045

Climate-driven differences on urban configuration:

A Space Syntax analysis comparing Mediterranean and Saharan urban settlements in Algeria.

Diego Altafini, Welsh School of Architecture, Cardiff University, UK; Department of Energy, Systems, Territory and Construction Engineering, University of Pisa, Italy;
altafinid@cardiff.ac.uk.
Okba Benameur, Department of Architecture, University of Mostaganem
okba.benameur@univ-mosta.dz
Safia Mahfoud, Department of Architecture, University of Béjaïa
safia.mahfoud@univ-bejaia.dz

ABSTRACT

The climate and environmental context in which an urban settlement is located has a crucial role in shaping its configuration, urban form, and socio-spatial life. Places with mild climates tend to develop traditional urban layouts where built spaces are intertwined with open spaces, often with water and vegetation presence. These, tend to be centres of social interaction and co-presence within cities. In contrast, cities located in arid climates, face unique challenges in urban development. The scarce access to water allows for limited vegetation and fewer open spaces, as high exposure to the sun requires a more compact urban organization, where clusters of buildings or the presence of architectural elements are incorporated to provide shade. Considering the few configurational studies in the matter and increase in the heatwaves' frequency that might come forth with climate changes in other parts of the world, this research provides initial insights in how climate characteristics can influence configuration in cities. Using Space Syntax angular analysis, six Algerian cities: Algiers, Béjaïa, and Mostaganem (Mediterranean cities), Biskra, Béchar, and Laghouat (Saharan cities) are compared. Focus is on describing patterns of relative accessibility, preferential routes, connectivity, and sprawl to unveil differences regarding mobility and morphology that emerge within these distinct kinds of settlements due to the climate in which they are placed. In that way, urban planners and policymakers can develop context-specific strategies to mitigate issues and address the unique challenges posed by the cities' environmental setting, promoting sustainable, adaptable, and comfortable urban spaces, and their socio-spatial life.

KEYWORDS

Urban Configuration, Climate, Sustainable urban spaces, Desert Cities, Urban Morphology

1 INTRODUCTION

Urban configuration is a result of a complex interplay of factors: ranging from the city's diachronic evolution (Cutini & Rabino, 2012), passing through decisions regarding infrastructure and land-use policies (De Koning et al., 2017; Karimi, 2018), and, of course, the socio-economic dynamics at play (Hillier et al., 1986; Hillier & Hanson, 1984). Associated to these factors – and in a way, not as conspicuous as the ones previously mentioned – climate driven parameters also have an important role in how a city is organized (Pattacini, 2012). Variations in average, maximum, and minimum temperatures, wind, humidity, precipitation patterns, and the susceptibility to extreme weather events, all have an important impact in urban design, shaping used building materials, the requirements for infrastructure's resilience, plus outlining the alternatives regarding modes of transportation and transport networks (Stokes & Seto, 2016; UN Habitat, 2013). Balancing these factors is essential in building cities that are resilient and adaptable to the challenges posed by the current climate and, above all, by a changing climate (IPCC, 2023), therefore ensuring a sustainable and livable urban environment.

Upon these aspects, we can trace compelling two parallels regarding the position and characteristics of a city and the requirements in terms of urban planning. In coastal cities – often set in milder temperatures – urban planning focuses on mitigating the risks associated with the coast: rising sea levels, winds, rainstorms and hurricanes and the often-high humidity. Those climate driven factors will shape infrastructural planning, demanding elevated foundations, more resilient outdoor building materials and deeper foundations, plus a facilitated natural ventilation to combat the humidity and heat – even though temperatures are often in a second thought. Moreover, urban planners at these areas prioritise the development of systems to manage water, such as robust drainage systems and seawalls, as well as protection against erosion and flooding, due to heavy rain. Climate-driven planning in such areas also emphasizes the conservation and restoration of coastal ecosystems, integrating green spaces such as wetlands and mangroves as natural buffers against storms, sustaining biodiversity, and safeguarding marine habitats. These climate-driven planning approaches have the objectives of: enhancing the cityscape resilience, minimize risks from natural disasters, and sustainably manage the coastal environment for future generations (Masson et al., 2020).

However, in cities set in dry and arid places, such as deserts, urban planning decisions are often influenced by the extreme climate, which demands innovative strategies to tackle heat and water scarcity – often with little precautions for rainfall (Zhong, 2024, Shanableh, 2018). Driven by such climate, urban planners design architecture with thick walls for insulation, materials that moderate temperature fluctuations, as well as a combination of narrower streets and higher buildings to provide shade to pedestrian areas. Water management and storage also becomes a focus, leading to the implementation of systems to obtain water from the underground such as aqueducts, cisterns, and efficient irrigation methods towards the optimization of scarce water resources. Moreover, land-use regulations in desert cities encourage sustainable practices, such as solar energy adoption and water-efficient landscaping, fostering a resilient urban environment that adapts to and thrives within the constraints of the desert climate (Li et al., 2022; Masson et al., 2020).

In addressing these urban climate issues, the Space Syntax analytical framework can be an asset. Used in urban planning and architecture to understand how spatial configuration influences movement, human behaviour and social interactions within built envitionments (Hillier, 2007), it has the potential be integrated to climate-related variables to offer valuable insights into the functional relationships and patterns of movement within urban areas which such different characteristics in terms of design and construction. Therefore, the differences highlighted in Space Syntax, when combined to other domains of knowledge – such as climate analysis – can aid in designing more efficient, accessible, and inclusive urban environments by optimizing layouts to enhance connectivity, encourage social integration, and improve the overall functionality of cities.

Considering this potential, this initial study examines how climatic data influences in the urban configurations in six Algerian cities — three on the Mediterranean coast and three near the Saharan Atlas. The research analyzes the influence of climate on urban planning and design across these diverse locations, aiming to correlate if and how climatic factors tend to shape the spatial layouts and infrastructures within cities. Understanding the outputs of correlations between configurational measures and climate variables can inform context-specific and adaptive urban development strategies in Algeria – transferable towards other regions with similar climates.

2 LITTERATURE REVIEW

2.1 Space Syntax, urban climate, and climate change.

The dynamic relationship between configuration and climate was the subject of several scientific investigations (Hamzah & Ebraheem, 2020; Nasehi et al., 2022; Papazoglou & Pigaki, 2023; Soltanifard & Aliabadi, 2019; Tao et al., 2022). Nevertheless, most of these research focus on limited areas of analysis, in approaches that combine: urban design and configuration to the formation of heat islands; relations between movement to the microclimate; understanding the effects of spatial design choices in outdoor and indoor environments in hot climates; and even configuration to aid in the mitigation of hazards and risks related to high temperatures. Likewise, all those studies have in common the “single-case” approach, focusing in a specific area and not undertaking on comparative analyses between different settlements.

A study that approximates to the assumptions set in this paper examines the link between spatial structure, land-use, and the logics of *relative accessibility,* to the local climate zones and the land surface temperatures (Nasehi et al., 2022). Incorporating to a computational framework Space Syntax and local climate zones (LCZ) obtained through remote sensing, the approach explores how explore how urban land-use and configurational patterns relate to the Land Surface Temperatures (LST). It is suggested that urban form and the patterns of socio-spatial segregation indicated by configuration can contribute to – and indicate – the formation of urban heat islands, owning to: a) the predominance of high-temperature land-uses; and b) the patterns of organic development – such as informal settlements – in certain areas, which tend to have higher habitative and dwellings density and less open and green spaces to regulate temperatures. The investigation also points out that higher integration values – a characteristic of coherent spaces and orthogonal grids – can lead to lower local temperature values (Nasehi et al., 2022), due to: a) lower building density/area; b) higher-rise, thus more shading; c) more efficient energy usage/building techniques/ materials, when compared to the older organic areas or deteriorated settlements. Other studies move towards an even more micro urban approach, yet also provide clues to the influence of microclimates in movement and the usage of urban spaces. Tao et al. (2022) highlight that openness, connectivity and accessibility in outdoor spaces – such as parks and plazas can be combined to climate-related variables to understand the logics of movement within those areas.

The Space Syntax methods was also widely implemented for understanding the effects of climate in the indoor design choices. A study conducted by Sattarpour; Shemshadi; Bemanian (2016), examined the characteristics of dwellings related to thermal confort, describing that room orientation and distribution, as well as open spaces has an important role in mantaining temperatures. Another case study drawn up by Beyti et al. in 2021 examines the influence of climate on the layout of rural dwellings in the different climatic zones of the province of East Azerbaijan. The research examined the spatial arrangement of residential units, revealing that most rural dwellings have shallow depths, yet compelling interconnections, highlighting the central role of the vestibule in their spatial organization, as well as an effort to aid in ventilation and cooling. Such vernacular experiences, according to the authors, can aid into the current design of dwellings, especially in a context of sustainable energy usage and climate change.

Those studies demonstrate that Space Syntax methods are versatile and can be interfaced with climate-related arguments. However, as described, there is still space for comparative analyses – especially at urban-regional scales that demonstrate differences amongst the urban settlements in terms of their design, configuration, and climate, which justifies this study.

2.2 A brief review on the Space Syntax methods

Axial and Visibility Graph Analyses (VGA) have established themselves as reliable methodologies to uncover the configurational logics in urban settlements, above all, considering local to small urban scales. However, their usage in larger scales, such as in metropolitan or regional contexts, was rather limited: or by methodological constrains, as in the case of Axial Analysis (N. Dalton, 2001; Ratti, 2004); or by purpose, as in the case of VGA (R. Dalton et al., 2023; Turner et al., 2001).

