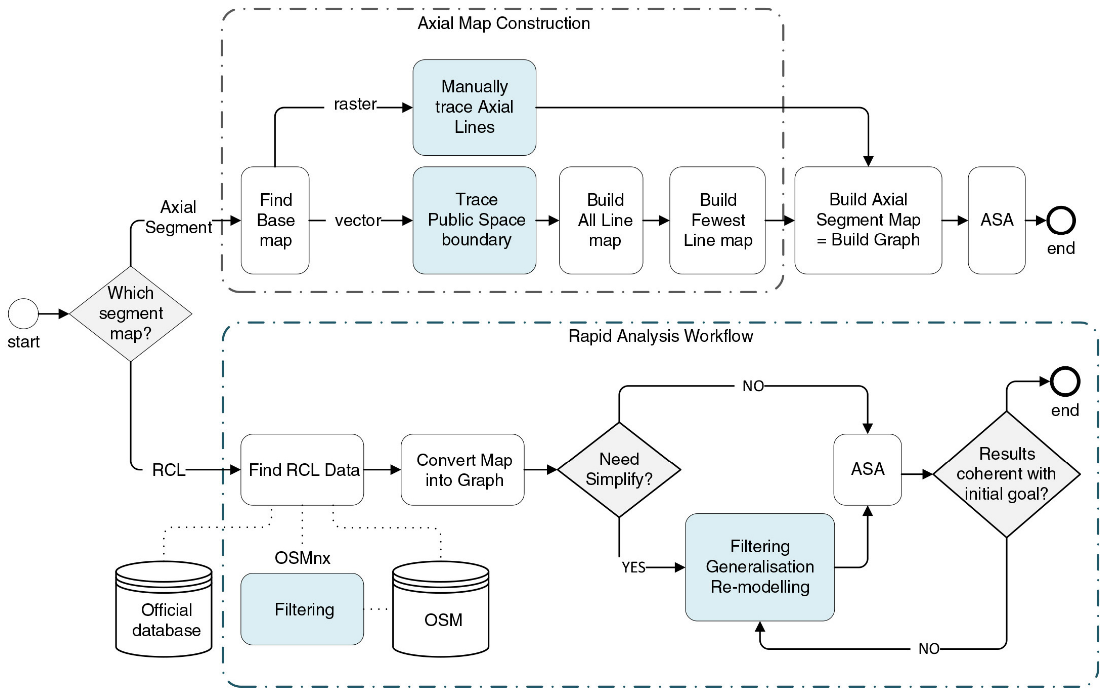

Figure 1. Flowchart of ASA alternative workflows

This study critically discusses some useful principles to find crowdsourced RCL data and subsequently convert it into useful ASA graphs. Specifically, it proposes the combined use of GIS and Python open tools within the configurational analysis workflow in order to:

(i) Enable a rapid extraction of RCL maps from the OSM repository;
(ii) Speed up the generation of different graphs in accordance to the analysis goal;
(iii) Increase the computational efficiency of the analysis process;
(iv) Highlight the consequences of different modelling choices on the analysis results.

4. THE DETAILED WORKFLOW

4.1 How to get the RCL map

Accessing the OSM repository to get the required RCL data can be hardly straightforward, despite the number of methods available to do it. The main problems usually come down to the computer science skills of the technician, the scalability of the request and the filtering of the data. There are no limits in terms of extension and customisation for the request, but querying the OSM API, named Overpass, by using the correct programming syntax is a non-trivial task. Intermediary platforms might overcome the need of having any programming knowledge but normally limit the possibilities of the query while increasing the time needed for data retrieval. For example, the OSM editing platform (JOSM) occasionally fails to download the data for larger territorial portions; Mapzen, takes up to one hour to run the requests for custom extracts; whereas Geofabrik, which deals better with larger territorial portions, charges for downloading Shapefiles. Using the OSMnx Phyton library (Boeing, 2017) is a user friendly option to acquire street network data in a way that is scalable and adaptable as it allows indirect access to the API and automates the extraction of required RCL data in isolation from the rest, retrieving only the OSM ways that correspond to the key “highway”. The library runs on Jupyter notebooks and needs only a couple of lines of Python code to download and save the OSM RCL map in Shapefile format, ready for GIS import. Requests can be done by inputting either: a) the name of a city/province/region/country so long as its administrative limits are presented in the OSM repository; b) the coordinates of a point and a radius; c) the coordinates of a point and the length of the side of a square; d) a shapefile containing a customised boundary.

4.2 How to convert the RCL map into a graph

In the Axial Segment workflow, the process of building the Axial Segment Map coincides with the automatic construction of its dual graph representation, in which streets are nodes and intersections are edges. In the RCL workflow, the dual graph is built after importing the network vector drawing, when creating the Segment Map. The conversion is rather implicit as the dual graph is not visible in Space Syntax analysis platforms.

Besides facilitating the download of OSM data as Shapefiles, OSMnx offers the possibility to retrieve immediately a correct and generalised primary graph representation of street networks, in which streets are edges and intersections are nodes, useful for complementary analysis applications (fig. 2). To contrast the edge effect, OSMnx automatically creates a buffer of half a kilometre around the requested area and uses the information contained in the buffer to construct the graph so that each node has a correct street count; then it clips the graph to fit the originally requested area extent.

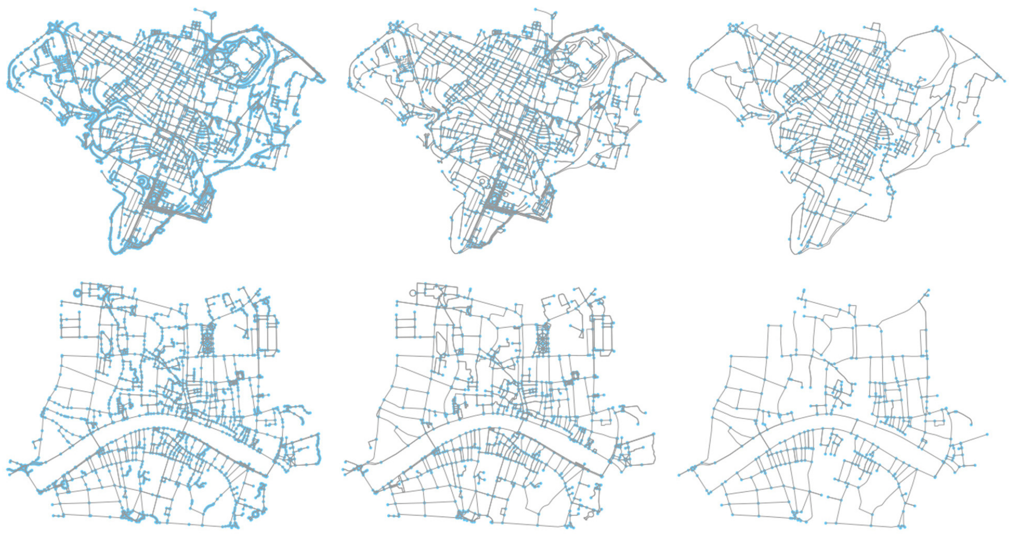

Figure 2. OSMnx original, corrected and filtered. Primary graph representations of Pisa (top) and L’Aquila (bottom), Italy

Additionally, the library allows the use of fine-grained information typically present in OSM data to automatically filter OSM data and build the graphs that correspond to different types of mobility networks.

