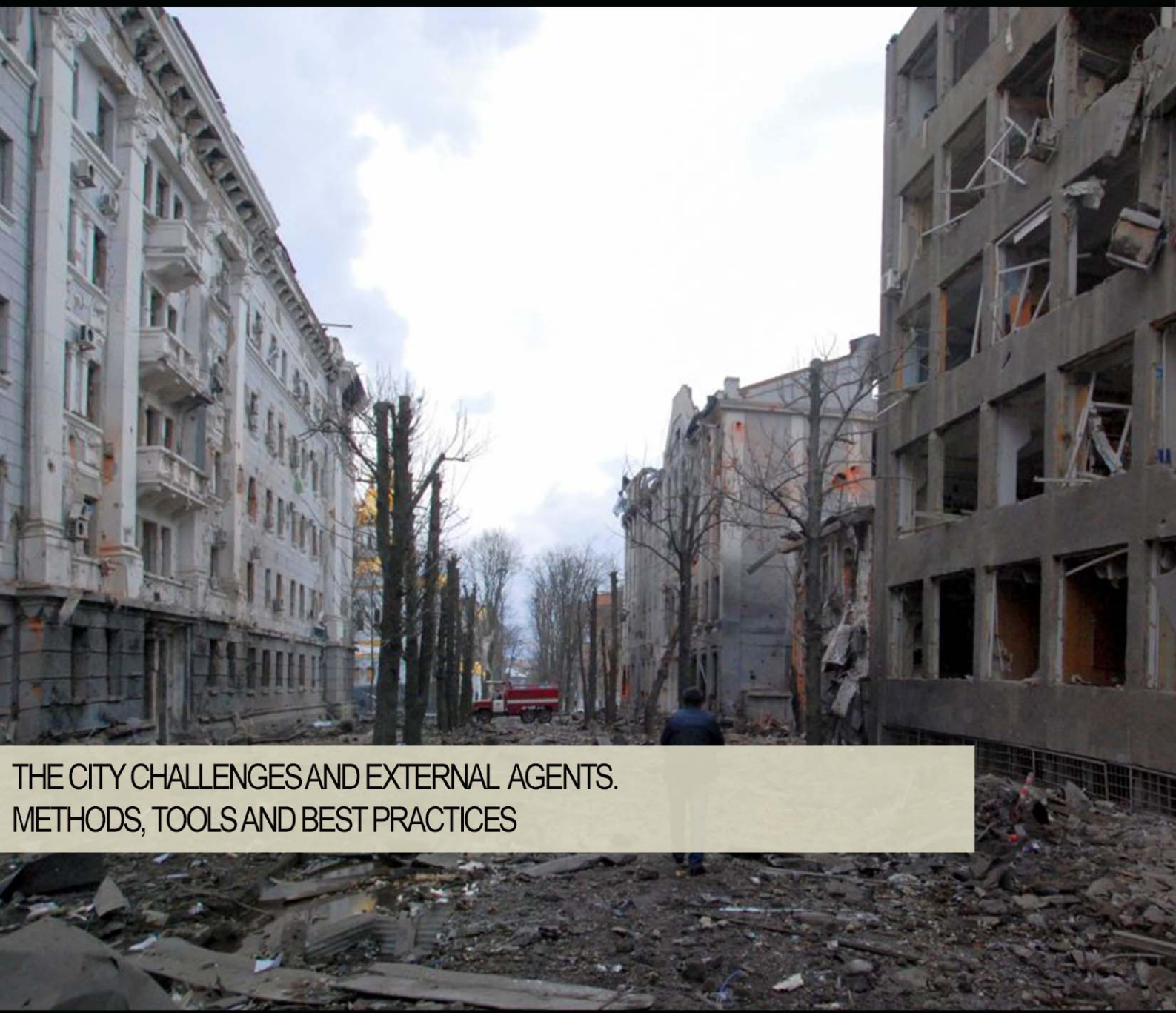


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THE CITY CHALLENGES AND EXTERNAL AGENTS.
METHODS, TOOLS AND BEST PRACTICES

TeMA

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Land Use, Mobility and Environment

THE CITY CHALLENGES AND EXTERNAL AGENTS. METHODS, TOOLS AND BEST PRACTICES

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Investigating the socio-spatial logic of historic urban areas through space syntax

A comparative analysis of the Roman towns Cosa, Nora, Timgad and Thuburbo Majus

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Abstract

Starting from the Late Republican and First Imperial ages, the Roman Mediterranean has seen the development and transformation of urbanised areas due to the newly gained stability conferred by the so-called Pax Augusta. This phenomenon has significant consequences in transforming pre-existing urban structures and establishing a large number of newly founded urban areas. This study aims to address a gap in the existing literature by developing a method to analyse the configuration of historical urban sites to understand the social and cultural antecedents of the transformation and development of urban areas in the Roman era. The study builds on Space Syntax theories and techniques to develop an analytical protocol that combines syntactical analysis and statistical analysis to measure and compare spatial, visual and social relationships in four urban Roman sites in the Mediterranean. The selected areas of study are the urban sites of Nora and Cosa in Italy, of Timgad in Algeria and of Thuburbo Maius in Tunisia. The study areas include planned urban sites constituted by a grid structure (Cosa and Timgad) and cities with continuity of life (Nora and Thuburbo Maius) formed by an organic inspired spatial layout. The study significantly contributes to archaeology and urban studies by proposing a combination of methods that associates distinct analytical techniques to investigate the large-scale configurational properties of historical urban environments whose spatial structure and, therefore, social logic have been only partially explored.

Keywords

Roman urbanism; Space syntax; Configuration; Spatial structure; Social logic of space; Movement.

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1. Introduction

Roman culture can be considered an urban culture (Stoger & Brandimarte, 2015). The Roman Empire included, in fact, more than 2000 urban sites. Intensive investigations on preserved roman urban sites focus on the urban space of roman cities, and on the relation between private and public space (Zaccaria Ruggiu, 1995), to understand social and economic implications of spatial organization (Stoger & Brandimarte, 2015). Urban space is thus considered a place where the relational structure that underpins a culture's political, economic, and social existence manifests and reproduces itself (Battistin, 2021; Stoger & Brandimarte, 2015; Stöger, 2011; Van Nes, 2009). More precisely, focusing on a structuralist approach, spatial structures from the Roman age are increasingly being explored to demonstrate the social logic of urban spaces, and a growing consensus has emerged about the social value of places (Stöger, 2011). From this point of view, space can be defined as an intrinsic component of social and cultural forms. Individual and social practices incorporate specific spatial forms and depend on specific structures of co-presence (Harcharan Pappu, 2018): the actions of congregating, interacting, moving, and socialising constitute spatial configurations (Yamu et al., 2021; B. Hillier & Hanson, 1984; B. Hillier, 2007). Configuration can be defined as the set of topological relations among inter-dependent spatial elements comprised in an overall structure. Topological relations determine access and visual connections among spaces, thus generating patterns of integration and segregation that influence the distribution of movement and co-presence across a spatial system (V. Cutini & G. Rabino, 2012; B. Hillier, 1999, 2007; B. Hillier & Hanson, 1984). As a result, the mutual relation of space and social practices is not understood at the level of the intrinsic, geometric properties of a space, but at the level of its extrinsic configurational properties, resulting from the relative position of a space in a spatial structure (Marshall, 2005). Consequently, from the perspective of archaeological studies, the configurational analysis of space is relevant for understanding the social, political, and economic systems of ancient cultures (Battistin, 2021; Kubat et al., 2019; Stöger, 2011; Van Nes, 2014). Moreover, the configurational analysis of spaces of ancient cultures is relevant, from the perspective of urban studies, to investigate the persistence of specific socio-spatial processes and to recognise configurations respondent to persistent social aspects of urban spaces, including access, encounter, residents and non-residents interactions, diversity, vibrancy, vitality, and control of spaces. Over time, empirical studies have demonstrated the validity of using syntactic analysis through space syntax techniques to investigate the socio-spatial logic of built environments. Therefore, this study builds on space syntax theories and methods to describe the urban layout of four Roman cities.