In that regard, Space Syntax had to develop a group of methodologies that: a) solved the issues of Axial Analysis; and b) addressed the problem of scale. Angular Segment Analysis (ASA) (Turner, 2001) came to revolutionize Space Syntax, providing answers for those issues and, above all, providing a more efficient solution to the analyses of larger scales (Turner, 2005, 2007, 2009). Angular analysis can be used to reflect spatial navigation and orientation and reproduce the cognition of individuals travelling in unfamiliar environments in a similar way as Axial Analyses (Turner, 2005; Hillier, Iida, 2005), with the advantage of not needing to construct an Isovist map, relying on readily available Road-Centre Lines (RCL) – a graph-based representation of the road-infrastructure. This not only allowed for the diffusion of configurational studies, but also allowed for more comparative analyses amongst urban settlements – after the process of normalization (Hillier et al., 2012) – as modelling several urban-sized road-circulation networks became a rather trivial endeavour.

ASA currently uses two main measures to address the patterns of configuration in urban settlements, Angular Integration (AIN) and Angular Choice (ACH). Those metrics are often used in their normalised versions (NAIN & NACH) (Hillier et al., 2012), that allow comparisons among systems with different depths. Other graph-based measures, such as Angular Connectivity, Node Count and Total Depth can also be used to inform certain network relationships between the road-elements in a graph. A summary of the angular and normalised metrics – which are used in this research – is presented on Table 1.

Since 2004, the use of metric distances on configuration analyses has been introduced to the ASA framework, summing to the traditional topological and geometrical distances (van Nes & Yamu, 2021; Yamu & van Nes, 2017). Metric analyses can reveal certain local patterns of configuration – inserted in the global context – within urban systems, highlighting the subcentres and centres of *relative accessibility* and densification within the network. Moreover, it presents a correlation with local pedestrian movement in smaller radiuses, such as 1.2km (Yamu & Garau, 2022) and with vehicular movement in larger radiuses, such as 4km and 5km (Berghauser Pont & Haupt, 2010). Those metrics can also be normalised to allow comparisons among systems (Table 1) (van Nes & Yamu, 2021).

Table 1. Metrics, formulas, concepts and literature references for Angular Total Depth, Node Count, Angular Connectivity, Normalised Angular Integration (NAIN) and Normalised Angular Choice (NACH).

Metric	Formula	Concept	References
Angular Total Depth	$TD = \sum_{j=0}^{i=n} d_{i,k}$	Defined by the sum of the angular depth from any node to all others	(Hillier, 2007; Turner, 2001)
Node Count	$NC = \sum k$	Is the number of segments encountered on the route from the selected element towards all others – the system size	(Turner, 2004)
Angular Connectivity	$G = (\alpha V, E)$	Describes the structure of the local urban network	(Hillier & Iida, 2005)
Normalized Angular Integration (NAIN)	$NAIN_{Rn} = \frac{Node\ Count^{1.2}}{Total\ Depth}$	Measures the *farness* between elements in a network; in *Space Syntax,* it denotes the *relative accessibility* or the movement potential *(to-movement)* of a road element, informing how close – in topological terms – a road element is in relation to all others in the system.	(Bavelas, 1950; Hillier, 2007; Hillier et al., 2012; Sabidussi, 1966; van Nes & Yamu, 2021; Yamu & van Nes, 2017)
	$NAIN_{Rmetric} = \log(Angular\ Int.) + 2$	At metric radiuses, NAIN can indicate the spatial hierarchies for local sub-centres in terms of movement potentials, *relative accessibility* and, above all, density of road-elements in the network; it highlights the overall location and distribution of sub-centres within a region.	
Normalized Angular Choice (NACH)	$NACH_{Rn} = \frac{\log(Angular\ Ch. + 1)}{\log(Total\ Depth + 3)}$	Measures the number of times a certain network element is traversed when moving through the shortest paths from all pairs of origin-destination elements within the network. In *space syntax*, it denotes the hierarchy of *preferential routes* throughout the system.	(Freeman, 1977, 1978; Hillier, 2007; Hillier et al., 2012; van Nes & Yamu, 2021; Yamu & van Nes, 2017)
	$NAIN_{Rmetric} = \log(Angular\ Ch,) + 2$	At metric radiuses, NACH can indicate the spatial hierarchies of the urban centres within the network, informing the weight of the intermediate urban areas that structure the *preferential routes'* system.	

In association to these analyses, experiments involving the integration of the standardised metrics were performed by Hillier et al. 2012, that resulted in a model resembling a four-point star. This four-pointed star method integrates Mean and Maximum values for NAIN and NACH and allows to streamline city comparisons, enabling conclusions on how extensively foreground and background networks interconnect. Fundamentally, the foreground network, identified through NACH analyses, plays a crucial role in linking the diverse centres pinpointed through NAIN analyses within a city's structure (Hillier et al., 2012). The vertical axis of the four-pointed star model illustrates the mean NAIN and NACH for each city, while the horizontal axis represents the maximum values for NAIN and NACH.

These measures are set as standardized scores centred around 0. The positive maximum is depicted at the outer edge, whereas the negative minimum is set at the centre of the diagram. Mean and maximum values for NAIN define the *relative accessibility* levels of the foreground and background networks respectively, offering insight into their Integration. Meanwhile, the mean and maximum NACH values provide an overview of the structural elements of the system. Mean NACH indicates the extent to which the background network forms a continuous grid, while the maximum NACH showcases how prominently the foreground grid structures the entire system.

3 METHODOLOGICAL APPROACH

3.1 Case study – Algeria and its Mediterranean and Saharan settlements

Algeria, a country located in North Africa, is known for its diverse climate. Our case study encompasses three Mediterranean cities and three Saharan cities as illustrated in Figure 1. A summary of their characteristics follows:

- Mediterranean cities (Green – Figure 1):

Algiers (الجزائر): The capital city of Algeria, Algiers is a metropolis that stretches from the Mediterranean Sea, following the Bay of Algiers, towards the hills located in the West, South and East outskirts, forming an amphitheatre-like geographical setting, that limited its urban expansion. The city is characterised by the superimposition of modern urban development on narrow winding streets, and historical Arab architecture. Examples of the latter can be seen in Algiers historical centre, known as *Al Qasbah* – or the Citadel, a UNESCO World Heritage site. Modern districts, meanwhile, feature a mix of green spaces and contemporary infrastructures, such as high-rise buildings, commercial centres, and new residential areas, that often follow an orthogonal grid structure.

Mostaganem (مستغانم): A coastal city known for its port and fishing industry. This urban settlement combines traces of its historical past with a modern urban plan. This has led to a diversification of spaces and types of construction, from colonial-era buildings to public markets and administrative offices. Nevertheless, the urban form is characterised by the presence and regularity of orthogonal grids, especially in the inland areas, with fewer winding streets when compared to Algiers, also due to its geographical context. The coastline set on the eastmost part of the Gulf *D'Arzew* features beaches and seaside resorts, while the outskirts are made up of agricultural lands and residential areas.

Béjaïa (بجاية): It's the eastmost Mediterranean city among the analysed, with a diverse urban landscape that overlooks the Gulf of Béjaïa. Its central area has a mix of historical Arab architecture, modern structures, public markets, and cultural and administrative institutions, in a mix of winding streets and orthogonal grids, in its newer developments, intertwined with many green spaces. The urban layout of Béjaïa. is influenced by its importance as a commercial port and its natural environment, comprised of hilly terrain. The city comprises an extensive network of smaller settlements, agricultural lands, and forested areas to the southeast, on the margins of an important river basin.

- Saharan cities (Red – Figure 1):

Biskra (بسكرة): The gateway to the Algerian desert and to the Sahara. Biskra has been designed according to an urban plan adapted to its desert environment, with a predominance of orthogonal grids, large blocks, and long-stretched buildings to provide shade especially in its modern eastern part. The city center comprises administrative buildings, public markets, and commercial areas, and while predominantly orthogonal, is comprised of smaller blocks and narrower streets. Most of the green areas in the city – as well as those on the outskirts – are comprised of palm trees and palm groves, which have an important role in the city's economy and landscape, by providing shade for the temperatures that can reach mean daily maximums of 41 °C during summertime. Biskra's architecture includes buildings designed to mitigate the heat of the desert and create comfortable indoor spaces. Besides the main urban area (the centermost part of the settlement), Biskra possesses several smaller settlements in its outskirts, located in the vicinity of the extensive palm groves.

Laghouat (الأغواط): A blend of traditional Saharan architecture and modern urban development, Laghouat is set within an oasis to the south of Algiers, and shares similarities with Biskra in terms of its urban form, with a predominance of regular and orthogonal grids. However, it also presents a greater compactness when compared to Biskra, since its historical centre is smaller and possesses narrower streets, reflecting both a colonial and Saharan heritage. Modern infrastructure is set near the outskirts of the main settlement and has a predominance of planned residential zones and commercial areas. Moreover, it concentrates many public services such as the local Hospital and the University. Laghouat peripheral areas are predominantly agricultural, characterized by the cultivation of dates. Unlike Biskra, Laghouat has a significative tourist inflow, being an important stopover for travelers exploring the Sahara.

Béchar (بشار): The urban form of the Béchar possesses a distinctive difference between centre and periphery. The urban core is compact, with a predominance of orthogonal grids, dotted with green spaces made up by palm trees, and comprises most of the residential areas, public markets and institutional buildings. The architecture of certain parts of Béchar reflects Saharan influences, with long-stretched buildings to provide shade for temperatures averaging 40 °C in summertime. As for the periphery, these are comprised of vast stretches of desert, cut by long single roads, with small settlements set near the areas where fruit-based agriculture (almonds, dates and figs) is practiced. Béchar is also an important commercial and administrative centre of the region, with an economy based on trade and crafts such as jewelry, traditional of the Saharan desert.