4.3 Multiple graph analysis and modelling issues

The concept of a multiple graph analysis has recently emerged in Space Syntax studies, after that some network representations have empirically proved more suitable than others to highlight certain aspects of the functioning of a given urban system. In time, several algorithms have been proposed to derive graphs reflecting a diverse focus in the analysis. Stavroulaki et al., (2017) noted that, by doing so, past research work has clearly challenged the one to one relation between the map and the graph while opening new opportunities for experimenting with alternative analysis workflows. To build new or simplified graphs from initial segment maps authors have mainly used either generalisation algorithms or re-modelling methods. In Jiang and Claramunt, (2004) and Jiang et al. (2008) the toponomy of the elements is considered as a primary semantic factor to model the network continuity, while Thomson (2003) calculates geometric properties such as angular variations to merge street segments into strokes. Others have used local simplification methods to correct specific geometric instances in the graph such as undershoot or overshoot dangle nodes, dual lines, road details and excessive segmentation. These two approaches reflect a different way to understand the street network as well as a particular purpose in the analysis and therefore present different advantages and limitations. The construction of the graph should match the type of analysis being done. Certain characteristics of OSM data described as problematic in the literature, such as its tendency to over-represent management features, may turn themselves useful depending on the focus of the analysis (e.g. concentration or conversely distribution of movement for informing logistics during the emergency phase).

Figure 3 shows an example of how a roundabout is represented in many locally re-modelled graphs. Past works have suggested representing roundabouts as simple intersections. A simplification, which reduces, to a certain extent, the complexity of the graph, but comes with further consequences that need to be understood. The simplification of a large radius roundabout into a simple intersection is likely to locally distort the output of the analysis by creating nodes where the value of Connectivity is artificially concentrated (see c values of nodes in figure 3) as well as influence the global distribution of configurational values including mean Connectivity; artificially altering estimates of relational resilience of the network. Roundabouts may also present complex shapes (see right side of Figure 3) making the simplification hardly straightforward.

An excessive simplification of traffic management features in an analysis at a larger scale may, for example, provoke the increase of the global Integration index for certain segments in the historic centre, while reducing the importance of external circulation roads. A zoom into one of complex clusters of roundabouts from Case study 2 (full case study in Figure 9) intuitively shows how the roundabout simplification process can alter the distribution of the two Space Syntax Centrality indexes. Finally, this simplification would probably not make much sense for certain analysis goals such, for instance, in the hypothesis of a vehicular analysis at the micro-scale that needs to consider the interruption of a single trait of the roundabout.

Figure 3. Re-modelling of roundabouts and new Connectivity values, Pisa

Data conversion processes are, hence, likely to have consequences, which may not reflect the intentions of the person conducting the analysis. To judge the right level of simplification it is important to have clear analysis goals, extent and scale. Similar considerations should guide all the modelling choices from its very early stages to ground the analysis workflow into a coherent and deliberate reasoning so choices that decision-makers have on the analysis tools are properly informed.

The ideas discussed so far are illustrated in Section 5 through a Space Syntax analysis of Pisa and L'Aquila: two historic towns of comparable size with a shared Roman origin and a similar spatial structure. An ASA on different graphs built upon RCL data retrieved from the OSM dataset is compared with an ASA using graphs directly derived from more "classical" data sources such as official RCL maps and Axial Segment Maps. To enable an effective comparison among the different graph types the values of Integration and Choices are normalised. NAIN (Normalised Angular Integration) and NACH (Normalised Angular Choice) are used to better illustrate the results of the ASA. The different graphs considered in this study include: 1) the Axial Segment graph; 2) the official RCL graph; 3) the original OSM RCL graph; 4) a set of differently filtered OSM RCL graphs; 5) a generalised graph obtained by using the Douglas-Peucker algorithm on OSM data; 6) a locally re-modelled version of the OSM RCL graph. The first three graphs correspond to the alternative benchmarks proposed in previous literature to evaluate the Angular Analysis results. Initially, their spatial characteristics are briefly discussed. A greater space is then given to the discussion of the remaining graphs, given their relevance for post-disaster applications. The last three graphs are studied in isolation to foster better understanding of the effects of the underlying three simplification processes on the Space Syntax analysis but may be used simultaneously in real-life applications. Basic statistics is used to highlight differences between graphs while the correspondent analysis results are visually compared.

5. DATA PROCESSING ON THE CASE STUDIES

5.1 The three reference graphs

In both case studies, the Axial Segment Map, and correspondingly graph type 1, is built over an official vector cartography, after drafting the perimeter of the urban space that allows limitless use by everyone (workflow in fig. 1). In the case of Pisa, the boundary was drawn out of the Carta Tecnica Regionale (CTR), planimetric base representation of the regional territory openly provided by the Tuscan regional administration (scale 1:2000, dated 2002). In the case of L'Aquila, the CTR provided by the Abruzzo open Database Territoriale Regionale (D.B.T.R) was used (scale 1:5000, dated 2007). For each case study, the delimited area was digitally populated with numerous Axial Lines (All Line map), which were reduced to a minimum number (Fewest Line map) to create the Axial Map using Depthmap10 software application which later allowed transforming the axes into segments and removing the short stubs (20% shorter than the average). Graphs produced in this way are classic Space Syntax representations of Axial Segments. They are used as a reference together with graph type 2 (the official RCL graph obtained by segmenting the RCL data contained in the two official datasets) to understand the characteristics of other graph variations. It is noted that official RCL data contains an accurate and balanced, but also rather generalist representation of the urban street-network. In fact, as reported in the Abruzzo region website ("C.T.R.N. Regione Abruzzo," n.d.), the CTR regional technical map provides a general representation of the urban morphology and is built in relation to a correct density of the cartographic plot.

