Comparative Study for the Investigation of Safe Movement with the Method of Space Syntax: The Case of Mati, Eastern Attica

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Abstract. Wildfires are destructive incidents of wide range and high impact in urban space, with climate change widely affecting their force and frequency, whereas their impact is extended to environment and society. The purpose of this research was to investigate connectivity and interaction between the "spaces" that were configured in urban space, aiming to contribute in spatial planning in emergency cases, like wildfires. The main concern of this research was how urban planning could take into consideration human movement in urban space and contribute in prevention and disaster management. Methodology was based on analyzing, examining and comparing the spatial configuration between two road network's scenarios, the Syntactic Configuration and the Urban Configuration. Provided that Space Syntax takes into consideration human perceptive in order to simulate human movement in urban space, Space Syntax was combined with Analytic Hierarchy Process (AHP) and criteria closely related to wildfires. Study case and main inspiration was the wildfire of 23/7/2018 at summer location of Mati, Eastern Attica.

Keywords: Space Syntax · Multi-Criteria Decision Methods · Spatial Analysis · GIS · Correlation · Space Planning · Safe Movement · Road Network · Wildfire · Mati

1 Introduction

Last decades, disasters are increasingly concerning the global scientific society due to the incidents' variation and the range of their consequences in society, economy and environment. The effect of climate change in frequency and intensity appear to be strong, making Disaster and Risk Management to be important scientific aspects in the effort of prevention, mitigation and recovery of society, environment and human life. In this recurring effort of research and improvement, technology and all the available means are the most helpful tools.

Mediterranean region is prone to wildfire incidents due to its climatic variety which is characterized by extended summertime with high temperature, long periods of humidity and local strong winds favoring the development of those disasters and complicating the damage control [1]. The continuous extension of urban space near to forest ecosystems

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and environments makes research about wildfires, fire risk factors and disaster management imperative to be held in order to protect and persevere the Mediterranean ecosystems due to climate change [2, 3]. As regards Greece, the years 2007 and 2018 were two of the most destructive fire seasons in recent history. Nowadays, Greek authorities like Fire Department, General Secretariat for Civil Protection and the relative Ministries are trying to develop strategies to prepare and inform the population for imminent events [1].

To reduce the fire risk, the analytical study of contributing factors is one of the most important measures to be taken into consideration in order to develop an affective prevention plan to protect the environment as much as the urban space. Topography determines fire behavior, whereas factors related to human activities and land use are strongly connected with fire ignition. Furthermore, vegetation and meteorological factors are connected to fire speed [4]. Build environments suffer with extended socio-economic impact in population and aspects of urban environment [1, 4]. Provided that fire spread and ignition factors are closely related to temperature and soil humidity, the continuous transition to warmer and drier conditions has a direct effect in the number of wildfires during fire season.

Based on methodologies related to disasters, this study presents a comparative analysis between two road network's configuration scenarios aiming to investigate the spatial functionality of urban space and contribute in urban design in emergency cases. The main concern leading to this research was to examine how human behavior could be integrated in urban planning in order to improve disaster and risk management. Space Syntax theory is being used to analyze the spatial relationships developed in urban environment taking into consideration human movement. Using the available techniques, spatial configuration was analyzed in various scales starting from pedestrian to vehicular movement. In order to connect Space Syntax theory with wildfires, a Multi-Criteria Decision Analysis method (MCDA) was incorporated in methodology, with Analytic Hierarchy Process (AHP) being the most common method. Fire risk factors were chosen to participate to the creation of fire risk maps for analyzing the functionality of urban space and road network in fire emergency cases. GIS technologies were integral part to the application of methodology. The research is concluded with correlation between the scenarios using Pearson's Correlation analysis and the assessment of the outcome.

The remaining paper is structured in four sections. The first section reports the study area along with the data, analyzes the scenarios and provides the framework of the methodology. Second section reviews the main theory about Space Syntax and AHP, provides a detailed description of the spatial patterns and describes the calculations and the necessary procedures. The third part of this paper refers to the results of the study by the fire risk maps and concludes with discussing the application of the methodology. The final part of this paper includes the study's conclusion followed by the potential improvements for future approaches and developments of the research.

2 Materials and Methods

2.1 Study Area

Four municipalities in Attica, Greece have been chosen as general study area, specifically municipalities of Penteli, Dionisos, Marathonas and Rafina-Pikermi (Fig. 1). Their area has been estimated to 365.928 km^2 and their population is approximately around 128.816 people according to 2011 Population-Housing Census of Hellenic Statistical Authority. The climate of Attica is classified as maritime with dry and very warm summer [5].