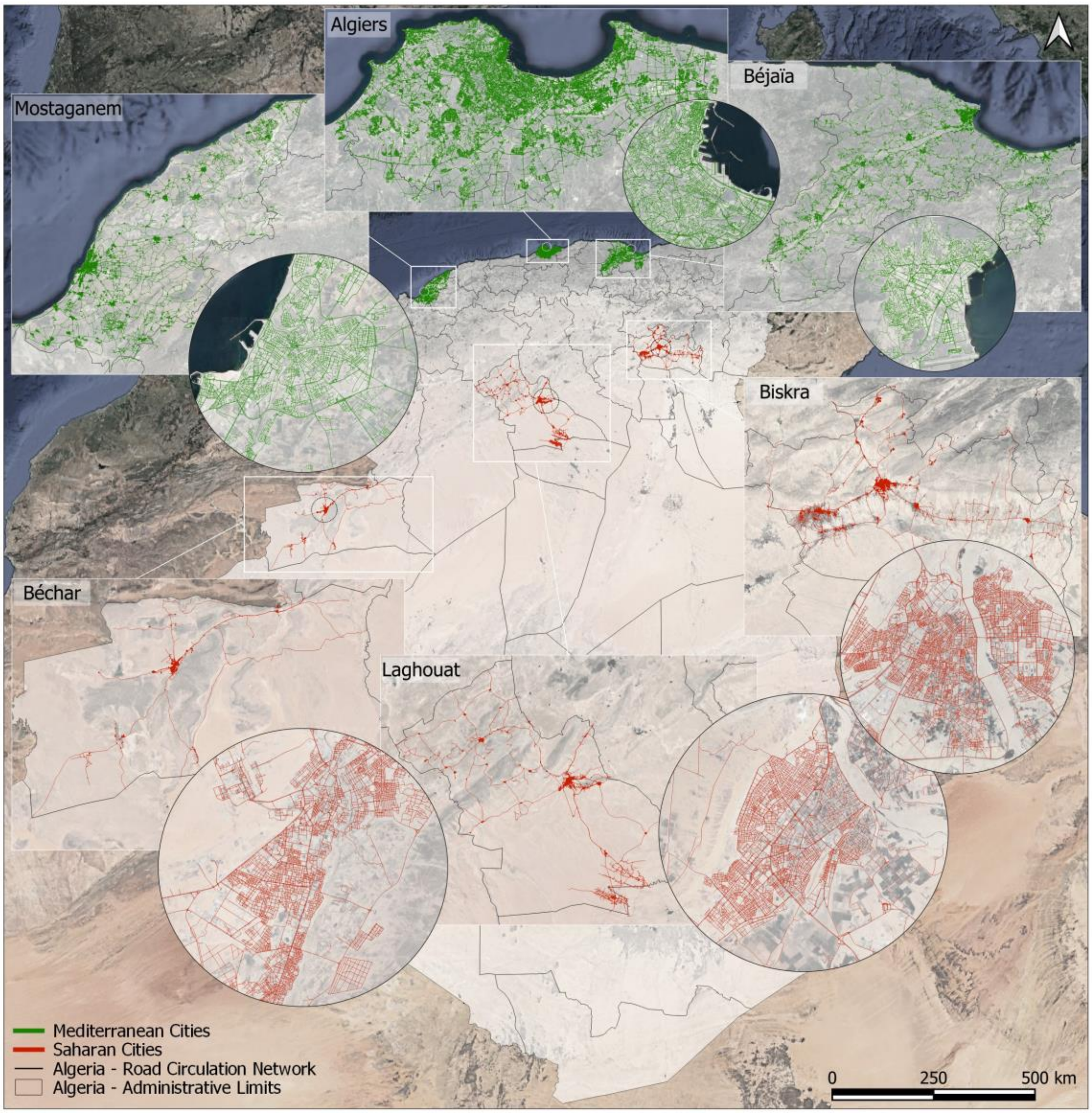

Figure 1: Case study presentation of the scrutinized cities.

Besides the pointed-out architectural and socio-economic differences between Saharan and Mediterranean settlements, it is important to highlight their strong contrasts in terms of local climate. Algeria features a range of local climate zones due to its vast and varying landscapes; yet it is generally categorized under five main climate zones, in accordance with the Koppen-Geiger scale (Beck et al., 2023; Geiger, 1961; Köppen, 1936) (Figure 2).

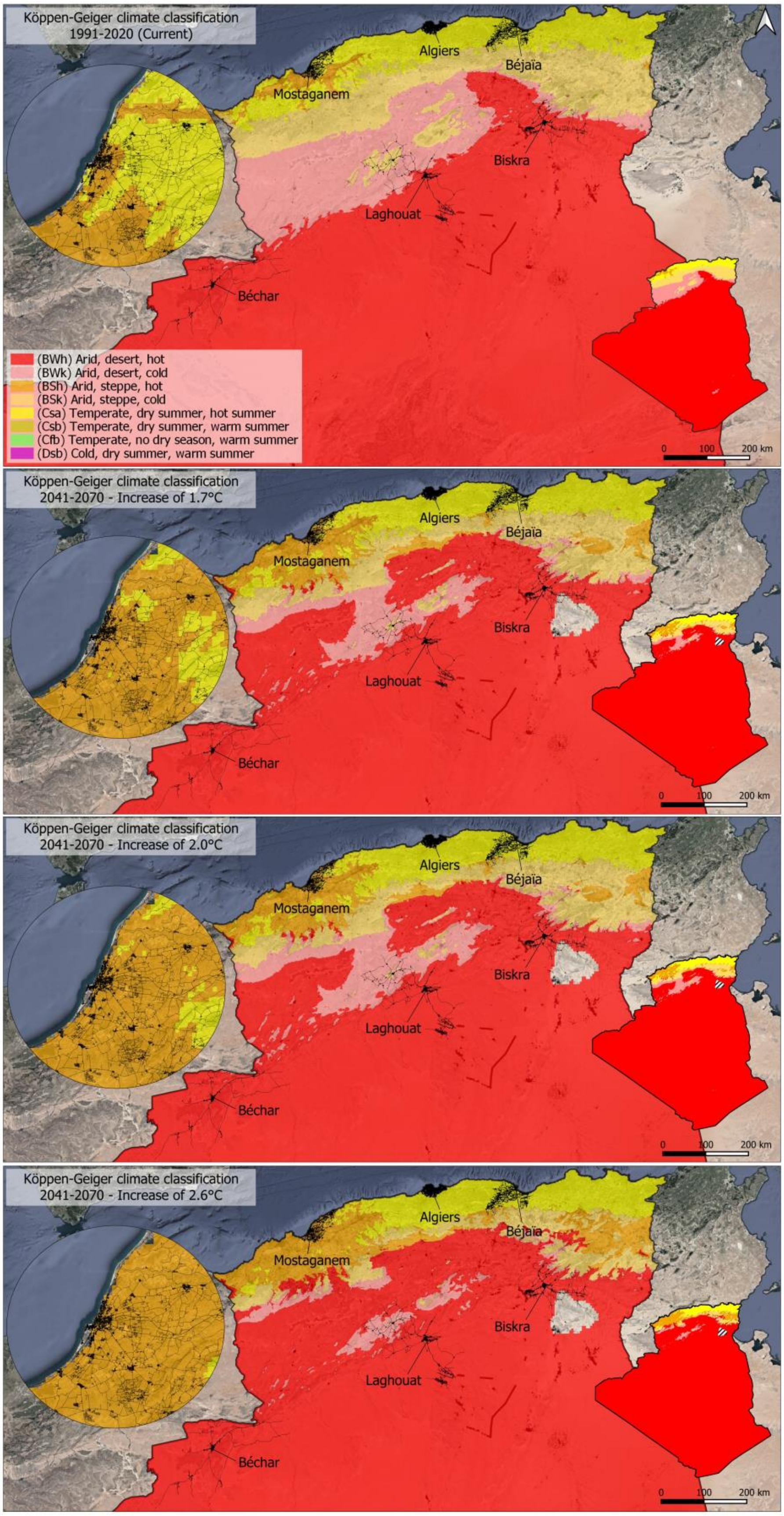

Figure 2: Köppen-Geiger climate classification of Algeria from 1991 to 2020 and prospects of climate change for the 2041-2070 period (Source: Beck et.al. 2023).

There is a distinctive – yet gradual shift in the climate zones between the two groups of cities. Mediterranean cities are mainly set in the temperate, with dry and hot summers zone (Csa), with stretches of Hot Arid Steppes (BSh), especially near *Mostaganem*. Saharan cities, instead, alternate between zones with Cold Arid Steppes (Bsk), Cold Arid Deserts (BWk) and, mainly Hot Arid Deserts (BWh). Besides those five main climate zones, Algeria also possesses several microclimates. The hills near *Algiers* and *Béjaïa* have a temperate, with dry and warm summers (Csb) climate, where small zones of temperate, with no dry season (Cfb) and cold (Dsb) climates can be also found within the arid, cold areas near the borders of Biskra, due the presence of high mountain peaks set within the Chélia national park.

However, it is important to make a mention to the forecasted climate changes for Algeria and the studied regions. Figure 2 demonstrates three possible scenarios of change for the near future 2040-2070, with increases in temperature ranging from 1.7 °C to 2.6 °C, with the most probable set at 2.0 °C – given a continuation of human activity without an expressive reduction on emissions. All scenarios of climate change demonstrate an expressive growth on the climate zones defined as Hot Arid Steppes (BSh) around the Mediterranean cities, a phenomenon that can be seen in *Béjaïa,* but, above all, in *Mostaganem*, which loses most of its areas set within a temperate climate (Csa). Moreover, this desertification process can also be observed in areas with Cold Arid Steppes (BSk) and Cold Arid Deserts (BWk). Large stretches set within those climates change towards a Hot Arid Desert climate (BWh), being in-line with the observed expansion of the Saharan desert, which grew more than 10% in the last century (Liu, Xue, 2020). It is important to also note that the temperate (Cfb) and cold (Dsb) microclimates set on hilled and mountainous areas are set to disappear with climate change, which might also affect the water cycles within the region.