In particular, the study focuses on the Mediterranean area and investigates the cities of Nora and Cosa in Italy, of Timgad in Algeria and of Thuburbo Maius in Tunisia. Specifically, this article describes the utilisation of axial and segment angular analysis to investigate historic urban sites.

The article is structured in five sections: following the introduction and clarification of the research objective, the section 3 presents Roman Urbanism and to space syntax analysis concepts. The methodology and case study are then described in section 4. The results of the analysis are presented and discussed in sections 5 and 6. Section 7 concludes the paper by summarising the study's findings and presenting hypotheses for future research development.

2. Research aim

This study addresses a gap in the research on the spatial structures of ancient cities. Indeed, the literature on syntactic and statistical analysis applied to investigating the social antecedents and consequences of spatial structures is limited. Web of Science and Scopus databases provide 15 and 21 results, respectively, related to the field of Archaeology, and including the terms "ancient" or "archaeolog*" or "space syntax". Moreover, the studies based on the syntactic analysis of Roman cities are focused on specific locations, in particular Ostia and Pompeii. As a result, the study's relevance for archaeology and urban studies lies in developing a method

that combines distinct techniques of syntactic and statistical analysis and in its application to investigate and compare the configurational properties of Roman cities with largely unexplored spatial structures.

3. Theory

The increasing significance of space as a primary object of research for understanding the social, political and economic structures of ancient cultures has led to the rising use of methods that include space syntax techniques to investigate historical spatial structures (Stöger, 2011). Space Syntax refers to concepts and analytical tools that provide the basis for interpretive models of socio-spatial phenomena (B. Hillier, 2007; B. Hillier & Hanson, 1984; van Nes & Yamu, 2021; Lee et al., 2023). Space Syntax theory is based on two key concepts: i) space is a fundamental aspect of human activities, and ii) the social relevance of space lies not in its intrinsic properties but in the interrelations among the elements of a spatial structure. The first concept implies that each basic action incorporates a specific geometry: movement is linear, interaction requires bi-dimensional convex spaces, and the perception of the environment is mediated by the articulated surface of the visual field, the *isovist* (B. Hillier, 2007; Hillier & Hanson, 1984; Turner et al., 2001; Turner, 2007).

The second concept implies that spatial configuration is structured by a formal logic that reflects and reproduces the relational structures underpinning social, economic and political systems.

As a result, configurational analysis via space syntax techniques represents a relevant contribution for the understanding of the interdependencies between the structure of spatial systems and social and cultural practices (Francini et al., 2017; Li & Zhang, 2023) in the field of accessibility analysis (Guida & Cagliani, 2020; Gaglione et al., 2019; Boglietti & Tiboni, 2022) urban sustainability assessment (Zali et al., 2016), urban planning and urban regeneration (Gargiulo & Sgambati, 2022; Tsai & Chang, 2023).

In particular, the theories of the movement economy and of centrality as a process explain the relationship between spatial configuration, natural movements, economic activities and space production (B. Hillier, 1996, 1999, 2007; Hillier & Hanson, 1984). The movement economy concept claims that the configuration of the urban layout influences the distribution of movement and that the concentration of movement along specific routes, in turn, influences the distribution of land uses, determining the emergence of vibrant centres and of quieter monofunctional areas. The concentration of movement and urban functions in specific areas can determine, in a sub-sequent stage, the iterative adaptation of the urban spatial structure consisting in the intensification and densification of the spatial grid, thus generating a recursive socio-spatial process denominated centrality as a process (B. Hillier, 1996, 1999, 2007; Hillier & Hanson, 1984).

Space syntax examines the interdependence of public spaces and street segments within a built environment, by measuring three variables: the degree centrality, which refers to the number of spaces contiguous to each street segment; the closeness centrality, which denotes the to-movement potential of a street segment with respect to other segments, and the betweenness centrality, which signifies the through-movement potential of a street segment relative to all other spatial elements. These parameters represent the accessibility potentials of a given spatial system, and are measured, respectively, by the indicators Connectivity, Integration and Choice. Notably, both to- and through-movement potentials can be evaluated using three alternative definitions of distance: metric distance is the number of metric units between an origin and a destination; topological distance is the number of turns – or intermediate spaces– along the route from a space of origin to a space of destination; lastly, geometric distance is the sum of angle deviations along the route from an origin space to a destination space (Hillier, 1999, 2007; Hillier & Hanson, 1984; Turner, 2007; Turner et al., 2001).

Depending on the considered form of spatiality, space syntax offers multiple representations of spaces and specific configurational metrics (Koutsolampros et al., 2019; Turner, 2007; Turner et al., 2001).

A review of the existing literature on the syntactic analysis of ancient urban sites underlines a broad set of metrics utilised to measure configurational properties at both macro and micro scales. Configurational metrics

include density and intervisibility between entrances (Laurence, 2010; Van Nes, 2009, 2014); integration of public and private spaces (Assassi & Mebarki, 2021; Laurence, 2010; Stoger & Brandimarte, 2015; Van Nes, 2014; van Nes & Yamu, 2021); visual integration and connectivity (Assassi & Mebarki, 2021; Battistin, 2021; Crawford, 2019; Stoger & Brandimarte, 2015); axial connectivity, integration and choice (Battistin, 2021; Crawford, 2019; Van Nes, 2009, 2014), segment connectivity, integration and choice (Battistin, 2021; Crawford, 2019); as well as agent-based models (Crawford, 2019). Findings from the investigation of configurational aspects underline the centrality of movement economy and residents and non-residents relation as the fundamental socio-spatial processes that structured Roman cities (Stoger & Brandimarte, 2015; Laurence, 2010; Assassi & Mebarki, 2021), the relevance of visual control as a spatial criterion informing the urban structure at the global and local scale (Assassi & Mebarki, 2021; Stoger & Brandimarte, 2015), and the co-relation among the density of economic activities in a space, number of contiguous spatial elements, density and inter-visibility of building entrances and integration of private and public spaces (Gundogdu & Ozkok, 2017; Van Nes, 2009, 2014). Configurational metrics are also utilised to investigate similarities and differences among urban sites resulting from the spatial manifestation of specific cultural factors (Eskidemir & Kubat, 2020; Kubat, 1997, 2010; Kubat et al., 2019) and the relevance of urban configuration in structuring the ritual landscape in a Roman city (Crawford, 2019). Lastly, Battistin (Battistin, 2021) compares distinct scenarios of reconstruction of the urban layout of Falerii Novi, in terms of an alteration of the centrality of routes and intramural relations among central and marginal areas.

Consequently, configurational indicators, such as Integration, Normalised angular Integration, and Normalised Angular Choice, emerge as central metrics for describing the spatial structure of urban areas. These findings are the basis of a method for comparing the configurational properties of four urban sites of the Roman Imperial Period, presented in the subsequent sections.