Wildfire in summer location Mati, Eastern Attica on 23rd of July 2018, was one of the most devastating fire events in Greece's recent history. Mati is located on Municipality of Marathonas at N 38° 2′ 58.95 and E 23° 59′ 14.86 and due to its seaside location is one of the summer destinations in Eastern Attica, along with Rafina and Nea Makri. As for the topography of the area, follows the tendency from the mountain edges to the sea. However, some longshore elevation differences leading to cliffs, as the Kokkino Limanaki area, differentiate the seaside topography causing problematic access and difficulties in movement at seaside area [6]. Coastal area has mostly dry species of vegetation, like olive trees, kermes and pines [7]. Furthermore, Mati appears to be densely populated with sprawling urban environment and problematic low-quality road network with many dead-ends, parallel roads connected to highways and inadequate signposting and road connectivity. A limited number of highways are the main network of transportation through the area, therefore gathers the majority of the area's traffic [7]. Particularly in summertime, Mati and nearby locations appear to have increase in seasonal population related with touristic activities and movements, according to Hellenic Statistical Authority. Relating to land use, there is a variety of summer and touristic activities in seaside area, with a few agricultural activities to appear in the suburbs [7].

Wildfire on 23rd of July 2018

The wildfire on 23rd of July 2018 and its impacts on the study area were the reason for attempting this research to analyze and compare the spatial configurations in order to suggest an integration of human movement in urban planning in emergency cases. According to Fire Service of Greece, the wildfire at Mati was a result of human negligence. Hellenic National Meteorological Service forecasted strong West/Northwest winds intensifying by noon, whereas Civil Protection Service had published relative fire risk map. At 16:41, Fire Service was informed for fire ignition at Ntaou Penteli, at the east edge of Penteli Mountain [8–10]. The extreme winds that blew that day, combined with topography, led the fire east towards Mati, which burned all through the urban space to coast. Fire speed in association with topography, the specific nature of urban environment and road network minimized residents' available response time leading to traffic problems and resulted in people being trapped, ending with unfathomable consequences for the population killing 103 people and almost destroying the summer location in Eastern Attica [2, 3, 8, 11].

2.2 Data Description

Aiming an all-around approach, data variety was determined from the thorough perusal of the literature [12–14]. Topography, vegetation and land use data were provided from

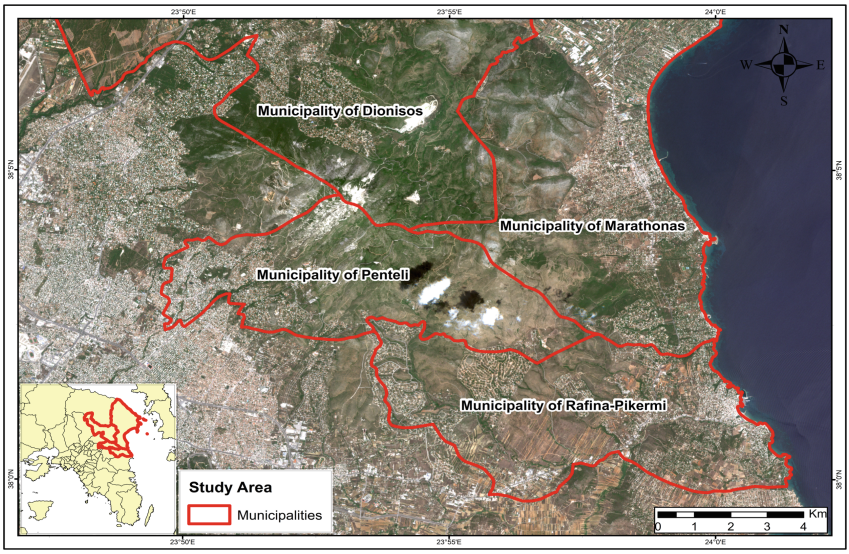

Fig. 1. Study Area

Copernicus program [15]. Digital Surface Model (DSM) with raster resolution of 25 m was used in order to produce the elevation, slope and aspect of the area. As for the vegetation, raster files for Dominant Leaf Type (DLT) and Tree Cover Density (TCD), with 10 m raster resolution, were acquired as well as an Urban Atlas raster file for the analysis of land use. DLT, TCD and Urban Atlas files were referred to 2018, the year of the wildfire in Mati. Hellenic Statistical Authority [16] was used in order to acquire files related to the 2011 Population-Housing Census, in particular excel files about population and buildings and shapefiles about Greek Municipalities, settlements and city blocks of the study area. Considering that wildfire event was part of the study, Fire Service of Greece [10] provided the relative shapefile data for hydrants, water tanks and the boundaries and points of service districts within the study area. Furthermore, daily data about temperature and wind speed and direction, from eight meteorological stations, were provided by the website of National Observatory of Athens (NOA) [17] in excel formats, for the time period 2015 to 2021. Ten-minute data were also acquired from NOA in text formats, from two meteorological stations and were referred to the fire day (23/7/2018). Road network, as one of the most important data, was downloaded from Geofrabrik's website [18]. Considering that a common coordinate system was necessary, the data were reprojected when needed. As for the software programs, ArcGIS 10.5 and QGIS 3.16 were used for executing all the necessary procedures of the methodology so that the final maps to be created.