Graph type 3, a complete, unaltered version of the original OSM highway, is used for further reference, providing a basis for discussing the characteristics of other OSM derivative graph types (4, 5, 6 and their combinations); which correspond to the three actions that can be done on the original OSM RCL graph to improve the operational efficiency of the configurational analysis process: filtering, generalisation and re-modelling.

All three reference graphs are shown in Figure 4.

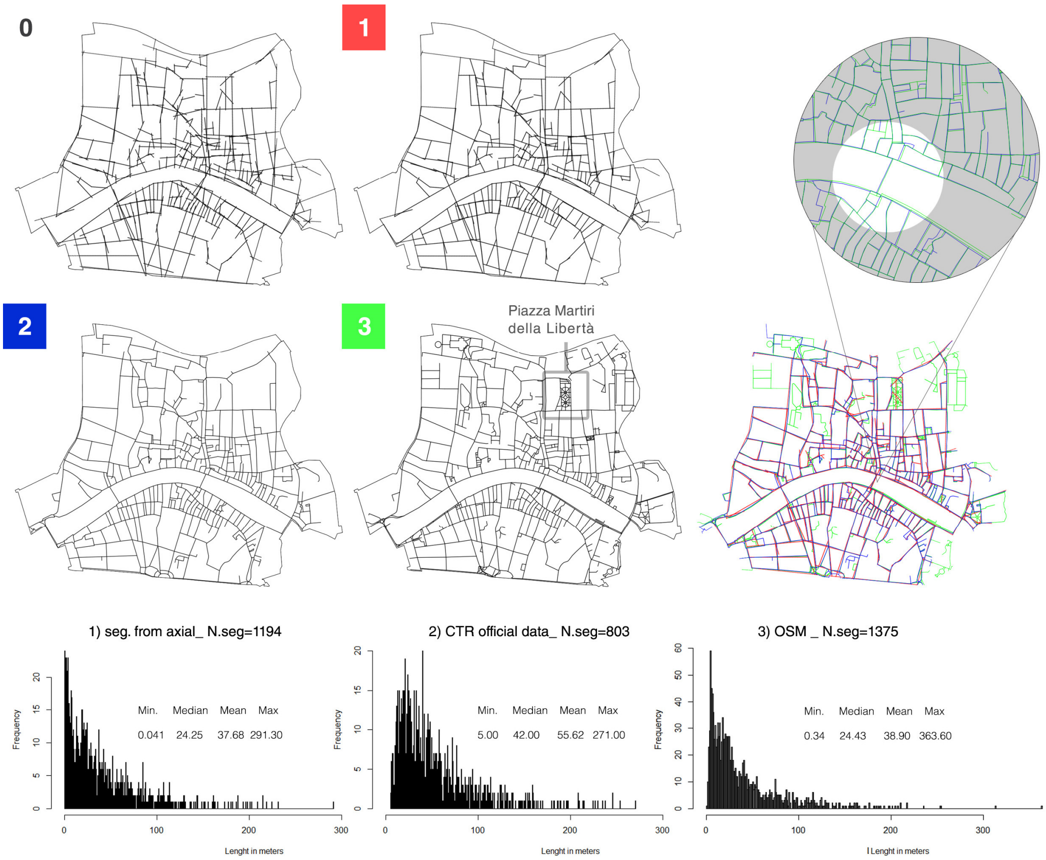

Figure 4. Pisa reference graphs and histograms of segments' lengths (meters): 0 = Axial Map; 1= Axial Segment Map; 2 = official RCL map; 3 = OSM highway data. On the right graphs 1,2,3 are overlaid. The zoom shows the way the two squares at the separate ends of Ponte di Mezzo in graph types 2 and 3

5.2 Filtering

The bottom right side of Figure 4, overlaid reference maps, shows that OSM data contains features that reflect the absence of a generalist view if compared with the official RCL datasets, but integrates local knowledge by embedding elements that closely pertain to the pedestrian realm such as links through buildings and paths through parks (see for instance *Piazza Martiri della Libertà*). In the OSM map of L'Aquila historic centre (figure 6), it is possible to spot a few red segments parallel to the main transversal urban axis corresponding to the pedestrian passages under the loggias, location of several commercial activities, which are tagged with the 'name' '*portico*'. This richness of information is probably a consequence of the collaborative and open nature of the OSM dataset. Despite being encouraged to maintain a certain consistency in using a suggested list of categories to classify street types ("Key: highway - OpenStreetMap Wiki," n.d.), contributors are not restricted to use only those semantic tags. The diversity and richness of information may eventually clutter the spatial analysis as well as hinder the use of a universal tag-filter prior to the ASA for improving analysis efficiency. To successfully filter OSM RCL data, it is therefore often necessary to accurately customise the choice of OSM 'highway' keys to be maintained in the simplified graph; this issue is generally overlooked in the literature.

Following a statistical reasoning, Corcoran et al. (2015), have suggested filtering out the semantic types that represent only a minimal percentage of the overall street network, or reversely, keeping just the most representative 'highway' labels, i.e. exclude the keys that fall into the last 5% of the cumulative curve of the labels' frequency distribution (see Pareto charts in Figure 5). This is a step forward in automating OSM tag-filtering but may eventually cause a fairly large number of semantic categories to fall into the group of the less represented 5% if the distribution is built by considering purely the number of segments tagged with a certain key. This paper suggests using street lengths as a weighting system to account more accurately for the representativeness of street segments corresponding to various OSM semantic types. Figure 5 shows that the set of most representative keys vary between the two case studies and that the weighting system based on OSM segment lengths changes the hierarchical distribution of the labels. For Pisa the introduction of weighting alters the ranking of the tags but ultimately does not affect the set of categories to filter. For L'Aquila the change influences the decision, causing the exclusion of the key 'steps' instead of the key 'secondary', in opposition to the results obtained from applying the unweighted filtering system. The simple distribution, based solely on the number of occurrences of tags, is in fact excessively dependent on how the OSM map is built (e.g. from the number of segments used by contributors to map a single road), whereas the weighting system produces more reliable results, invariant in relation to the level of (over)segmentation of the original OSM map.

This conclusion is supported by a quick comparative visual analysis of the two maps of L'Aquila obtained by applying both filtering methods, L'Aquila* and L'Aquila** in figure 5, which are superimposed on the original OSM map, coloured in red. Comparing the two maps shows that introducing the weighting system allows long roads, used for external circulation and represented in the original dataset by only a few segments, to be maintained in the filtered graph. Next, it is recommended to double-check the suitability of the adopted tag-filtering threshold, set here at 95%, and increase or decrease the percentage of streets to keep as required. For instance, it is possible to note from L'Aquila** map that filtering out the key 'steps' is likely to provoke discontinuities in the graph by interrupting some streets, isolating single lines and creating 'islands' (small groups of lines disconnected from the rest of the graph) with potential detrimental effects on the ASA. Thus, if the initial filtering threshold is maintained, these topological inconsistencies should be dealt with prior to the analysis.