4. Materials and Methods

The study develops a quantitative description of the urban layout of four urban sites of the Roman Imperial age by integrating configurational metrics determined by Axial Analysis, Segment Angular Analysis and Visual Graph Analysis. The areas of study include the urban sites of Cosa and Nora in Italy, Timgad in Algeria, and of Thuburbo Maius in Tunisia. The research locations are situated in the Mediterranean area and represent a variety of urban configurations. In fact, both Cosa in Italy and Timgad in Algeria have a regular urban form based on a rectangular grid (grid street plan). Nora, in Italy and Thuburbo Maius in Tunisia, present an organic structure.

Four steps constitute the analysis: i) Selection of study areas, data collection and reconstruction of the site plan of the cities investigated; ii) Construction of the Axial Map and of the Segment Map of the study areas; iii) Measurement of conditions of integration and segregation of spatial elements via the measurement of Connectivity, axial integration (AI) and topological distance or steep depth (SD) of the Forum from the most integrated space; iv) Identification of centre and sub-centres of and main routes via normalised angular integration (NAIN), normalised angular choice (NACH). Global and local relations of intervisibility are part of this study and will be described in a future article.

The reconstruction of the system of open spaces of the urban sites is based on on-site plans retrieved from scientific literature, georeferenced and reproduced in a GIS environment. After importing the plans of public spaces into DepthmapX, the Axial Map, Segment Map, and Visual Graph for the study areas are created.

The axial map reproduces the spatial layout as the minimum set of longest lines of movement intersecting the spaces in the study area (Al-Sayed et al., 2014; B. Hillier, 2007; van Nes & Yamu, 2021). The Segment Map is generated in DepthmapX from the axial map, dividing axial lines at intersections. As a result, the Segment Map represents the urban layout as a set of segments delimited by consecutive intersections.

Segment and axial analysis focus on the metrics of connectivity, integration and choice. Connectivity refers to the number of spaces contiguously connected to a space of origin and measures a local aspect of centrality, denominated degree centrality. Integration expresses the distance between any origin space and all destination spaces in a global spatial system; segment angular integration, in particular, measures distance among spatial elements in terms of the sum of angular deviations along the routes from any space of origin to all spaces of destination.

Choice measures the probability that a space is comprised of the least cost routes from any space of origin to any space of destination. As a consequence, integration measures the to-movement potential of a space, and, thus, its significance as a destination; choice measures the through movement potential of a space and hence its relevance as a space of movement.

Choice and Integration are normalised to enable the comparison of distinct spatial layouts. Normalised measures, in fact, account for the influence, on integration, of the size of the spatial layout considered and of the type of configurational structure on choice values (Hillier et al., 2012; van Nes & Yamu, 2021).

Moreover, the co-relation of global and local choice – calculated, respectively, at radius n and at the metric radius of 200 meters – is measured to identify spatial elements with a significant potential for the intensification of socio-economic activities. The 200 meters radius is selected to discern local and global patterns. Due to the limited surface area of the excavated parts of the selected urban sites, the coincidence of global and local metrics is determined by the superior values of the local analysis radius. Specifically, the coefficient of determination R^2 , which measures the co-relation of NACH at radius n and of NACH at radius 400 meters, varies from 0.92, for the urban site of Cosa, to 0.99 for Nora and Thuburbo Majus. Moreover, the 200 meters radius is a relevant parameter for measuring NACH, commonly used in walkability research (Bielik et al., 2018; Dhanani et al., 2017).

Axial Intelligibility measures the extent to which the global structure of a spatial system can be inferred from its local configurational properties. It is formalised as the co-relation between local connectivity and global integration. An intelligible space is a system where the perceivable properties of a space, and the number of spatial elements it is connected; it is a good predictor of its non-perceivable properties, related to its functional significance in the global structure (Hillier, 2007). The selected areas of study are described via a set of configurational metrics and compared via measures of central tendency and dispersion. The following section discusses the criteria for selecting the case study.

4.1 Selection of the areas of study

The Roman expansion in the Mediterranean resulted in the formation of several urban landscapes, each with its own distinct traits and development. The analysis of four cities investigates the issues of spatial and perceptual interdependency in Roman cities: the foundation cities of Cosa and Timgad and the organic evolving cities of Thuburbo Maius and Nora. The criterion is to prioritise cities situated in the southern part of the Empire in Punic-culture areas (Thuburbo Maius, Timgad and Nora) and presenting optimal grid street plans (Timgad and Cosa). The authors concentrate on two distinct types of urban evolution in order to verify if spatial alterations, during the Roman age of the organic evolving cities can be framed in terms of specific cultural identifiers. From this perspective, the four cities can be perceived as two main case studies (Nora and Thuburbo Maius) and two control samples (Cosa and Timgad) (Fig.1).

4.2 The case studies: a deeper focus on the 'organic' cities Thuburbo Majus and Nora)

Thuburbo Majus is one of the main towns of Tunisia known during the Late Imperial period as Colonia Iulia Aurelia Commoda Thuburbo Maius. The city, originally a Punic centre (Gascou, 1988), is located in the Fahs plan in the Miliane ouad, 60 km south-west from Tunis-Carthage (Ben Akacha, 2011). After the Roman conquest, the city becomes first a municipium thanks to the emperor Hadrianus (117-138 AD) and lately a

Colonia under Commodus (See Fig.1 and 2). The promotion generated several benefits for Thuburbo, including the installation of the forum, which altered the urban plan (Ben Akacha, 2011) and the concurrent construction of a temple dedicated to Mercurius Augustus to commemorate the emperor. The town's history suggests the complexity of its urban plan, which has developed over many centuries and experienced extensive reconstruction after the Roman conquest.