Those prospects of climate change for the next half-century will require an adaptation, both in socio-economic and in urban terms, with a review of how cities are built to withstand climate. This justifies an initial approach on understanding the characteristics of those particular cases – and the overall differences between them.

3.2 Datasets, methods and tools:

This research investigates how climate can influence urban configuration in the scrutinized cities. The methodological approach merges climate data with configurational analysis and statistics to unveil potential connections between those environmental factors and the urban layouts for these diverse geographical settings (Figure 1). The methodological approach can be defined in the flowchart below (Figure 3):

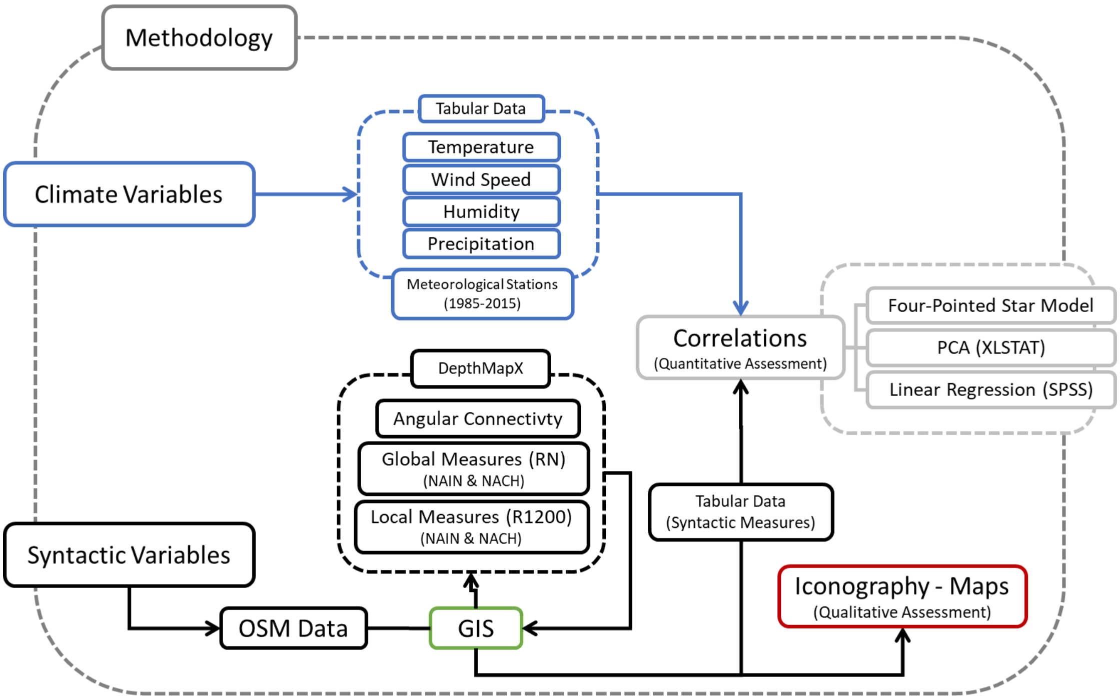

Figure 3: Methodological approach flowchart.

The climatological dataset covers the selected parameters of: temperature, wind speed, humidity, and precipitation (Figure 3). Those were compiled from weather reports collected from several meteorological stations in Algeria. Data is periodic and comprises mean values for a period of 30 years, set between 1985 and 2015 (Figure 3). The datasets are organised as tabular data and incorporated to the statistical analyses software's' (*IBM SPSS* ; *XLSTAT*).

The urban road-circulation networks used for configurational analyses are extracted from the OpenStreetMap (OSM) database (2023) comprising the whole Algerian road-network. This network was simplified and generalised to: a) remove the road-elements that are unsuited for configurational analysis of vehicular and pedestrian movement in urban settings, such as tracks and mountain roads; and b) diminish considerably the processing time-lapses, by reducing the number of elements created after angular segmentation in DepthMapX 0.8 (Hacar et al, 2024). ASA analysis is performed for each settlement, following the formulas outlined in Table 1, to obtain first the Rn (global) the values for Angular Connectivity, NAIN and NACH. Furthermore, models for the R1200 (local) NAIN and NACH were produced. Completed models are exported to

QGIS (2023) and spatialised using a statistical division based in an equal count (quantile). Colour ranges are established using 10 classes for a qualitative analysis.

Quantitative analysis is performed, initially, using the four-pointed star model (Hillier et al. 2012), to highlight the relationships between background and foreground networks. Then, further exploration is performed through statistical analyses, that establish the correlations between climate-based and configurational variables. This exploratory statistical analysis comprises a Principal Component Analysis (PCA), made through the XLSTAT extension of Microsoft Excel; and a Linear Regression, made using the SPSS software. PCA provides insights into the underlying structure and patterns present in the data. Hence, it demonstrates what are the variables that better explain the differences among the cities, capturing trends (the principal components) and then smaller, more subtle variations. The Linear Regression, instead, demonstrates the influence of the climate variables on each of the urban patterns captured through the configurational analyses.

4 RESULTS AND DISCUSSION

4.1 Configurational analysis results – qualitative assessment:

The configurational analysis for the Algerian cities focusses on a comprehensive exploration of the Integration metric. The differences in *relative accessibility* were highlighted by the PCA, both at global and local scales; and by the Linear Regressions, especially at local scale, as the pivotal factors that explain – and guide – the differences among the urban settlements (see Figures 7 & 8). In that aspect, the qualitative analyses are mainly focused on NAIN Rn and NAIN R1200 measures (Figure, 4 & 5; Table 2).

Considering the results for NAIN Rn (Figure 4), related to the Mediterranean cities, one can discern their similar patterns: a marked, yet sprawled centrality core, characterized by the highest values of integration within those settlements, that is set along the modern urban developments – and, in most cases, also comprising the historical centre. In all Mediterranean cases, Integration decreases in strength towards the suburban areas, in a classic pattern that informs the prevalence of a higher *relative accessibility* – thus, a higher movement potential towards the urban cores. Geography also has a role on configuration, by creating barriers and spaces of segregation, well-marked in the case of Algiers (Figure 4). This intricate logic translates also locally, as the metric radius (NAIN R1200), that highlights not only the historical centres, but also the several sub-centres and satellite settlements within the main centrality core at global scale, with the spaces of segregation marked by local geography (Figure 5).

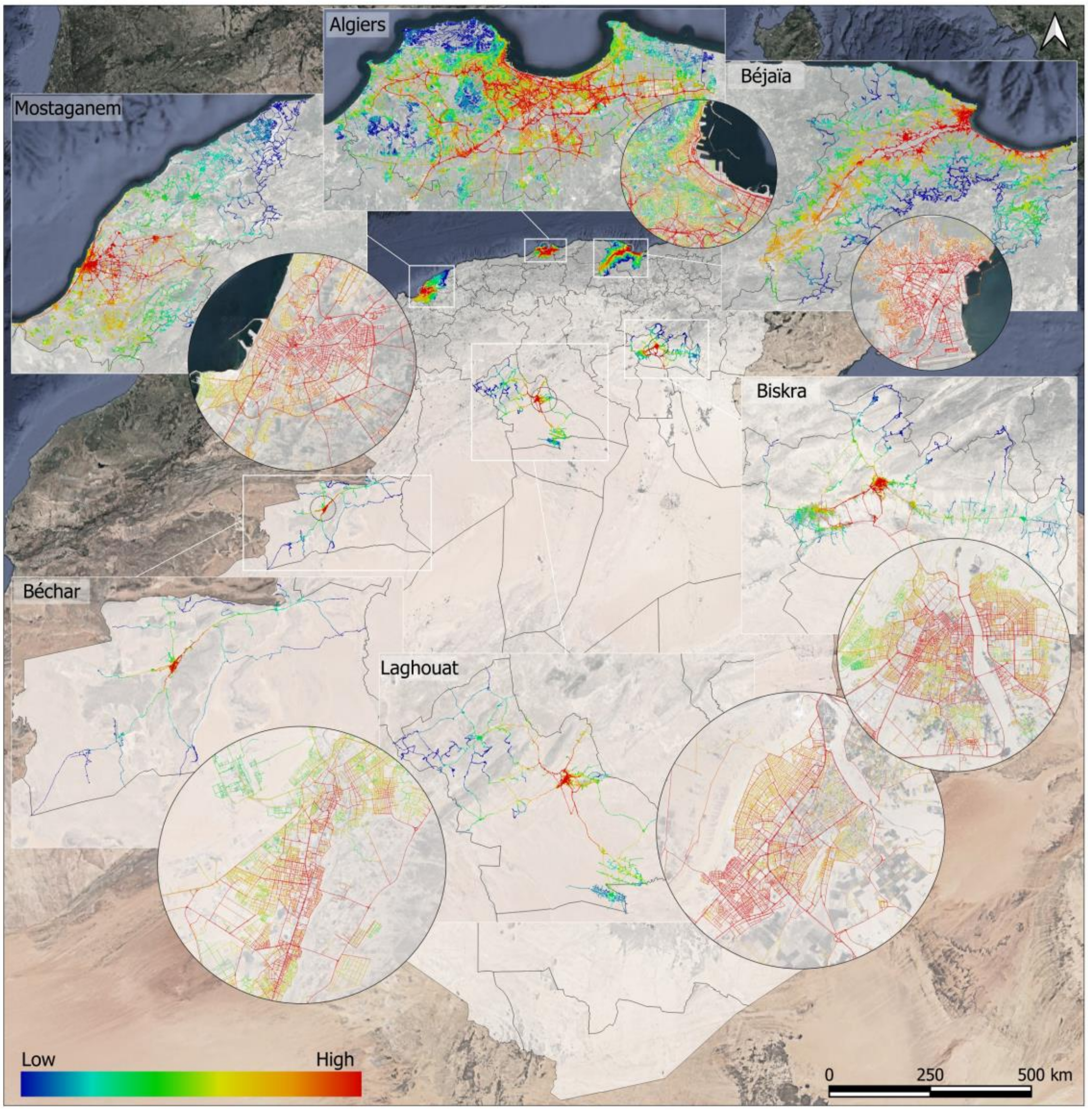

Figure 4: Differences in configuration metrics and centrality distributions amongst Mediterranean and Saharan-based urban settlements in Algeria (NAIN – Rn).