It is important to note that, some open GIS applications offer the possibility to automatically verify the topology of street networks' graphs in order to correct it. As a further consideration, for setting the right filters in cases where the humanitarian mapping effort is ongoing, it may be useful to bear in mind that OSM maps grow following an iterative processes of spatial 'exploration' and 'densification' (Corcoran et al., 2013), meaning major circulation streets (the network foreground structure) are more likely to be added before small ones (the background network structure).

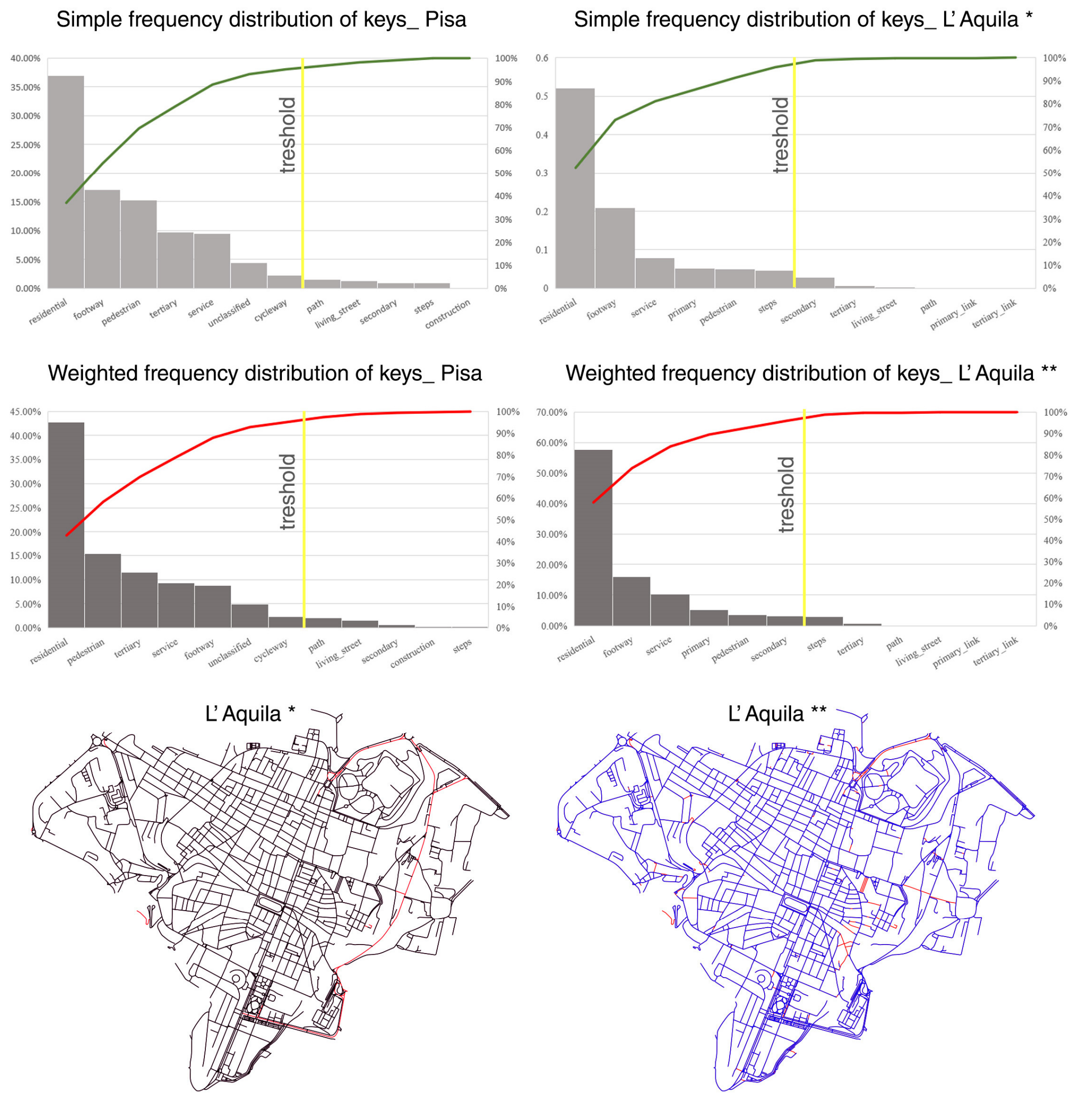

Figure 5. Simple and weighted distributions of OSM highway keys, pedestrian network, of Pisa and L'Aquila

Another way to filter OSM RCL data is extracting different mobility networks based on OSM labels. This process can be automated and performed in little time using the OSMnx Python library. The mobility networks that OSMnx can filter are essentially three: the pedestrian, the vehicular and the cyclable. Specifically, by using the keyword ‘walk’ it is possible to retrieve an undirected, non-planar graph containing all the streets pedestrians have access to, including paths through parks and links between buildings besides residential streets. The keyword ‘drive’ corresponds to the network of streets that are drivable and public, discarding service roads, whereas ‘bike’ considers only the roads and paths used by cyclists. The underlying idea of rapidly generating more graphs corresponding to different navigation modes from a unique, collaboratively built base map seems to hold a great potential in terms of methodological flexibility for post-disaster applications, whereas the automation of the process contributes to improve replicability. More generally, the OSMnx tool seems to effectively answer the need to get targeted graphs ready for ASA within little time and by making economy of resources. Figure 6 shows the OSM Walk (red), Bike (green) and Drive (blue) networks of L’Aquila obtained after filtering using the Python Library. The image overlaps the three mobility layers starting from the most spatially extended up to the least one so that it is possible to appreciate the reduced extent of the drivable network with respect to the pedestrian one in L’Aquila historic centre. The official RCL map offers a compromise between these two extremes, showing a sort of hybrid drive-walk network (see later figure 7 and 8). For targeted applications such as studies addressing different types of mobility the use of such a filter may prove particularly convenient and therefore preferable to the use of the more general official RCL data.