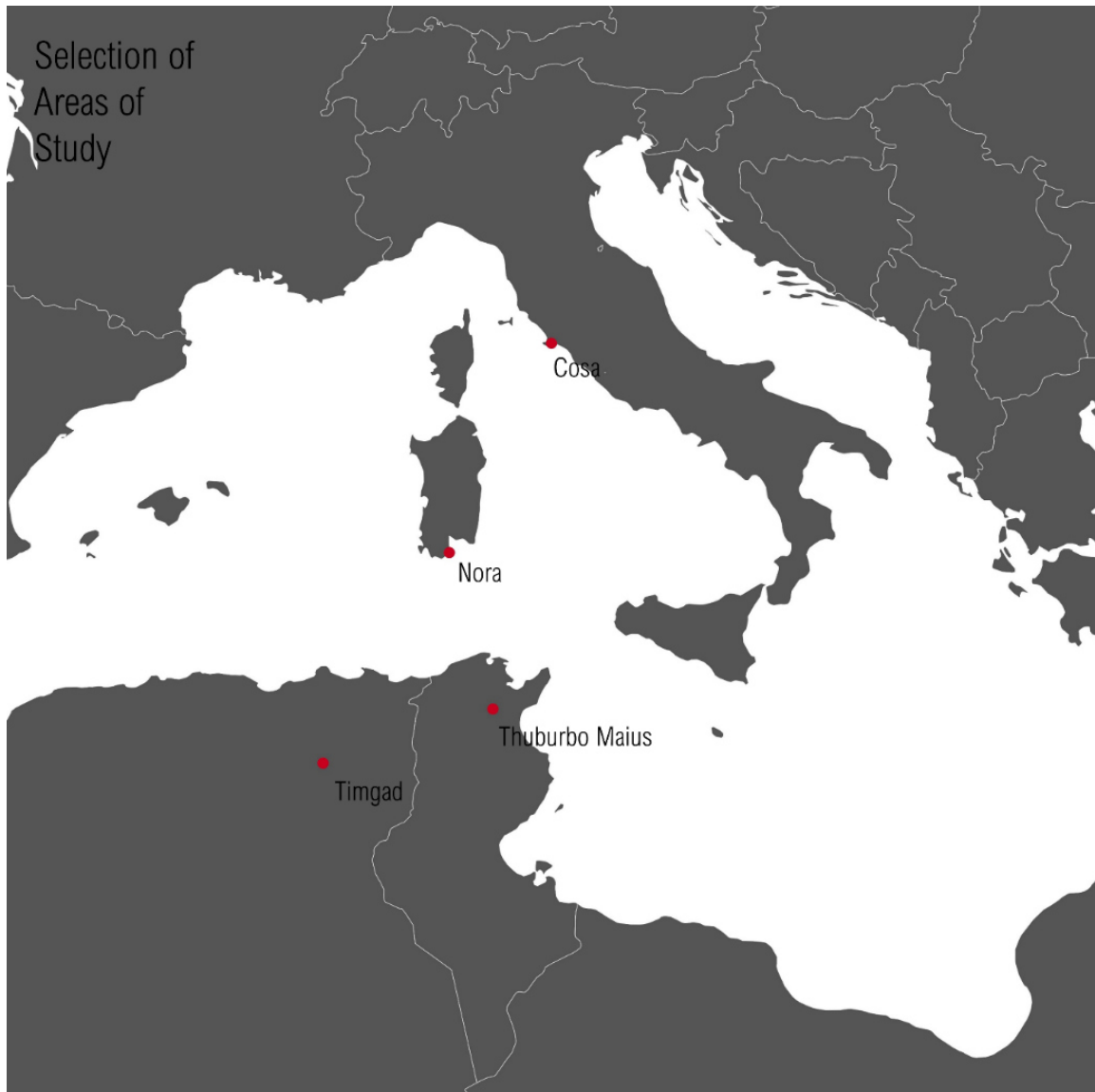


Fig.1 Selection of the areas of study

Nora is one of Sardinia's major Punic-Roman urban towns. The city is situated on the island's southern coast (Bonetto, 2009) (See Fig.1 and 2). The city's southern section (Bonetto, 2009) was significantly altered by the construction of the Roman Forum in the first century BCE (Ghiotto, 2009). A sensitive issue in Nora's study is the ancient coastline and the bradyseism phenomenon that affects the isthmus, mostly in the southern and eastern gulfs. Although the harbour's position is unknown, scholars hypothesised that the docks may be in either the western or eastern gulfs (Finocchi, 1999), (Bonetto et al., 2014, 2017).

The city was subjected to a massive urban expansion during the Punic period (late 6th-3rd century BCE). The resulting intricate configuration of roads and built-up areas of the central district, denominated 'kasbah' (Pesce, 1957), has informed the city's urban plan throughout its history. After the Roman conquest (238/237 BCE), the settlement reached the status of municipium in the 1st century BCE. In this same period, it is possible

to identify the construction of the Roman Forum and the modification of the orientation of buildings and roads. A deep renewal of the urban structure dates back to Severan times, when various traces suggest the construction of a paved road throughout the settlement and the readjustment of the northern blocks (Angiolillo et al., 2014; Bonetto et al., 2017).

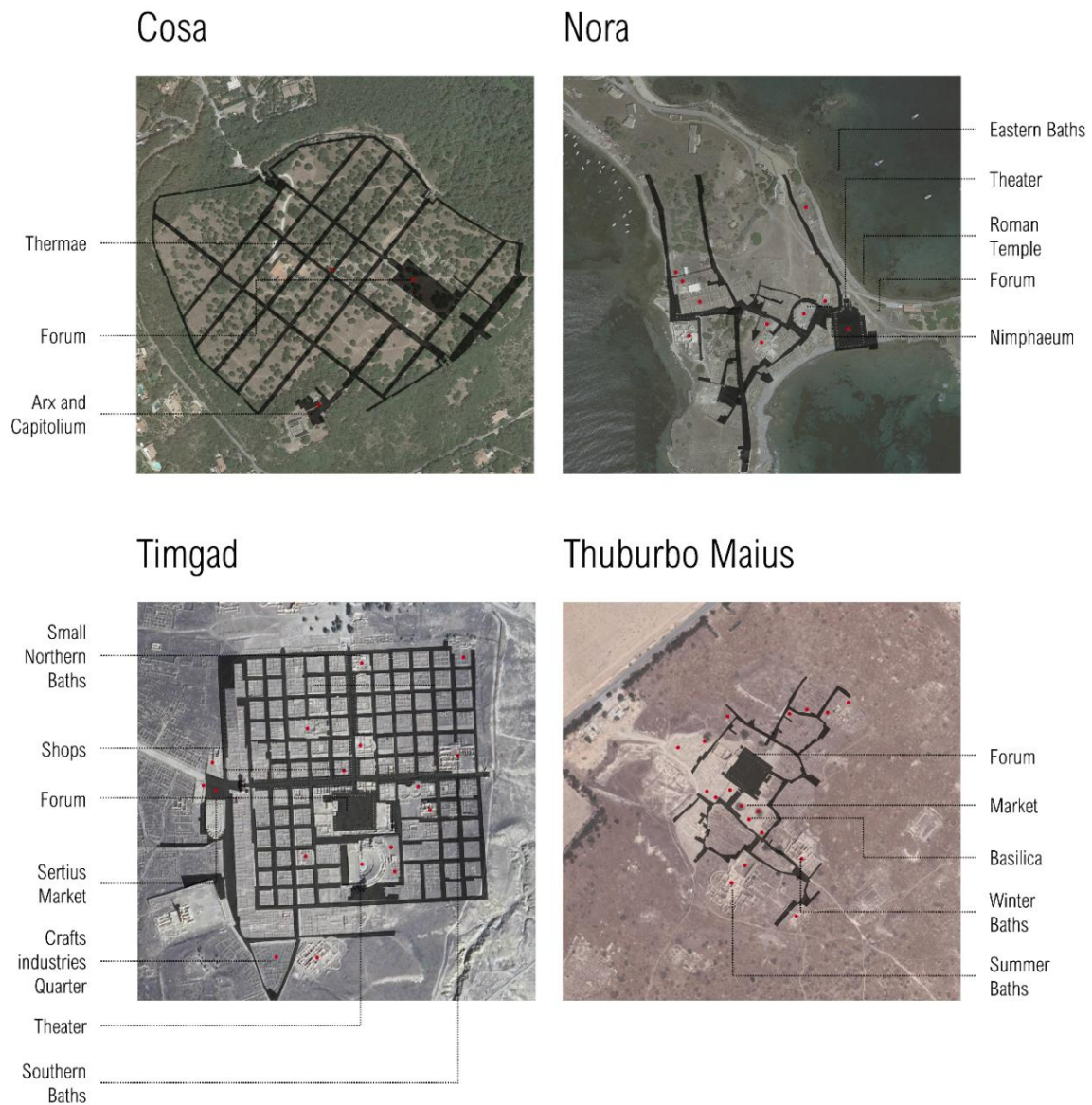


Fig.2 The system of public spaces in the selected urban sites

The city of Cosa, situated in the area of the contemporary Ansedonia harbour (Fig.1 and 2), is the focal point of a large agricultural production area (Carandini et al., 2002; Casarotto et al., 2016). The city was founded in 273 BCE as a Colonia Latina on the lands of the former territory of Vulci and then became a colony in 197 BCE (Fentress & Perkins, 2016)(Conventi, 2004). The city of Cosa is an excellent example of an ex-Novo middle-Republican grid settlement and provides insight into the issues and features of an integrated urban design. Excavations in this area in the last 50 years, have been mainly conducted by the archaeologist Frank Brown and the American Academy in Rome (Brown, 1980; Dyson, 2013).