This phenomenon of the emergence of sub-centres due to urban expansion is exemplified on the outskirts of Mostaganem with settlements like *Mezghrane*, *Hassi Mameche*, *Mesra, Sirat,* and *Kheir Eddine*, that corresponds to the suburban centres of movement. Moreover, this logic is also well-defined in the urban hubs that surround the Bay of Algiers – in the neighborhoods of *Bouzareah, Ben Aknoun, Baba Hassen*, *Bordj el Kiffan, Dar el Beida*, as well as the historical centre of Algiers. Bejaïa, instead, has a slightly different pattern when confronted to those found for the other mediterranean cities, with a linear organization of annexed municipalities and sub-centres including *El Kseur, Amizour, Semaoun, Sidi-Aich*. This, however, can be mainly associated to the geography and access to natural resources, since this linear continuity is set along the along the river *Oued Ghir*, which further underscores the complexity of configurational determinants and these spatial arrangements at local scales (Figure 5).

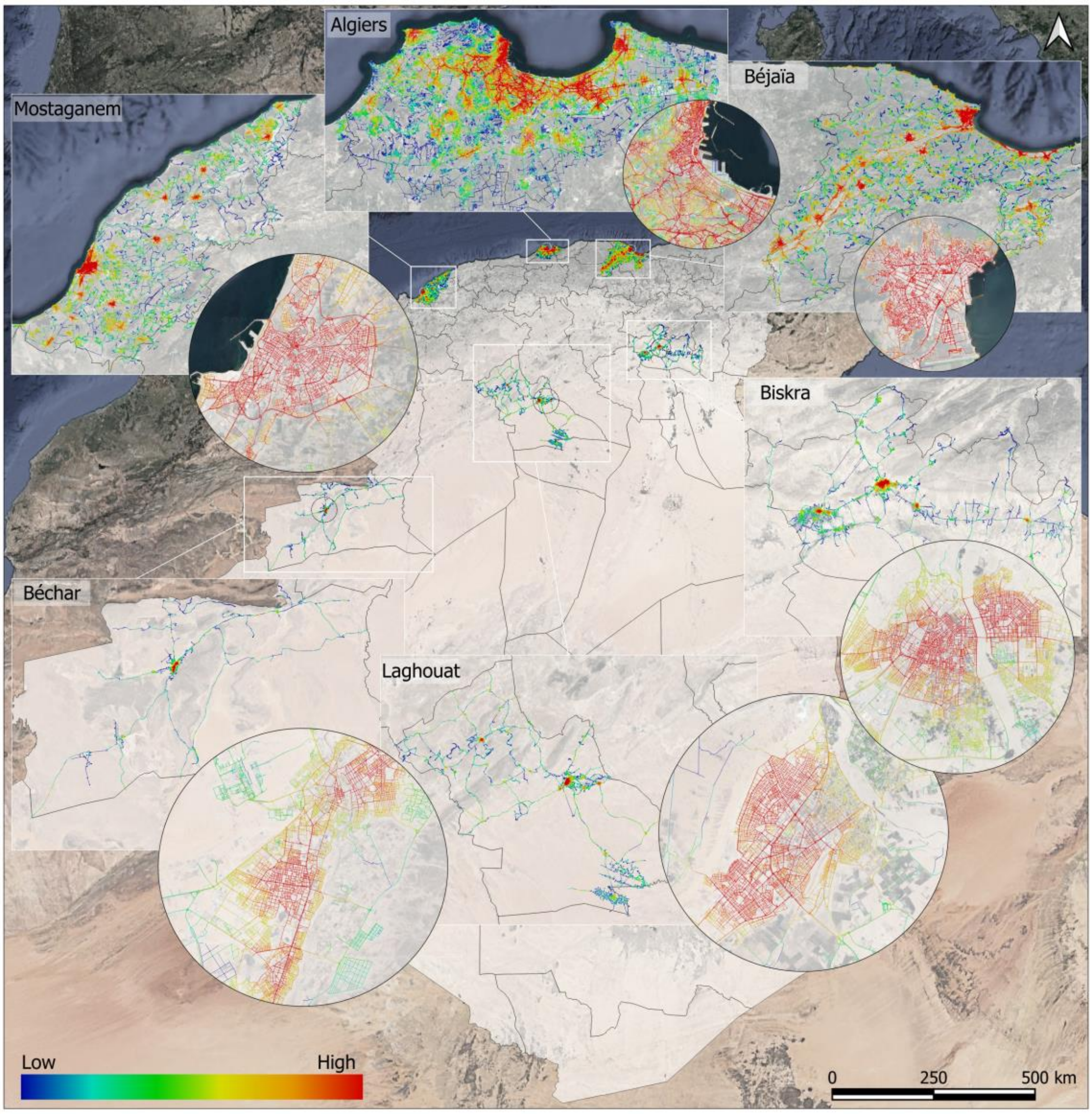

Figure 5: Differences in configuration metrics and centrality distributions amongst Mediterranean and Saharan-based urban settlements in Algeria (NAIN – R1200).

Contrastingly, a distinct pattern emerges when examining the Saharan settlements' values and patterns for NAIN Rn (Figure 5). High values for *relative accessibility* are restricted to very compact centrality cores in all urban areas, indicating that movement potentials are confined to a small geographical area, tendency exacerbated by the prevalence of orthogonal grids, which are natural attractors of movement potentials in urban settlements, given their high connectivity and shallow depth. This observation leads to the distinctive characteristic of a distant and "outer-walls" oriented urban growth, stemming away from the "oasis" where initial settlement began. This phenomenon becomes evident in the NAIN R1200, where there are way less sub-centres, in comparison to the Mediterranean cities. Biskra outlines the neighbourhoods of *Lhadjeb*, *Chetma*, *Tolga*, and *Sidi Okba,* where agricultural activities take place; Laghouat, instead, highlights *Ain Madi*, and *Tadjemout,* all those areas have in common a prevalence – or intensification – of the orthogonal grids. These patterns are even more distinctive in Béchar, where the small settlements of *Abadla* and *Kenadsa* are highlighted by the analysis due to their regular orthogonal patterns. This imparts a unique and shared pattern of these Saharan cities – where the peripheries are actually rather distant and peripheral in relation to the core – setting them apart from their Mediterranean counterparts, where peripheries are more integrated to the urban fabric.

Table 2. Configurational metrics for Mediterranean and Saharan cities: Angular Connectivity (AC), Angular Total Depth (ATD), Node Count (NC), Normalised Angular Integration (NAIN Rn & NAIN R1200) and Normalised Angular Choice (NACH Rn & NACH R1200).

Metric	Mediterranean Cities			Saharan Cities		
	Algiers	Bejaïa	Mostaganem	Béchar	Biskra	Laghouat
AC (Mean)	2.02	1.05	1.62	2.13	2.06	1.94
ATD (Max.)	$\approx 1.18\times10^{7}$	$\approx 4.40\times10^{7}$	$\approx 7.33\times10^{6}$	$\approx 2.46\times10^{6}$	$\approx 5.35\times10^{6}$	$\approx 3.70\times10^{6}$
NC	145,636	120,385	59,234	22,956	41,913	40,471
NAIN Rn (Max.)	0.88	0.11	0.20	0.58	0.47	0.06
NAIN Rn (Mean)	0.55	0.07	0.28	0.39	0.33	0.04
NAIN R1200 (Max.)	2.90	2.75	2.94	3.31	3.36	3.61
NAIN R1200 (Mean)	2.24	1.48	1.87	2.16	2.12	2.01
NACH Rn (Max.)	1.50	1.38	1.40	1.45	1.45	1.46
NACH Rn (Mean)	0.79	0.88	0.82	0.87	0.86	0.85
NACH R1200 (Max.)	5.89	5.55	6.00	5.81	5.94	5.72
NACH R1200 (Mean)	3.37	3.33	3.07	3.10	3.21	2.95

The four-pointed star model comprises a first quantitative analysis for each group of cities (Mediterranean and Saharan), that uses the mean and maximum values of NAIN and NACH to reveal the relations between foreground and background networks (Figure 6, Table 2). The results reveal insightful patterns regarding urban configuration.

In the context of Mediterranean cities (Figure 6a), Béjaïa and Mostaganem exhibit elevated Mean NACH values – owning to the presence of longer connective roads when compared to the more compact Algiers – indicating the sustained continuity and regularity of their urban network concerning the background. Moreover, these high values demonstrate a direct connection to the background in these cities. In contrast, Algiers stands out with a high Max. NACH value, owning to the increased deformation and often interruption in its foreground structure; it can be said that Algiers is different from all other urban settlements in that aspect – which can be explained by its hilly geography which deems a more sinuous road configuration. However, Algiers also boasts high Mean and Max NAIN values, suggesting that, despite the road-network deformation, both foreground (Max. NAIN) and background (Mean NAIN) networks are accessible.

Turning to Saharan cities (Figure 6b), the four-pointed star model demonstrate that all share similarities, showing notably similar Mean NACH values, which underscores the continuous nature of their structure – especially in their peripheral areas – as *preferential routes* are limited to a *singular* route. It is interesting to note that the four-pointed star model deems Béchar and Biskra are more similar among the Saharan cities, even though those present the most striking visual differences in their urban forms. This denotes that, despite an urban form that is seemingly distinct, the road-network patterns follow the same principles in terms of spatial configuration. This result is also in line with the qualitative differences noted between Biskra and Laghouat, with the latter being more compact and possessing a narrower, more irregular historical centre. This comes in opposition to the rigid regularity observed for Biskra and Béchar road-networks. Nevertheless, the results reinforce an overall regularity of the Saharan settlements in relation to the background is verified, as well as a direct connection it, especially when compared to the mediterranean settlements.