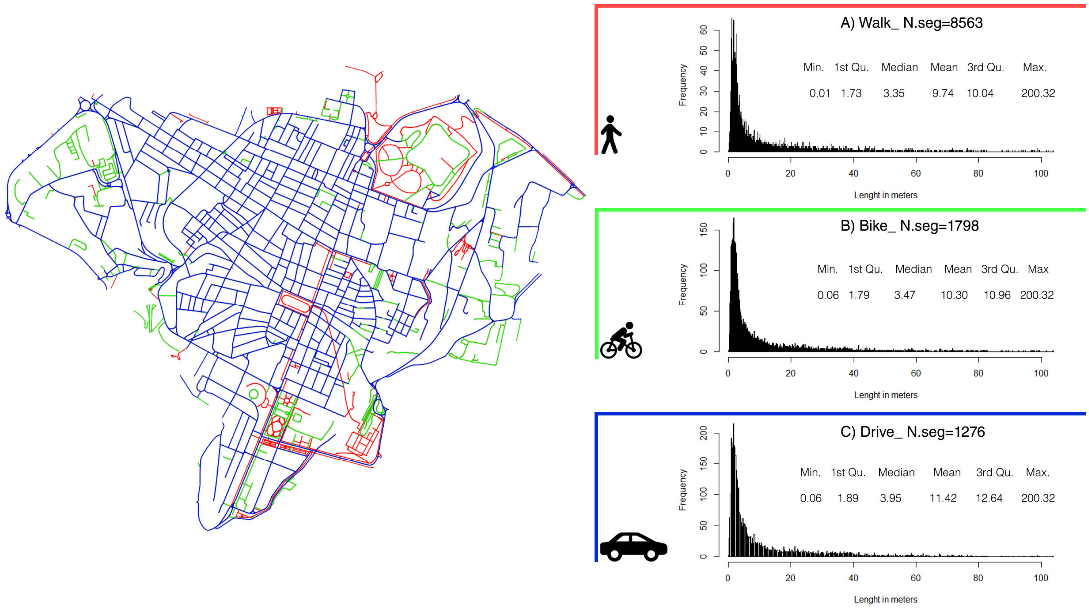

Figure 6. Filtering, L’Aquila. Walk, Bike, Drive mobility graphs

5.3 Graph Type 5: Generalisation

Another technique used in the literature to simplify OSM data is called ‘generalisation’. Among cartographers, generalisation is known as the process of simplification of geographic data to produce a map at a certain scale in a way that is readable. Such a process involves using various techniques to achieve a required geometric simplification in data representation. One of the most popular generalisation algorithms is the Douglas-Peucker algorithm, which uses an iterative fit procedure to reduce the complexity of a curve composed of numerous line segments and replace it with a similar one with fewer points. This algorithm works at different intensities, modifying the initial geometry according to a given tolerance value corresponding to the required level of simplification. The value needs to fit the scale of the analysis to avoid the risk of high tolerance thresholds altering the initial geometry so to affect the configurational qualities of the graph.

In a First test, the Douglas-Peucker algorithm has been applied to the OSMnx mobility networks of L’Aquila and Pisa using the GrassGis tool available for open use in QGIS, by progressively incrementing the algorithm’s tolerance value (set in order to 2, 5 and 10). In the case of Pisa, pushing the tolerance further generates geometrical inconsistencies such as the appearance of new intersecting edges that originally did not cross, in correspondence of points where the urban grid becomes narrow and streets have an articulated, meandering, shape. This is a consequence of how the OSMnx library builds the graph, which is using strokes instead of street segments as graph edges. To avoid the

problem, it may be advisable to re-construct the topology of the graph before applying the generalisation algorithm. In a Second test, an ASA has been performed on the three generalised graphs of L'Aquila mobility networks, to assess the effects on the analysis of using generalisation.
Figures 7 and 8 show the distribution of NACH and NAIN in the original OSM graphs and those obtained after applying a tolerance 10 Douglas-Peucker generalisation. These results are confronted with the ones obtained from the analysis of the official RCL segment map (left side of figures 7 and 8), but comparisons between all graphs are not straightforward, due to the hybrid nature of the CTR (official dataset). In some cases, generalisation moves the results of OSM graphs closer to those obtained from the official dataset (see distribution of NACH in the OSM 'drive' network or NAIN in the OSM 'bike' map); in others it causes the outputs to diverge from those of the CTR (see distribution of NAIN for the OSM 'walk' network). This may indicate that a different generalisation threshold is required for the three mobility maps. Choosing the tolerance value according to a comparison with the official dataset seem however an ill-defined strategy; possibly a correlation test with empirical data could help exploring this issue further.
The experiment shows that for lower tolerance values using Douglas-Peucker generalisation preserves the relational character of the initial OSM graphs while offering a neater global output, which highlights more effectively the hierarchical distribution of both NACH and NAIN. Previous studies have argued that applying generalisation to OSM data should shift the values of Choice closer to those of axial representations. Generalisation in fact produces a more abstract representation of reality, rectifying and regularising the edges of the graph. For example, when it comes to roundabouts, generalisation causes the initial circumference-like polygonal shape to change into a simpler polygon, by progressively reducing its number of edges. However, despite it being helpful in this respect, using generalisation does not guarantee the ASA reflecting the results of an Axial Segment analysis, as demonstrates the test made on Pisa (second row in figure 10). An in-depth study on generalisation methods applied to different RCL datasets would probably help clarifying this phenomenon further. Finally, applying generalisation on a dataset prior to the analysis reduces in a non-linear way resources and time required for computational processing, and thus can contribute to greatly improve the efficiency of configurational analyses at regional and national scales for disaster management purposes (e.g. improve infrastructure resilience). At urban scales further studies are yet needed to yield any conclusion.