2.3 Scenarios

In this study, a scenario-based methodology is chosen to analyze and evaluate the contribution of Space Syntax theory into the urban planning in emergency cases, like wildfires

in urban environment. Provided that road network configuration is one of the main parameters related to safe movement and evacuation in cases of emergency, two spatial configuration scenarios are chosen. According to Giuliani, Falco and Cutini's research [12], a scenario-based methodology is conducted to analyze and examine the road network's configuration and emergency management after a seismic event in Italian historic centres using Space Syntax techniques. That research consists the main idea for the comparative analysis of syntactic and urban configurational patterns in fire emergency cases that this paper studies. Attempting to combine two different research methods, Space Syntax and AHP, along with fire risk factors, are chosen in order to examine spatial configuration in a case of a fire incident inside the urban space and how this cooperation could provide information to emergency management.

The two road network scenarios are:

- Scenario 1: The Syntactic Pattern of road network is investigated with Space Syntax theory and its techniques, given that Space Syntax takes into consideration the human movement and analyzes the urban configurational patterns in pedestrian and vehicular movement scale.
- Scenario 0: The Urban Pattern of road network is investigated as it is depicted from the road categories, such as major and minor roads and the topography of study area as it is configured from the slope.

2.4 General Framework

The methodology refers to the analysis and examination of spatial configuration patterns of road network and their functionality in fire emergency cases in Eastern Attica area and the settlement of Mati.

The methodology (Fig. 2) is developed on the following stages:

1. First stage includes two analyses. The first is the analysis of the syntactic pattern (Scenario 1) with Space Syntax for investigating the configuration of road network and urban space of the study area. The second one is the analysis of the surveying of urban patterns (Scenario 0) which occur from the categories and the slope of road network.
2. On the second stage, both of the scenarios' functionality is examined with the use of AHP and fire risk factors. This stage is extended in three parts in order to fully analyze the impact of the parameters on road network's configuration pattern.
3. The third stage concerns the comparative analysis of the road network's functionality and usage rates with the use of Pearson's Correlation analysis.

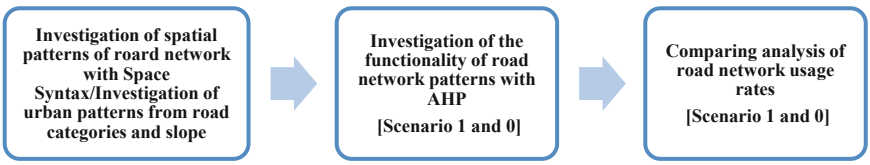

Fig. 2. Study's Conceptual Framework

3 Theory, Methodology and Calculations

3.1 Space Syntax

Urban environment tends to have a diverse morphology starting from neighborhood level to small and metropolitan cities, arising the need to analyze the spatial relationships that develop between urban space and the people living and moving within, making societies spatial phenomena [19]. As a result, human activities affect the shape and pattern of urban space, having consequently urban space affecting people's behavior and their movement and making spatial analysis an important tool in analyzing, designing, maintaining and changing urban functionality [20]. The potential connection of spatial analyses with external spatial factors, like population and land use, could make them more intricate and extend in scale allowing the research of more complex urban systems [20, 21]. Space Syntax theory and methods are based on analyzing how the network is spatially connected and interrelated within the urban space and how its spatial functionality is configured concerning human behavior and movement (pedestrian and vehicular) [22].

There are three potential methods of analyzing the urban space in Space Syntax theory, topological, metric and geometrical (angular) analysis. Every one of the foresaid analyses measures the shortest possible distance through road network's streets between one space to the participating others in the examined urban space [19].