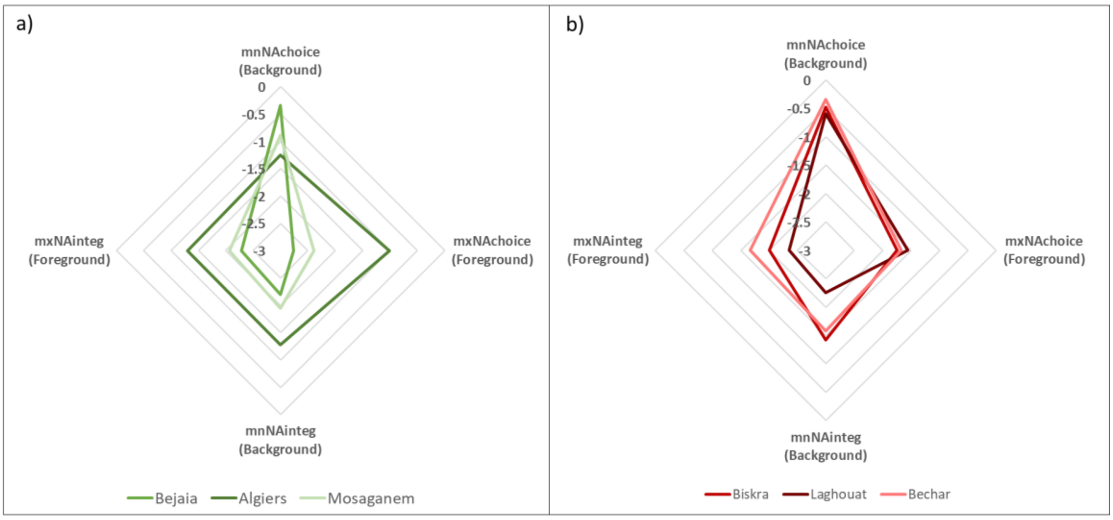

Figure 6: Four-pointed star model of the analysed cities – clustered by climate conditions

4.2 Spatial configuration and climate:

The principal components analysis (PCA) considers the different configurational and climate-related variables to explain the variances between the data. The PCA results (Figure 7) reveal a compelling city clustering, where it is possible to identify which are the cities that share similar configurational and climatic characteristics. Saharan cities appear clustered in the positive part of the coordinate axis (F1), while Mediterranean cities are set in the negative section of F1.

The biplot diagram (Figure 7) also demonstrates that Local Integration (NAIN R1200) and Angular Connectivity (AC) are positioned in the same quadrant and have similar angles in relation to the climate factors, with implies similar patterns of variation; NAIN Rn, while positioned in the negative part of F1, is positioned in the positive part of F2, presenting a similar behaviour to NAIN R1200 and Angular Connectivity. The NACH measure on the other hand, has a very distinctive opposite behaviour between the global (Rn) and local (R1200) measures. These base results for the PCA justify the further focus given to NAIN measures in this research qualitative assessments.

Observing the climate variables, Temperature and Wind Speed tend to exhibit a similar behaviour, with both being set in the positive part of F1, alongside the Saharan cities, which implies that those tend to present similar patterns of variation. Humidity and precipitation are set in the opposite quadrants of the diagram, also being opposite among themselves.

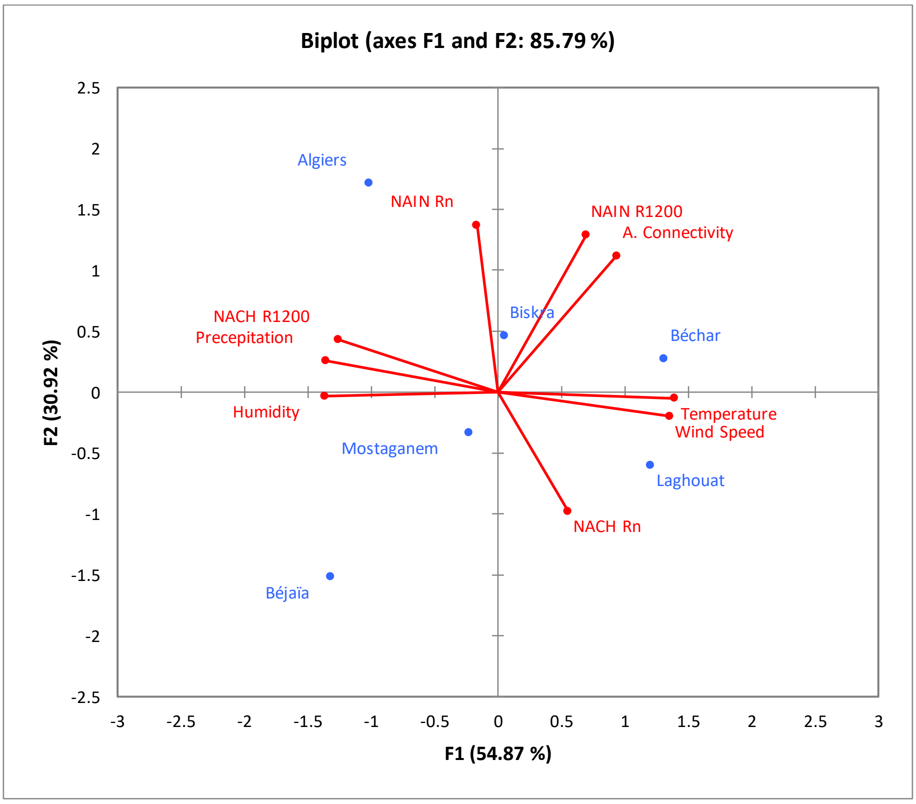

Figure 7: Principal Component Analysis Biplot of syntactic and climate-driven variables.

The PCA results set the basis for further investigations observing the correlations between configuration and climate. In the proposed analysis with linear regressions, the climate variables are grouped with the mean values for the configurational measures (NAIN Rn, NAIN R1200; NACH Rn and NAC R1200). The standardized linear regression coefficients indicate the tendency of statistical changes in the standard deviations of the dependent variable, given changes of one standard deviation on the independent variable. It must be noted that in these linear regressions are only looking at the standard deviations between the variables, accordingly it relies only on the standard coefficients of the regressions to explain the differences between the cities.

The diagrams portrait the behavior of the compared variables, facilitating the assessment of impact, given variations in scale or units. Applying the linear regression to the variables reveals varying strengths and orientations between the climate and configurational variables (Figure 8).

The results show that temperature, wind speed, humidity, and precipitation exert distinct influences on the dependent variables. A substantial increase in temperatures substantially enhances NAIN R1200 values (21.784) and slightly increases NACH Rn (3.381).; conversely, there is a notable negative impact on Angular Connectivity (-18.860), which denotes that urban areas with higher temperatures have more compact urban cores, mostly regular – in line with what is observed for the Saharan cities. It must be noted that temperature is the variable that most exerts influence on local configuration among those explored (Figure 8).

As indicated on the PCA, wind speed follows temperature patterns, and its increases affect positively NAIN R1200 (16.588) but adversely influences connectivity (-15.651). The higher wind speeds are often characteristics of the Saharan cities. Precipitation's noteworthy effects include a substantial decrease in NAIN R1200 (-17.872) and an increase in A. Connectivity (16.595), while humidity, when increased, moderately enhances the connectivity (7.099). Both precipitation and humidity have a similar behavior, as they denote lower NAIN R1200 values, thus more sprawled urban cores with the presence of several sub-centres, characteristics from the mediterranean settlements.

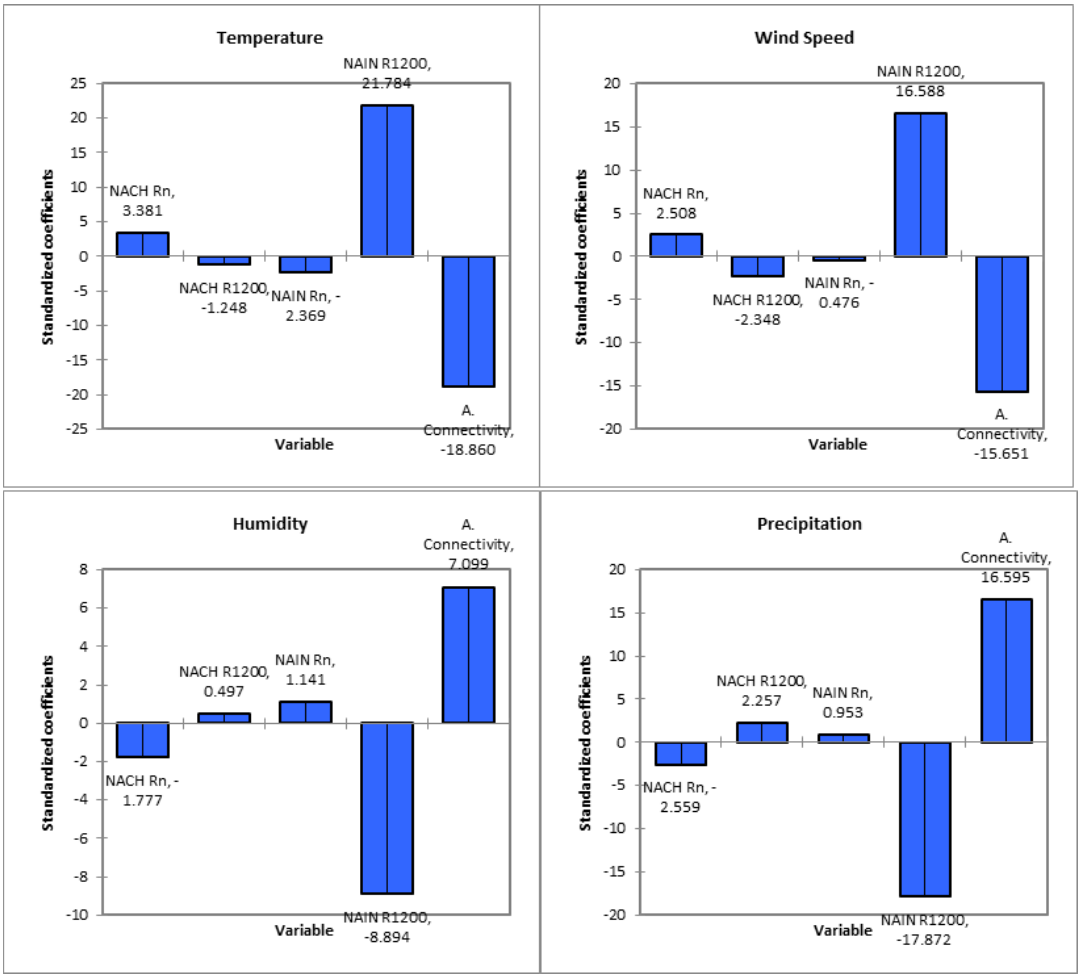

Figure 8: Standardized coefficients of linear regression (95% of confident interval) of Climate and syntactic variables.