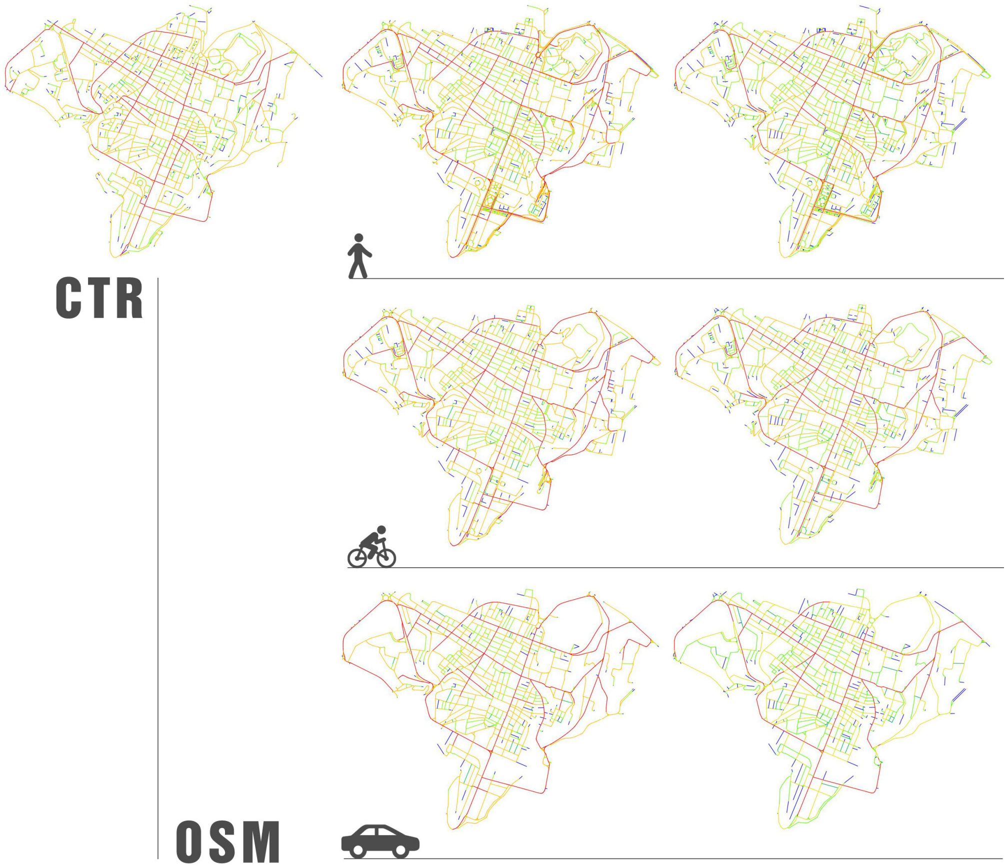

Figure 7. Generalisation, L'Aquila, NACH Rn. From left to right: CTR, OSM walk\bike\drive networks and their generalised versions (Douglas-Peucker tolerance 10)

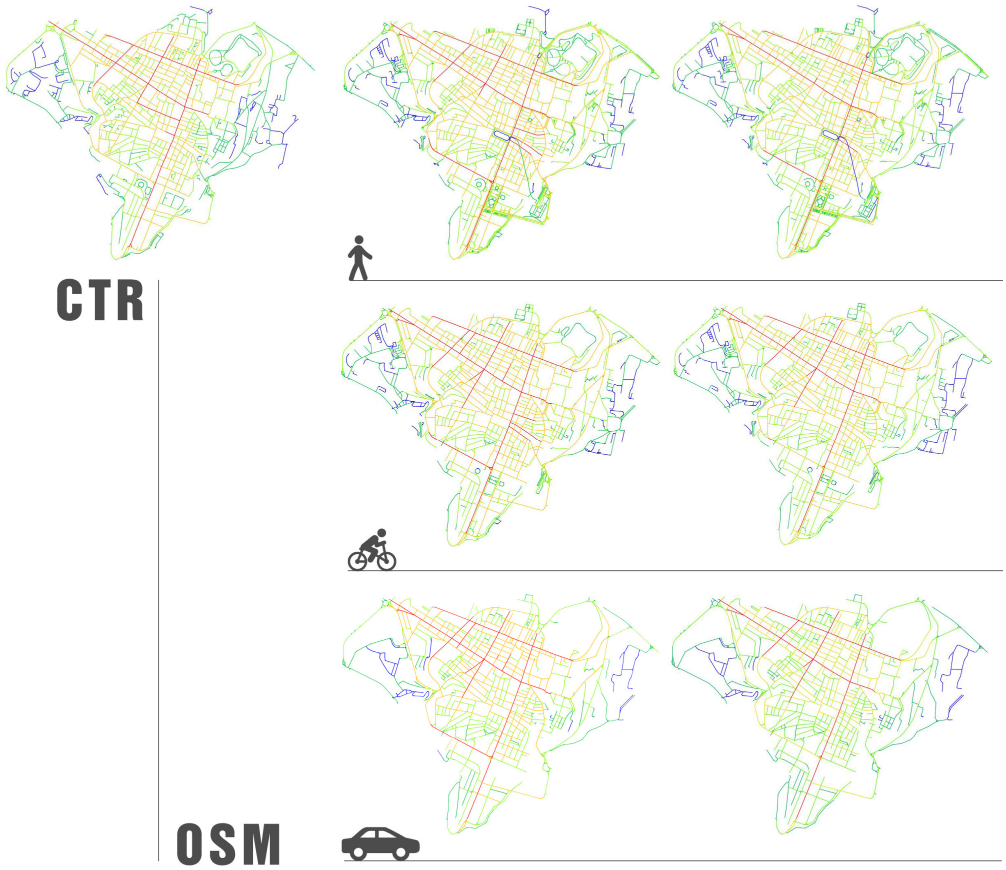

Figure 8. Generalisation, L'Aquila, NAIN Rn. From left to right: CTR, OSM walk\bike\drive networks and their generalised versions (Douglas-Peucker tolerance 10)

5.4 Graph Type 6: Re-Modelling

Re-modelling refers to the strategy of locally modifying the original graph either manually or automatically to produce a model more coherent with a preferred interpretation of reality. It could be used, for example, to model Choice in a focused way to guide strategic decisions about post-disaster infrastructure reconstruction priorities, without diverging the attention on details. However, using re-modelling properly requires a certain level of critical thinking.

Kolovou et al. (2017) suggest using some local re-modelling rules on RCL data as part of a graph simplification process aiming to achieve analysis results closer to those of a traditional Axial Segment Map. Krenz (2017) claims that a targeted re-modelling step is needed to avoid ASA analytical results to be skewed towards an undesired emphasis on elements of secondary importance. Both studies suggest re-modelling traffic management features such as traffic islands, artificial cul-de-sacs, roundabouts, staggered junctions as well as meandering trunk links and streets with parallel lanes. Some additional complex and special cases are represented by Public Squares. The specific rules proposed in these two studies to re-modelling such features follow a logic coherent with the authors' modelling needs and therefore do not have a universal value. Re-modelling principles need to be carefully considered during the modelling phase as changing the spatial representation of one or more features provokes the immediate redistribution of configurational weights within the new model.

Figure 9 shows the experiment conducted on the extended Drive network of Pisa, where all roundabouts have been re-modelled into simple intersections. Roundabouts are exemplary because of their large diffusion in bigger and smaller European cities. In Pisa there are around fifty of them, and many are clustered in groups of three or five in the surroundings of the historic urban walls. As expected, the results show that local re-modelling affects the analysis outputs. Specifically, it influences the distribution of NACH to the extent that new roads emerge as parts of the urban foreground structure whereas others disappear from it. NAIN is affected as well, but less strongly. The results also confirm the hypothesis of Kolovou et al. (2017) as the global (radius n) distribution of the two normalised Centrality indexes in the re-modelled graph is closer to that of the Axial Segment Map; which supports the appropriateness of the adopted re-modelling rule for that aim.