Material is abundant about the major structures in Cosa's urban plan, but there is a paucity of data on the remaining areas. Moreover, during the Republican era, important elements of numerous Cosa's public structures are disregarded. (Fentress & Perkins, 2016).

The Arx, in the city's south-western district, one of the city's holiest monuments, acting as the Capitolium's seat [44], is connected to the Forum via the Via Sacra. (Dyson, 2013). However, the Forum/Curia-Comitium complex, located in the eastern part of the city, is the main focus of the city's excavation effort, allowing a comprehensive view of those structures' development (Brown et al., 1993; Fentress & Bodel, 2003; Fentress & Perkins, 2016) and their visual integration with the road system. The Forum, excavated since 1950, was constructed soon after the city's demise in the first quarter of the 2nd century BCE. The curia was reconstructed a few years later (after 180 BCE) above a previous private house on the north-eastern side of the Forum (Fentress & Perkins, 2016). The Forum (m 88 x 35) had a monumental entrance in the form of a three-aisled arch (fornix) made in concrete (Brown et al., 1993) on the western side of the portico and a secondary entrance in the north-western corner linked to the street Q, which entered in the Forum and was later incorporated in the colonnade (Brown et al., 1993).

The city of Thamugadi, in contemporary Algeria, is one of the best examples of a Roman-era grid street plan (Figg.1 and 2). In the words of J.B. Ward Perkins, Timgad represents a "textbook example" of an organised city designed to establish a proper relation between domestic and civil spaces. The settlement has been used as a model for understanding the geometrical indications of how to build a city. Pierre Gros has highlighted how this sentence must be contested due to the obvious inconsistencies in the urban layout, which nonetheless conveys a positive impression of a Roman colonial city (Gros & Torelli, 1988). Around 100 AD, the Legio III Augusta under the emperor Trajanus established the Colony on the plateau of Aurès, a border region of North Africa that had not yet been pacified. The city is 328x317 meters in dimensions and is divided into four blocks by two major roadways that intersect not far from the forum. The original design probably foresees the construction of 144 blocks measuring 20 meters on each side, but the western section was left incomplete. This original design has regular spaces for the realisation of civic spaces. Four spa complexes, a market, and one library are located on the normal grid, while a regular lot is set aside for the theatre, which was completed 50 years after the colonisation.

The spread of the city beyond the city walls is significant from the perspective of this article. The Capitolium, for example, was built extramoenia, years after the Colony's foundation, and had the same dimensions as the Forum. Furthermore, the Decumanus' southern entrance is decentralised from the Forum, emphasising its distinctiveness from the military castra's layout. (Ballu, 1897; Ballu et al., 1905). The grid street plan is the object of several studies, resulting in a vast literature on the proper interpretation of the grid's design and its relationship to military camps (Rezkallah & Marmi, 2018).

5. Results

The configurational metrics provide a quantitative description of the spatial structure of the four studied urban sites (Tab.1). Axial analysis reveals the structure of integrated and segregated spaces (Figg. 3 and 4). In Timgad and in Cosa, the Decumanus is the most integrated space, with integration values of 3.33 and 2.09, respectively. In Nora, the Decumanus emerges as the most integrated space (AI= 2.76), and in Thuburbo Majus, the forum and the contiguous spaces are the most integrated elements. As a result, the topological distance of the forum from the most integrated spatial elements is 0, in Thuburbo Majus, 1, in Timgad, 2 in Cosa and 3 in Nora.

Measures of central tendency reveal a superior average integration in Timgad. Thuburbo Majus has modest values. The standard deviation and the variation coefficient underline a clear distinction of integrated, vibrant spaces and of quieter segregated areas in Nora.

Indicator	Statistic	Area of Study			
		Cosa	Nora	Thurburbo Maius	Timgad
Axial Integration	Number of Lines	43	40	43	56
	Min Value	0.636	0.581	0.473	0.678
	Max Value	2.099	2.763	1.177	3.326
	Mean	1.247	1.290	0.787	1.741
	Median	1.223	1.218	0.768	1.678
	Standard Deviation	0.371	0.429	0.182	0.501
	Variation Coefficient	0.297	0.333	0.231	0.288
	IQR	0.459	0.598	0.281	0.639
Relativised Entropy (Axial)		Cosa	Nora	Thurburbo Maius	Timgad
	Min Value	1.483	1.292	1.887	1.349
	Max Value	2.871	2.988	3.152	3.177
	Mean	1.972	1.979	2.520	1.877
	Median	1.941	1.930	2.536	1.771
	Standard Deviation	0.309	0.360	0.327	0.408
	Variation Coefficient	0.157	0.182	0.129	0.217
	IQR	0.366	0.512	0.500	0.380