The differences in Local Integration measures (NAIN R1200) among Mediterranean and Saharan cities become apparent when examining and juxtaposing the spatial layouts of two cities situated in distinct climates, exemplified by Algiers and Biskra (Figure 9). Through a more granular analysis, it is possible to examine the differences both in size, density and extent of the sub-centres highlighted by Integration. While Algiers (Figure 9a) has at least 15 sub-centres – with a lesser density especially on the smaller ones, Biskra (Figure 9b) has just 5, and the main centre is much larger than the sub-centres – which lead to the observed NAIN R1200 higher values (Table 2).

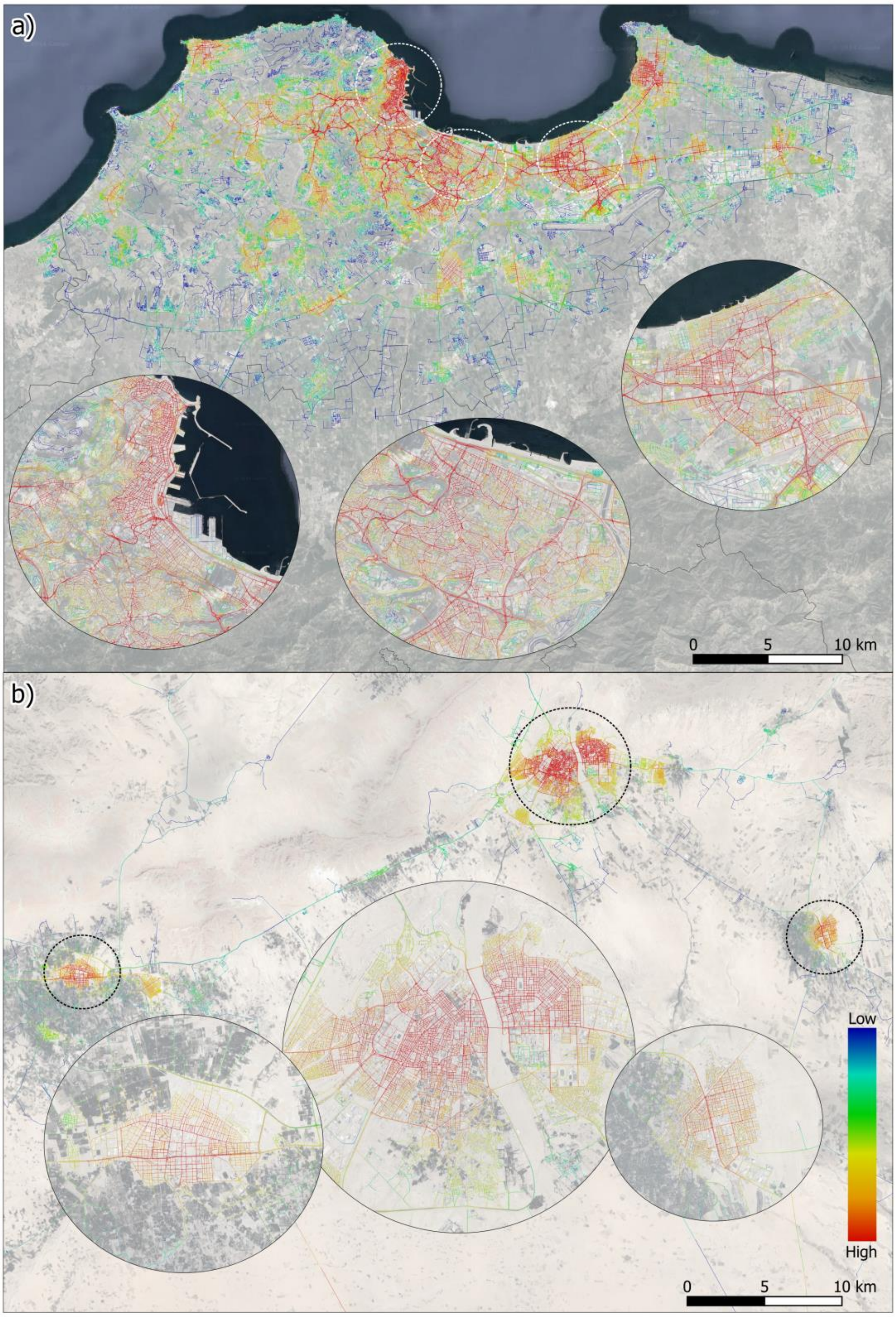

Figure 9: Algiers and Biskra: evidence of configurational and morphological differences between cities set in different climates (NAIN R1200).

Moreover, it is possible to see the differences in terms of regularity between the settlements road-circulation networks. Biskra (Figure 9b) has a very regular orthogonal network, while Algiers (Figure 9a) tend to be more sinuous, especially regarding the roads that establish the connections between the historical centre and the sub-centres that are located in the central part of the urban settlement.

These results provide an initial overview of how different climates can guide the patterns of configuration of the urban settlements, demonstrating that certain patterns tend to emerge – and be more reproduced in certain climates, as an adaptation, mostly, to high temperatures. Nevertheless, further studies are needed to understand the impact of climate, configuration and urban form in such different contexts in a granular manner, especially considering the different urban microclimates that emerge in different parts of the city, given the differences in the overall construction patterns.

5 CONCLUSIONS

Climate has a important influence in determining the urban form and the configurational patterns in urban settlements.

This approach explored how different urban areas, set in rather different climates – the Mediterranean coast of Algeria, and the Saharan desert – possess certain similarities in urban form that emerge as adaptations to the environmental conditions – some, quite extreme. In that regard, Space Syntax helps to uncover the distinctive patterns of spatial organization in each context, that while can be qualitatively verified, now have a quantitative basis. It establishes that, above all, temperatures, tend to greatly determine the emerging form, as the values of *relative accessibility* at local scale tend to be higher due to the compactness of the urban fabric where temperatures are higher, a requirement to minimise the distances and movement under desert environments.

Therefore, findings underline the crucial role of climate in structuring, not only form, but also the socio-spatial dynamics within urban areas. In Mediterranean cities – such as *Algeirs, Béjaïa* and *Mostaganem*, characterised by milder climates, it is observed that the centrality cores tend to be more spread-out, with a distribution of the overall *relative accessibility*, and the presence of urban centre. This orientates movement towards farther distances and allow spaces of co-presence and social interactions (such as parks or plazas) to be larger. In contrast, the Saharan cities, faced with arid conditions and limited water availability, feature more compact centrality cores and the predominance of orthogonal grids, which reflect a more confined spatial layout; a necessity, due to their environmental constrains. This, in turn can be verified through their higher values for *local relative accessibility* as movements need to be constrained to smaller areas so people can cope with the climate extremes, reducing their necessity to move in-between spaces. All these factors are supported by the results of the correlation analyses between climate variables and configurational measures, which revealed nuanced relationships. The temperature differences seem to exert influence on local integration patterns and angular connectivity – both informing urban form –, meanwhile wind speed, humidity and precipitation have distinctly minor effects on urban morphology and movement patterns, yet aid to describe punctual differences among the Mediterranean and Saharan cities.

The findings highlighted in this study, even though being an initial overview to be further explored with the employment of more detailed datasets, have valuable implications for urban planning and policymaking, as it highlights the importance of context-specific strategies to address the unique challenges posed by diverse climatic conditions – and the further changes that the society may face.

In that aspect, approaches such as this, that merge different domains – such as Space Syntax movement analysis and Climate-oriented analysis – ought to become more commonplace, as they contribute decisively to decision-making in those times of change. Further studies in the subject should aim to address the problem of scale, aiming towards comparative studies that take urban microclimates and configuration in consideration for different contexts, but also how the collective microclimates define the citywide climate, and how this affects the cities' socio-spatial life. By understanding the complex interplay between climate, configuration and urban form, planners and policymakers can develop interventions to promote sustainable, adaptable and comfortable urban spaces that improve both the physical and social well-being of residents.

ACKNOWLEDGEMENTS

This research has received funding from the **United Kingdom Research and Innovation Post Doctoral Fellowship Guarantee Scheme, set over the European Union's Horizon Europe – Marie Skłodowska Curie Actions Post Doctoral Fellowships**. **UKRI Grant no. 101107846-DECIDE/EP/Y028716/1**. Views and opinions expressed are those of the authors only, and do not necessarily reflect those of the United Kingdom or European Union. Neither the United Kingdom or European Union nor the granting authority can be held responsible for them.