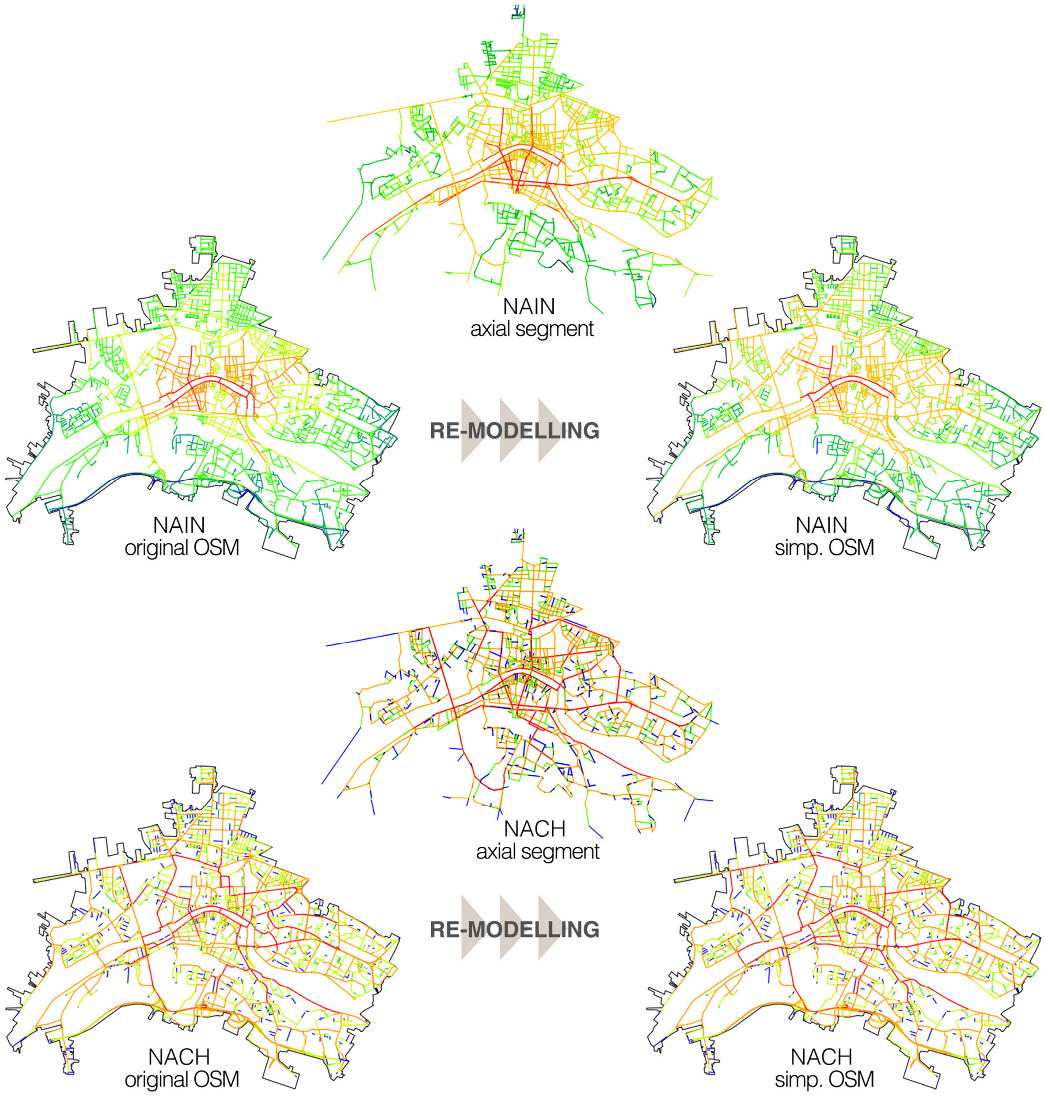

Figure 9. Re-modelling, Pisa, NAIN Rn and NACH Rn. From left to right: original OSM, axial segment, simplified OSM map

6. DATA ANALYSIS ON THE CASE STUDY OF PISA

A visual comparison of results for all cases is presented in the case study of Pisa. The ASA is conducted on different graphs representing the pedestrian network of the city centre using a local (800m) and a global radius. Figure 10 shows that the spatial reading offered by the Axial Segment graph differs from the others' as that highlights the Roman cross-shaped structure of Pisa. The official RCL representation is spatially closer to the OSM model and shows some elements of hybridity. In this respect the case of *Ponte di Mezzo*, the central bridge connecting the two major commercial streets of the town corresponding to the vertical axis of the Roman cross, seems exemplary.

6.1 The case of Ponte di Mezzo

Ponte di Mezzo is an element of primary importance for the functioning of Pisa and its potential collapse would certainly affect the way the city works, by redistributing the flows and dividing the commercial area in two parts. However, not all the analysed RCL models are able to appreciate this fact properly and would therefore lead decision-makers to underestimate the magnitude of its importance.

In fact, both the CTR and the OSM segment maps represent this important link in a somehow loose way compared to that of the Axial Segment map, but the former maintains the bridge in the Integration core for both the analysed radii.