In this paper, Angular Analysis is used in order to analyze the study area's road network. Angular Analysis defines the analysis that every road segment is calculated based on the angle that is connected to every other segment of the system. Thus, Angular Analysis quantifies the possibility of participation of each segment of the network to a possible route and visualizes the human movement and potential route choice within the urban environment [20]. The most commonly used syntactic properties from Space Syntax methodology are Angular Choice, Angular Integration and Connectivity. Angular Choice defines and quantifies the "through movement" in a road network's route, namely the possibility of a road segment to be used in a route. Furthermore, Angular Integration depicts and measures the integration of road segments, the "to movement" in a road network's route, namely the accessibility potential of a road segment through a route [19, 20, 22]. As for Connectivity, it defines the count of direct connections between neighboring street segments. High and low connectivity appears in segments with many and few connections, respectively [20]. Parts of the road network with high connectivity are connected with increased people's mobility and activities [12, 22]. The scale level, distance and radius are important factors in urban analyses. As for distance and radius, they are three alternatives, topological, metric and geometrical distance and radius, similarly defined as Angular Analysis. Metric radius is used in this paper, as it is the mostly used alternative in researches [20]. There are two scales, Local and Global, with Local scales referring to pedestrian movements until 800 m and related to neighborhood patterns and Global Scales referring to vehicular movement, radii farther than 1000 m and related to city and metropolitan patterns [20].

Angular Choice and Integration is used in this Space Syntax analysis and there are seven different radii for Local and Global scales that being examined (200 m, 400 m, 800 m, 1200 m, 1600 m, 3200 m and 6000 m). PST plugin in QGIS is used for the analysis of the chosen radii for Angular Choice and Integration as well as the analysis of hydrants'

service areas and accessibility within the study area. The appropriate preparation and topological examination of the network is conducted beforehand in order to assure the accuracy of the research. Figure 3 shows the Space Syntax's framework.

Angular Analysis. Angular Analysis is conducted to study the syntactic pattern through the chosen syntactic properties, Angular Choice and Angular Integration, and provides the relative maps for the examined radii for Local and Global scales. Indicative maps are adduced in Fig. 4 and depict both syntactic properties. In Local scale radii (200 m, 400 m, 800 m), syntactic pattern's spatial configuration gives more emphasis on local street segments. Provided that Local scale refers to pedestrian movement, the neighboring aspect of the road network is appointed for both Choice and Integration, creating local centers within the urban space which appear to have increased mobility and functionality. Apparent distinction among the syntactic patterns for both Choice and Integration is mainly seen between 200 m and 1200 m radii. In Global scale radii (1200 m, 1600 m, 3200 m and 6000 m), there is different configuration in the syntactic patterns considering the fact that these radii are referring to vehicular movement. In Angular Choice, the emphasis is moved to the main road segments of the network which are extended to the whole study area. The configuration of the syntactic pattern shows the movement through the highways of the network connecting distant districts of the study area. In Angular Integration on the other hand, the syntactic pattern appears to have local centres, likewise in local scale radii. However, the centres are configured more extended and refer to the global scale. Road network's connectivity is not developed evenly throughout the whole study area in all syntactic patterns for both syntactic properties. This fact leads to limited mobility and functionality in Angular Choice syntactic patterns, whereas in Angular Integration patterns the centres appear disconnected with one another amplifying their local character and leading to the intermediate study area to have low integration, thus low functionality and usability.

Hydrants Service Areas and Accessibility. The hydrants as firefighting means are used in order to investigate the extension of service areas within the study area. Figure 4 shows indicative maps about the distribution of hydrants within the service areas. The first observation is that there are hydrant gathering centres in similar areas within the network for all the radii. However, as moving from local scale to global scale, the centres seem to appear expanded in size but also in number of connected hydrants serving larger areas in the network. The expansion of the service areas reflects to the connection between the centres and their location relates to dense urban space and road network.

3.2 Analytical Hierarchy Process (AHP)

Multi-Decision Making Methods (MCDM) constitute a wide scope of methods related to the definition of the most effective solution to a problem among a set of alternatives. Analytical Hierarchy Process (AHP), developed by Thomas L. Saaty [23], is used in current paper in order to investigate the two scenarios' spatial patterns (Syntactic Pattern – Scenario 1, Urban Pattern - Scenario 0) functionality combined with fire related factors and analyze their impact to urban configuration in cases of emergency. AHP is one of the most used methods for scientific purposes since it is useful and leads to