REFERENCES

Bavelas, A. (1950). Communication Patterns in Task-Oriented Groups. *The Journal of the Acoustical Society of America*, *22*(6), 725–730. https://doi.org/10.1121/1.1906679

Beck, H. E., McVicar, T. R., Vergopolan, N., Berg, A., Lutsko, N. J., Dufour, A., Zeng, Z., Jiang, X., van Dijk, A. I. J. M., & Miralles, D. G. (2023). High-resolution (1 km) Köppen-Geiger maps for 1901–2099 based on constrained CMIP6 projections. *Scientific Data*, *10*(1), 724. https://doi.org/10.1038/s41597-023-02549-6

Berghauser Pont, M., & Haupt, P. (2010). Spacematrix : space, density, and urban form. In *TA - TT* -. NAI Rotterdam. https://doi.org/ LK - https://worldcat.org/title/505749966

Cutini, V., & Rabino, G. (2012). The urban growth: development, sprawl and spatial configuration. In Z. C. Campagna M, De Montis A, Isola F, Lai S, Pira C (Ed.), *Planning support tools: policy analysis, implementation, evaluation.* (pp. 981–992). Franco Angeli.

Dalton, N. (2001). Fractional configurational analysis and a solution to the Manhattan problem. In S. Peponis, J., Wineman, J. & Bafna (Ed.), *the 3rd International Symposium on Space Syntax* (pp. 26.1–26.13). Georgia Institute of Technology, Atalanta, GA.

Dalton, R., Dalton, N., McElhinney, S., & Mavros, P. (2023). Isovist in a Grid: Benefits and Limitations. *The Journal of Urban Design*, *4*(042), 46–59.

De Koning, R. E., Van Nes, A., Ye, Y., & Roald, H. J. (2017). Strategies for integrated densification with urban qualities: Combining Space Syntax with building density, land usage, public transport and property rights in Bergen city. *XI SSS: 11th International Space Syntax Symposium 2017*, 51–56.

depthmapX development team. (2020). depthmapX (Version 0.8.0) [Computer software]. Retrieved from https://github.com/SpaceGroupUCL/depthmapX/

Freeman, L. C. (1977). A Set of Measures of Centrality Based on Betweenness. *Sociometry*, *40*(1), 35. https://doi.org/10.2307/3033543

Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239. https://doi.org/10.1016/0378-8733(78)90021-7

Geiger, R. (1961). Überarbeitete Neuausgabe von Geiger, R.: Köppen-Geiger. *Klima Der Erde. (Wandkarte 1:16 Mill.), Klett-Pert*.

Hamzah, M. J., & Ebraheem, M. A. (2020). Analyzing Urban Attraction Nodes by using GIS and Space Syntax (case study-Al-Adhamiya). *IOP Conference Series: Materials Science and Engineering*, *737*(1), 012181. https://doi.org/10.1088/1757-899X/737/1/012181

Hacar M., Mara F., Altafini D., Cutini V. (2024) Preprocessing Open Data for Optimizing Estimation Times in Urban Network Analysis: Extracting, Filtering, Geoprocessing, and Simplifying the Road-Center Lines. In: Lecture Notes in Civil Engineering (LNCE) – Proceedings of the 12th International Conference on Innovation in Urban and Regional Planning (INPUT2023), L'aquila, Italy, 06 September 2023, pp.1-12 (Forthcoming)

Hillier, B. (2007). Space is the machine: A configurational theory of architecture. In *Press Syndicate of the University of Cambridge* (UCL).

Hillier, B., Burdett, R., Peponis, J., & Penn, A. (1986). Creating life: or, does architecture determine anything? *Architecture \& Comportement/Architecture \& Behaviour*, *3*(3), 233–250.

Hillier, B., & Hanson, J. (1984). *The Social Logic of Space*. Cambridge University Press. https://doi.org/10.1017/CBO9780511597237

Hillier, B., & Iida, S. (2005). Network effect and physichological effect: a theory of urban movement. *Spatial Information Theory*, 475–490.

Hillier, B., Yang, T., & Turner, A. (2012). Normalising least angle choice in Depthmap and it opens up new perspectives on the global and local analysis of city space. *Journal of Space Syntax*, *3*(2), 155–193.

IBM Corp. IBM SPSS Statistics for Windows. (28.0). (2021). Armonk, NY: IBM Corp. https://www.ibm.com/spss

Karimi, K. (2018). Space syntax: consolidation and transformation of an urban research field. *Journal of Urban Design*, *23*(1), 1–4. https://doi.org/10.1080/13574809.2018.1403177

Köppen, W. (1936). Das geographische System der Klimate. *Handbuch Der Klimatologie*, *1*(Berlino, Borntraeger).

Li, X., Stringer, L. C., & Dallimer, M. (2022). The Impacts of Urbanisation and Climate Change on the Urban Thermal Environment in Africa. *Climate*, *10*(11), 1–21. https://doi.org/10.3390/cli10110164

Liu, Y., Xue, Y. Expansion of the Sahara Desert and shrinking of frozen land of the Arctic. *Scientific Reports* 10, 4109 (2020). https://doi.org/10.1038/s41598-020-61085-0

Masson, V., Lemonsu, A., Hidalgo, J., & Voogt, J. (2020). Urban climates and climate change. *Annual Review of Environment and Resources*, *45*(1), 411–444. https://doi.org/10.1146/annurev-environ-012320-083623

Nasehi, S., Yavari, A., Salehi, E., & Emmanuel, R. (2022). Role of local climate zone and space syntax on land surface temperature (case study: Tehran). *Urban Climate*, *45*. https://doi.org/10.1016/j.uclim.2022.101245

Papazoglou, A., & Pigaki, M. (2023). *Comparative Study for the Investigation of Safe Movement with the Method of Space Syntax: The Case of Mati, Eastern Attica* (pp. 579–597). https://doi.org/10.1007/978-3-031-37108-0_37

Pattacini, L. (2012). Climate and urban form. *URBAN DESIGN International*, *17*(2), 106–114. https://doi.org/10.1057/udi.2012.2

QGIS, Firenze, version 3.28.15 (2024) Available at: http://www.qgis.org/en/site/index.html

Ratti, C. (2004). Space Syntax: Some Inconsistencies. *Environment and Planning B: Planning and Design*, *31*(4), 487–499. https://doi.org/10.1068/b3019

Sabidussi, G. (1966). The centrality index of a graph. *Psychometrika*, *31*(4), 581–603. https://doi.org/10.1007/BF02289527

Shanableh, A.; Al-Ruzouq, R.; Yilmaz, A.G.; Siddique, M.; Merabtene, T.; Imteaz, M.A. (2018) Effects of Land Cover Change on Urban Floods and Rainwater Harvesting: A Case Study in Sharjah, UAE. *Water*, *10*, 631. https://doi.org/10.3390/w10050631

Soltanifard, H., & Aliabadi, K. (2019). Impact of urban spatial configuration on land surface temperature and urban heat islands: a case study of Mashhad, Iran. *Theoretical and Applied Climatology*, *137*(3–4), 2889–2903. https://doi.org/10.1007/s00704-018-2738-4

Stokes, E. C., & Seto, K. C. (2016). Climate change and urban land systems: bridging the gaps between urbanism and land science. *Journal of Land Use Science*, *11*(6), 698–708. https://doi.org/10.1080/1747423X.2016.1241316

Tao, C., Li, J., Zhou, D., Sun, J., Peng, D., & Lai, D. (2022). Outdoor Space Quality Mapping by Combining Accessibility, Openness, and Microclimate: A Case Study in a Neighborhood Park in Shanghai, China. *Sustainability (Switzerland)*, *14*(6). https://doi.org/10.3390/su14063570

Turner, A. (2001). Angular Analysis. In S. Peponis, J., Wineman, J. & Bafna (Ed.), *Proceedings 3rd International Space Syntax Symposium* (pp. 30.1-30.11).

Turner, A. (2004). *DepthMap4: A Researcher's Handbook*. http://www.vr.ucl.ac.uk/depthmap/depthmap4r1.pdf

Turner, A. (2005). Could A Road-centre Line Be An Axial Line In Disguise? *Proceedings 5th International Space Syntax Symposium*, 145–159.

Turner, A. (2007). From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design*, *34*(3), 539–555. https://doi.org/10.1068/b32067

Turner, A. (2009). Stitching Together the Fabric of Space and Society An Investigation into the Linkage of the Local to Regional Continuum. In D. Koch, L. Marcus, & J. Steen (Eds.), *the 7th International Space Syntax Symposium* (pp. 116.1-116.12).

Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environment and Planning B: Planning and Design*, *28*(1), 103–121. https://doi.org/10.1068/b2684

UN Habitat. (2013). Global Report on Human Settlements 2011: Cities and climate change. In *United Nations Human Settlements Programme*.

van Nes, A., & Yamu, C. (2021). Analysing Linear Spatial Relationships: The Measures of Connectivity, Integration, and Choice. In *Introduction to Space Syntax in Urban Studies* (pp. 35–86). Springer International Publishing. https://doi.org/10.1007/978-3-030-59140-3_2

XLSTAT Statistical Software for Excel (16.0). (2016). https://www.xlstat.com

Yamu, C., & Garau, C. (2022). *The 15-Min City: A Configurational Approach for Understanding the Spatial, Economic, and Cognitive Context of Walkability in Vienna* (pp. 387–404). https://doi.org/10.1007/978-3-031-10536-4_26

Yamu, C., & van Nes, A. (2017). An Integrated Modeling Approach Combining Multifractal Urban Planning with a Space Syntax Perspective. *Urban Science*, *1*(4), 37. https://doi.org/10.3390/urbansci1040037

Zhong, R. (2024) Hot Oceans Worsened Dubai's Dramatic Flooding, Scientists Say The New York Times, available at: https://www.nytimes.com/2024/04/18/climate/dubai-floods-what-we-know.html?smid=url-share