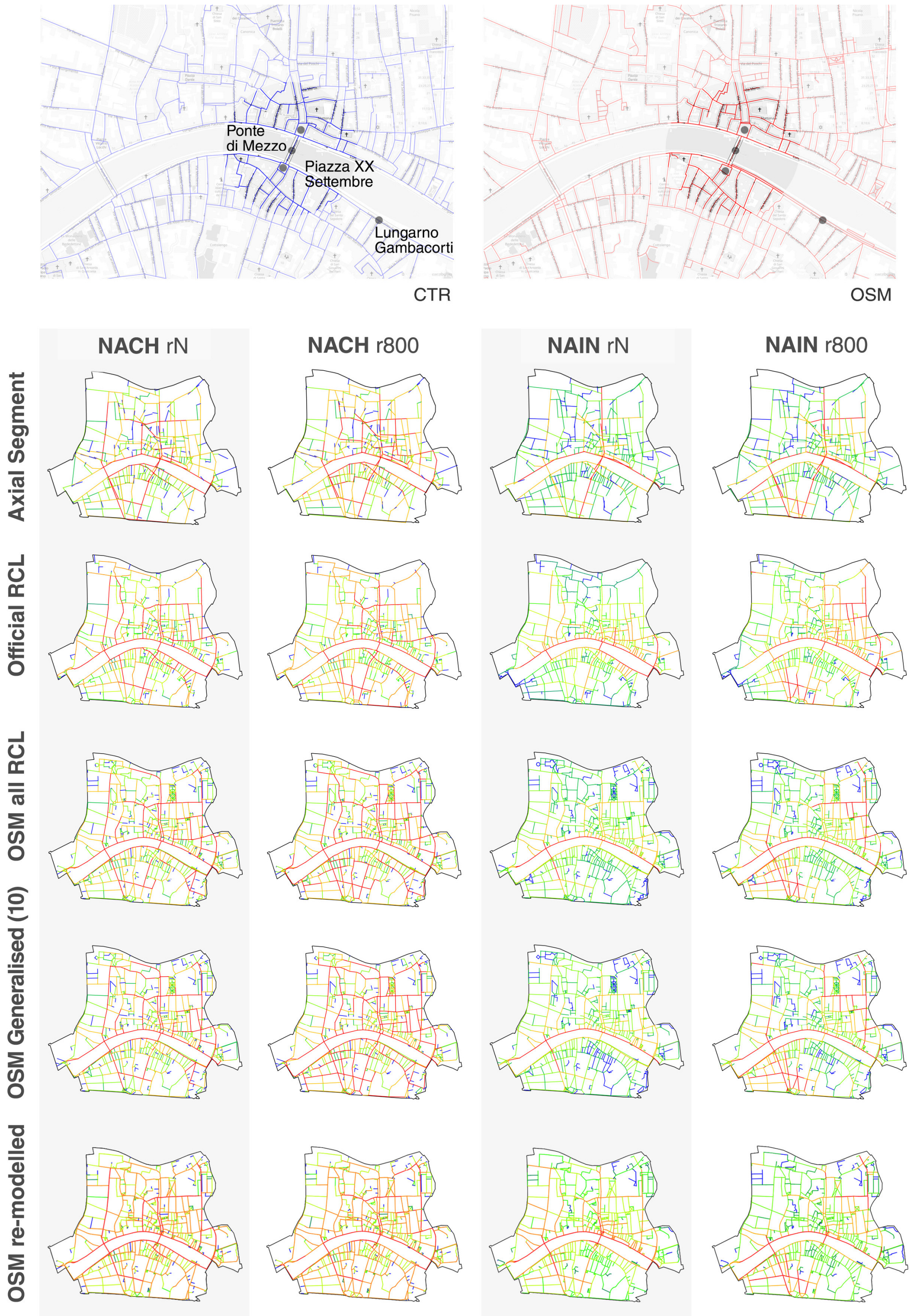

Figure 10. ASA, Pisa city centre

The zoomed OSM and CTR maps in figure 10 show that this modelling weakness comes from a conflict with the representation of two public squares placed at the separate ends of *Ponte di Mezzo,* corresponding to the end and the beginning of the commercial streets. The Axial model simply ignores the presence of the squares and connects the commercial streets directly whereas the other ones interrupt the continuity of the network representation by inserting a closed polygon in correspondence of the squares' boundary, which introduces a heavy angular weight that ultimately diminishes the Centrality value of the bridge. The CTR and the OSM maps diverge in the way they

trace the boundary of the South square, named *Piazza XX Settembre*: in the first the northern edge of the square matches a trait of *Lungarno Gambacorti,* the road that runs parallel to the river, whereas the OSM map keeps the Piazza separated from the drivable network to which it is connected via a single link. This small mismatch and minor angular differences present in the two RCL maps are ultimately able to determine whether the bridge belongs to the group of the most integrated segments.
To further explore the issue, a local re-modelling of Pisa public squares has been done based on OSM RCL data by connecting the segments entering the squares with the squares' central points (see last row of maps in figure 10). For completeness, it is reported that alternative re-modelling rules have been suggested in previous literature such as connecting each entrance with all the others. Next, paths crossing parks and public gardens have been eliminated from the graph, including those crossing *Piazza dei Miracoli*, the place where the leaning tower is, as this cannot be considered a public square, but the equivalent of an Acropolis. The results of the ASA show that the distribution of the configurational indexes in the locally re-modelled graph is closer to that of the Axial Segment Map, with stronger correlations for global and local NAIN, while being generally coherent with that of the official RCL dataset.
What the experiment ultimately demonstrates is that modifying the graph affects the ASA results - more so when angular change is introduced - but no analysis output can be judged strictly right or wrong. The coherency of modelling choices and underlying reasoning should be judged instead.

7. CONCLUSIONS

This study prepares the ground for further research aimed at using Space Syntax to conduct a multi-dimensional study of urban street networks in a way that is more accessible to people working in disaster management practice. To this end, the paper proposes a fit-for-purpose analysis workflow oriented at ensuring the feasibility of the analysis in post-disaster situations. It suggests evaluating different analysis methods in terms of their rapidity, ease of implementation, adaptability capacity and output accuracy. The initial results of this ongoing research support the idea that a plurality of methods to the analysis of urban configuration can provide a step forward for the use of Space Syntax in guiding decisions under uncertainty.
Specifically, this paper defends the legitimacy of performing a rapid analysis using open collaborative geodata. In order to deal better with the likely modelling challenges associated to the use of collaborative data sources, it is suggested to make targeted simulations combining different simplification techniques such as filtering, generalisation and re-modelling as required by the decision-maker, provided that the effects of these actions on the analysis are under control. It demonstrates that any modelling activity is an act of simplification and abstraction and therefore any simulation is ultimately a result of these. On such basis, the success of the method and the analysis ought to be judged according to the analysis scope and original goals. Issues which are usually considered modelling technicalities (details about how to construct a part of the graph for the analysis) are anything but trivial: on the contrary, they are often crucial for ensuring the coherency of the analysis activity. Especially because little data is likely to be available for subsequent empirical validation in disaster contexts.
Finally, it is suggested that further research should be done in some key areas such as, for instance, studying the effects of using different tolerance values in generalisation methods. In addition, future studies should compare complementary alternatives for the construction of the analysis model that remain within the framework of the configurational study of urban grids and which show a high potential of integration with external models. Among the possibilities worth exploring there could be, for instance, the Mark Point Parameter Analysis (Ma.P.P.A) developed by Cutini et al. (2004), which adapts a primary representation of the urban grid, so that it closely reflects the cognitive principles underlying Space Syntax theory. Furthermore, future research could consider both the primary and the dual approaches (Porta et al., 2006, 2004) and explore their relative strengths and weakness in order to offer a richer toolbox to those operating in the field of post-disaster management.

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