Tab.1 Results of the axial analysis and of the segment angular analysis

Axial Integration

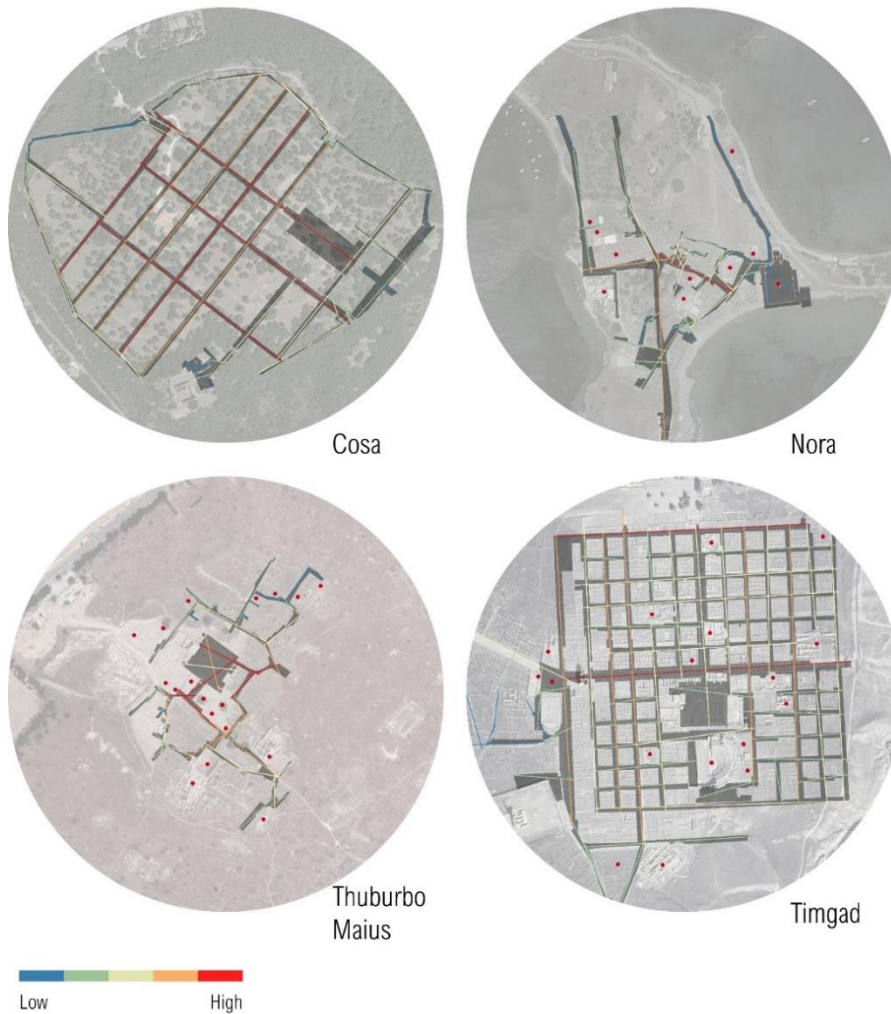


Fig.3 Distribution of values of Axial Integration in the selected urban sites

Cosa presents a clear distinction between the integrated elements of the regular grid that define the core area and the segregated spaces of the Arx and along the perimetral fortifications. In Timgad, a distinction emerges between the rectilinear continuous streets, that form the grid structure of the original urban core, and the spaces that form the organic structure of the later urban development. The organic structure of Thuburbo Majus reveals a more subtle differentiation.

However, the edge effect might limit the understanding of a spatial layout via Axial Integration. The edge effect refers to the disproportionate segregation of spaces at the axial model's edge (B. Hillier, 2007).

Axial Integration + Connectivity

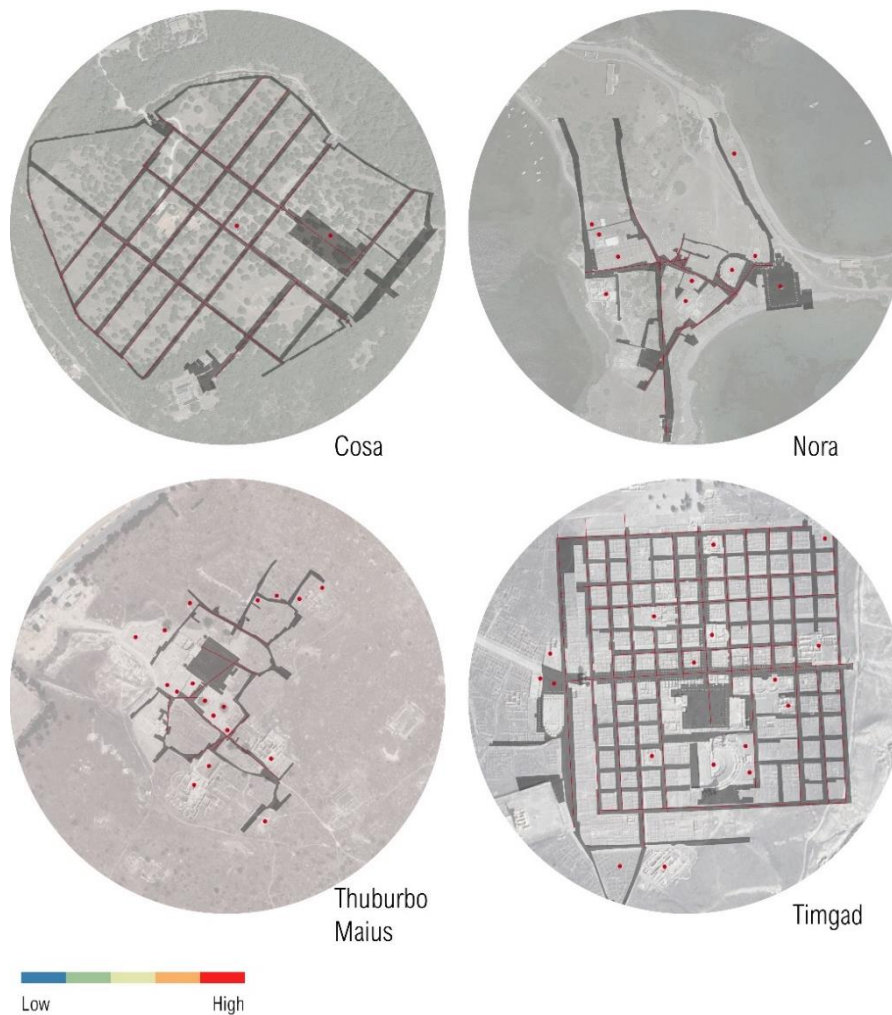


Fig.4 Emergence of spatial structures constituted by the most connected and integrated lines

The correlation between global axial integration and local connectivity underlines that the regular grid structure of Timgad and Cosa as well as the urban layout of Nora are more understandable than the organic structure of Thuburbo Majus. The coefficient of determination R^2 is 0.77 for the urban layout of Timgad, 0.79 for Nora, 0.74 for Cosa and 0.33 for the spatial layout of Thuburbo Majus (See Fig.4).

Moreover, by selecting the axial lines comprised in the first and second quintiles of the values of Integration and Connectivity, a spatial sub-structure of spaces relevant for orientation across the urban sites emerges. In Cosa, this spatial sub structure presents a coefficient of determination R^2 equal to 0.87 and it comprises 12 spaces, including the Cardo and the Decumanus and the longest longitudinal north-south and transversal east-west routes. In Nora 13 spaces present significant local and global configurational properties including the

main east-west street, the perpendicular street directed towards the coast and the spaces contiguous to the Theater.

The Coefficient of determination R^2 , measured for this spatial sub-structure, is equal to 0.73. In Thurburbo, a spatial structure emerges comprising 8 spaces, including the main east-west street and the spaces contiguous to the Forum. Yet, the co-relation of connectivity and integration, measured in Thurburbo is marginal. The Coefficient of determination R^2 is equal to 0.13. Thus, the analysis underlines that the function of a space in the urban layout cannot be inferred from the number of spaces it is contiguous to. Lastly, in Timgad, the sub-structure of spaces relevant for spatial orientation is constituted by 19 spaces, including the Cardo and the Decumanus and the long linear streets that structure the regular grid of the center of original formation. Yet, this spatial sub-structure presents a modest coefficient of determination R^2 , equal to 0.47.

Normalized Angular Integration

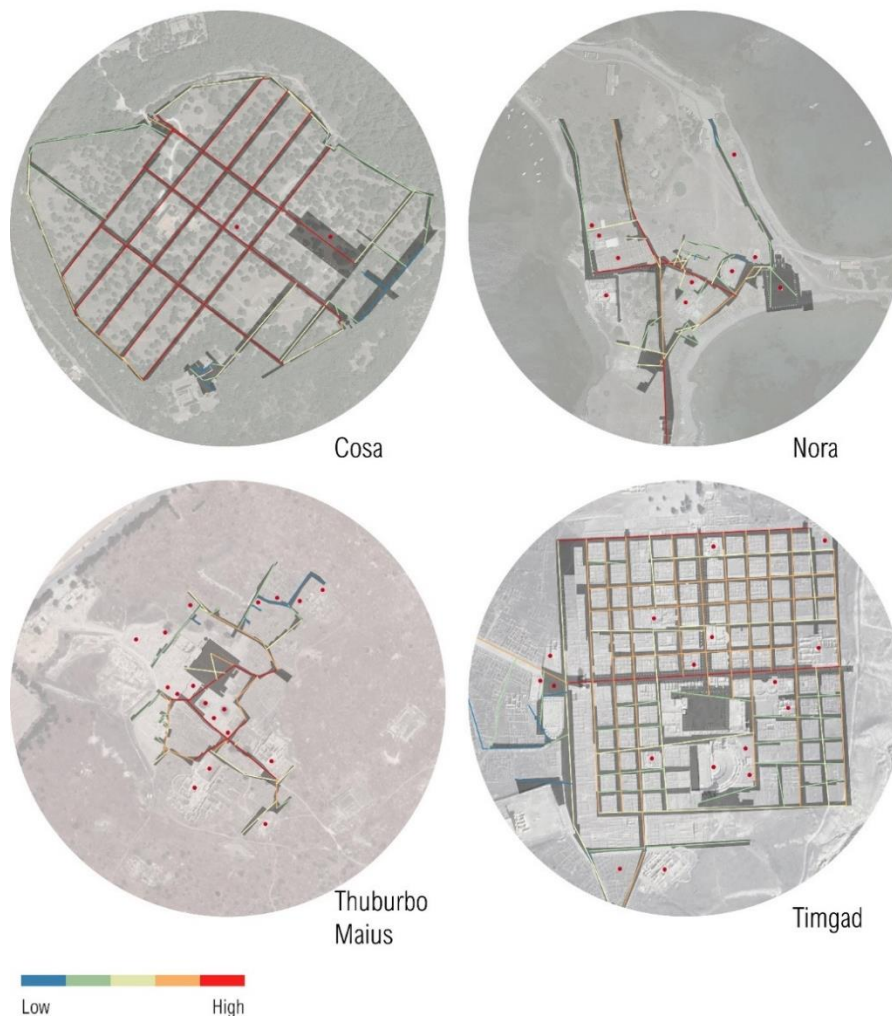


Fig.5 Distribution of Values of Normalized Angular Integration (NAIN)

At the global scale, normalised angular integration (Fig.5) underlines the emergence of integrated spatial structures concentrated around the Decumanus and the Cardo in Nora, in Timgad, and in Cosa. In Thurburbo, an integrated structure emerges, comprising portions of the Forum and of the main east-west street. Measures of central tendency and of dispersion underline the isotropy of the regular grid structure of Timgad and its general condition of significant integration. Vice versa, Thurburbo Majus presents a more segregated structure. Nora and Cosa demonstrate a more evident distinction of segregated, quieter areas and integrated spaces: the system of spaces contiguous to the Amphitheatre in Nora, and the Arx and the spaces along the perimetral

In Thurburbo Majus and in Nora, the strong co-relation among values of NACH calculated at radius 200 meters and at radius n, determining a coefficient R^2 equal, respectively, to 0.96 and to 0.95, can result from the modest size of the portion of the urban structure investigated, that prevents the distinction of global and local spatial structures of central streets.

Lastly, in Timgad, the Coefficient of determination R^2 equal to 0.68 indicates a clearer distinction of spaces central at the local scale and of spaces important at the global scale. The trans-scalar system of central spaces presents a modest co-relation of local and global choice, indicated by a value of 0.26 of the R^2 coefficient. This spatial structure comprises 72 segments, including the Decumanus, and a dendritic structure of segments located in the western area of the urban site.

Normalized Angular Choice Radius 200 m + Radius N

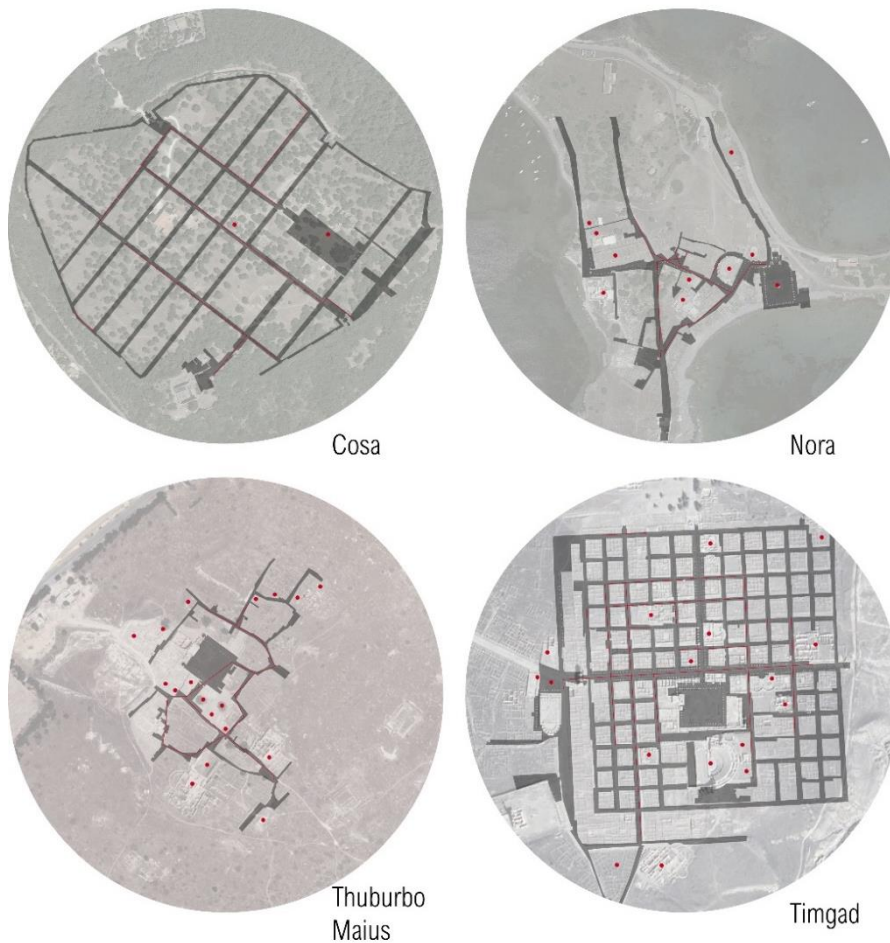


Fig.7 Emergence of spatial structures composed by the most central spaces at the local and global scale

6. Discussion

The results presented in the previous section underline significant specific configurational properties of the investigated urban sites. Firstly, the Forum emerges as a space central and integrated into, and distinct, from the urban structure. Thurburbo Majus presents a specific situation: the most central segments, in terms of integration and significance as spaces of movement, intersect the Forum.

In Thurburbo Majus a strong contrast in terms of dimension and form exists between the regular, monumental space of the Forum and the discontinuous spaces that comprise the organic structure of the urban site. A similar scalar and morphological contrast is also in Nora, underlining the adaptation of the original urban

structure and the insertion of forms of public space, specific to Roman urbanism, in a layout produced by a diverse spatial culture.

A relevant observed aspect concerns the emergence of the Decumanus as the most integrated and central space in the grid structure of Cosa, Nora and Timgad. In Thuburbo Majus, the Forum and the contiguous spaces are the most integrated and central spaces. Moreover, in Cosa and Timgad, an eccentric rectilinear road, perpendicular to the Decumanus, represents an integrated space and a central space for urban scale movements.

The Cardo is a less integrated and central space, in relation to movement, and a central space in relation to intersecting long visual lines. In Cosa, the distribution of segment integration evidences the strategies of distinction and separation of the Arx, reflecting a symbolic use of distance and segregation to convey the sacrality of the religious space.

The distribution of centrality underlines the permeability and isotropy of grid structures and the anisotropy of organic structures. In Cosa and Timgad, continuous spatial elements forming the regular grid constitute a structure of integrated and central spaces distinct from the system of segregated spaces comprising side local streets and spaces of the later urban development, in Timgad, and spaces along the perimetral fortifications in Cosa. A strong distinction between integrated and vibrant spaces and quieter and segregated areas is observed in Nora and Thuburbo Majus.

A preliminary investigation related to the location of functions and civic and public buildings, reveals the combination of general models, criteria of positional convenience and local conditions as the determinant of urban form. In Timgad the Forum and 5 civic buildings, including four commercial spaces and a vast bath complex are located along the Decumanus.

The small northern baths and the public library are located along the Cardo. The theatre and the Temples of Ceres and Mercury are close to a street, rotated in relation to the Decumanus, that results as a central and relevant space in terms of urban scale movement.

Several Civic buildings are located outside the urban core of ancient foundation, indicating the absence, inside the ancient core, of adequate spaces for the construction of monumental civic buildings as a central aspect of the rapid urban development of the III century, and of the radical alteration of the urban form. In Thuburbo, economic activities are contiguous to the central and integrated segments intersecting the Forum. The Basilica, the Baths of Labyrinth, the Winter Baths are located along the east-west main street. Production spaces, vice versa, are contiguous to spaces presenting poor levels of global centrality.

As a result, in the four investigated urban sites, economic and recreational, social functions are located along central movement spaces, or along spaces integrated in terms of long visual lines. Production spaces are located along segregated spaces in Thuburbo Majus Nora, and in Timgad. A relevant limitation of this study is related to the availability of spatial datasets. For instance, the scarcity of complete data related to the function of buildings and on the position and orientation of entrances, prevented the identification of constituted and un-constituted streets and the measure of the co-relation of axial integration and density and inter-visibility of entrances. Lastly, the limited quantity of data related to the configuration of spaces, location of public buildings and function, in a specific time period, of investigated buildings, also limits the analysis of the co-relation between the distribution and diversity of land uses and configurational properties. For instance, in Timgad, studies are focused on monumental buildings, and omit to investigate the configuration of spaces in the area of urban development outside the core of the ancient foundation. In Nora and Thuburbo Majus the reconstruction of the site plan concerns a specific, limited area close to the Forum and to pre-eminent public buildings. In Nora the alteration of the coastline determines a peculiar situation, further limiting the prospect for a precise and complete reconstruction of the urban structure.

7. Conclusions

The findings from this study underline the relevance of methods combining distinct configurational metrics for identifying spatial patterns and transformations that manifest and reproduce cultural, political and socio-economic processes. Several studies demonstrate the validity of Configurational metrics as a tool for describing the spatial structure of cities and its influence on urban functionings including patterns of avoidance and encounter (Hillier, 2007), mobility (Dhanani et al., 2017; Cutini & Rabino, 2012; Hillier, 1989) and distribution of land uses (Bielik et al., 2018; Pappu, 2018; Hillier, 2007). The proposed study investigates the relevance of configurational metrics for the understanding of the spatial culture of ancient civilizations. As a result, this study significantly contributes to the fields of urban studies and archaeology in two ways: firstly, this study addresses a gap in the research on the urban form of ancient cities, consisting in the limited utilization of syntactic and statistical analysis for understanding the social antecedents and consequences of the configuration of spaces. The combination of specific configurational metrics, in fact, encompasses a quantitative description of spaces that is instrumental to the understanding of the specific socio-spatial configurations of ancient civilizations. Moreover, the study focuses on historical Roman urban sites whose spatial structure is mostly unexplored. Secondly, by identifying spatial structures related to specific socio-cultural meanings, this study contributes to the understanding of the persistence and evolution of specific socio-spatial configurations, related, in particular, to the distribution of land uses and the formation of centres as a function of the configuration of spaces, the symbolic value of distance in relation to the position of sacred sites, the systems of encounter and avoidance among social groups, and the separation of particular functions, for instance entertainment spaces, based on specific systems of compatibility and incompatibility of land uses. By underlining the distinction of integrated, vital spaces and segregated and monofunctional residential zones, the study demonstrates the intrinsic relevance of spatial configuration in influencing the distribution of urban functions, as a result of urban structure's impact on the distribution of natural movement. Hence, the findings of the study underline the relevance of Hillier's concept of movement economy, for understanding urbanity and the socio-spatial structure of urbanized environments (Cutini & Rabino, 2012; Hillier, 1999, 2007; Hillier & Hanson, 1984). The measurement of the topological distances of the forum from most integrated axial lines, and the analysis of the location of religious buildings confirm Van Nes' findings on the separation of sacred political and religious spaces from main movement spaces (Van Nes, 2014). Moreover, the study of configurational properties can underline the transformation of urban structures as a consequence of socio-political events. For instance, the distribution of integration in Nora and in Thuburbo Majus underlines the emergence of sub-structures of regular and monumental urban public spaces that represent the most evident spatial sign of the adaptation to the criteria of Roman spatial culture of pre-existing urban systems. In Timgad configurational variables can be used to understand the impact of the rapid economic development, on the crisis of the spatial organization based on the regular grid model, by underlining the specific configurational and structural properties of the center of ancient formation and of the districts built outside the fortified perimeter as a consequence of the increased demand for larger residential buildings and for larger, more specialized and representative spaces for cultural, social and recreational activities, (Zanker, 2013; Gros & Torelli, 1988). In general terms, the proposed set of configurational variables can be used to identify and describe the criteria constituting a spatial culture, hence the criteria of organization of spaces that produce and reproduce the principles for ordering social relations (Hillier, 1989). In particular, the future development of the study will be focused on the use of configurational variables to conduct synchronic and diachronic analyses of the spatial structures of Roman cities. The objectives will include: i) the definition of a set of tools for demonstrating and describing the principles of spatial organization constituting the Roman Spatial culture; ii) understanding, from a synchronic perspective, the relation between general models of spatial organisation and local factors, and the impact of local cultural, socio-economic factors on the adaptation and alteration of

general models; and iii) understanding, from a diachronic perspective, the evolution and transformation of Roman spatial culture as a result of general cultural, social, political and economic processes.

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Authors' contribution

This paper is the result of the joint work of the authors. In particular, "Materials and Methods", and "Results" are written jointly by the authors. Chiara Garau wrote "Research aim", "Selection of the areas of Study" and "Discussion", Alfonso Annunziata wrote "Theory", Claudia Yamu wrote the "Introduction", Dario D'Orlando wrote "The case studies: a deeper focus on the 'organic' cities Thuburbo Majus and Nora)", and Marco Giurman wrote the "Conclusions".

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Image Sources

Fig.1: Elaborated by the authors via the Software QGIS 3.16.8. Background Image from Google Earth;

Fig.2: Elaborated by the authors via the Software QGIS 3.16.8. Background Image from Google Earth;

Fig.3: Elaborated by the authors via the Software Depthmap X and QGIS 3.16.8. Background Image from Google Earth;

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Fig.7: Elaborated by the authors via the Software Depthmap X and QGIS 3.16.8. Background Image from Google Earth.

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