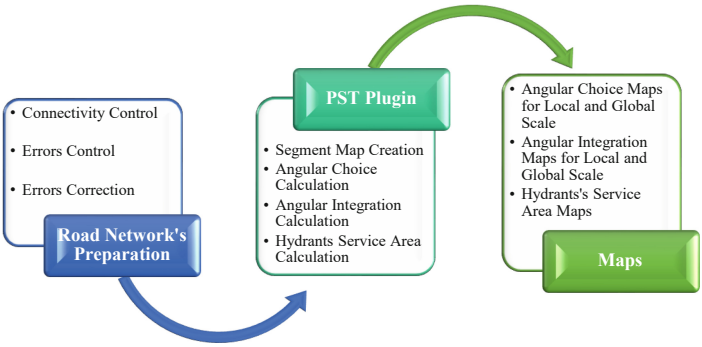

Fig. 3. Space Syntax's Methodology

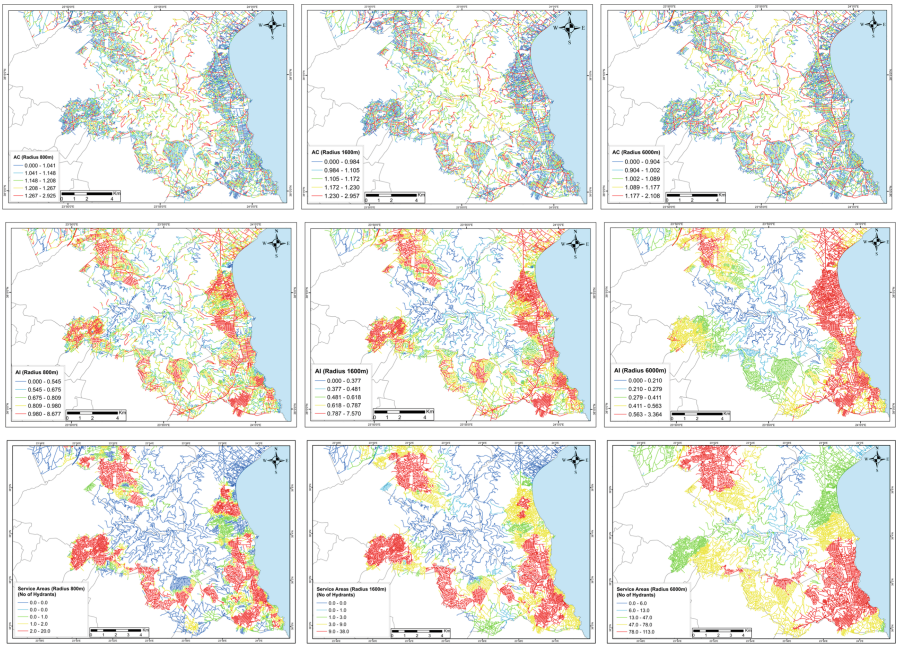

Fig. 4. Angular Choice, Angular Integration and Hydrants' Service Areas Maps (Indicative Radii 800 m, 1600 m and 6000 m)

problem solving results through the evaluation of criteria and studying of alternatives [13]. In a general way, it simplifies the problem in order to examine the relationship between cause and effect [24].

In order to complete AHP, there are four stages need to be followed. On the first stage, the researcher analyzes the problem, constructs the hierarchy leading to the alternative solutions and finalizes the criteria and subcriteria that are going to be used in the process. Furthermore, the criteria are calibrated in a unified scale (from 1 to 5 or 1 to 10) [13]. On second stage, the pairwise comparison is executed in order to rank the criteria and

subcriteria's priority using a ranking scale from 1 to 9 to evaluate their importance in the process (Table 1) [13, 25, 26]. The following third stage calculates the weight of every criterion/subcriterion, which provides the contribution rate of each one of them in the final result regarding problem's solution [25, 27].

On the fourth stage, the consistency of the whole process is examined in order to validate the necessary credence and accuracy and allow the conclusion of the process. The calculation of Consistency Ratio (CR) provides the consistency check of pairwise comparisons between the criteria and subcriteria. In order to proceed with the process, the CR should be not greater than 0.10, as it is indicated from the AHP. If not, the comparison should be revised until the CR is 0.10 (10%). However, for the CR to be evaluated, the Consistency Index (CI) calculations precedes. CR and CI equations are given in Eqs. (1) and (2) [13, 25].

$$CR = \frac{CI}{CR} < 0.1 \sim 10\% \tag{1}$$

$$CI = \frac{\lambda Max - n}{n - 1} \tag{2}$$

Therefore, as CI is the Consistency Index, λmax is defined as maximum eigenvalue, n the number of participant criteria/subcriteria and RI is the Random Consistency Index which is based on the number of the participant criteria/subcriteria in the study. This study uses the scale as it is provided from Vargas [25]. This study uses AHP as explorative tool in order to analyze the road network's functionality and safe movement in emergency cases for the two scenarios. Aiming to include factors related to wildfires into road network's examination, the papers of Sivrikaya and Küçük and Sari [13, 14] are studied in order to choose the appropriate criteria and subcriteria to integrate in AHP process. The final maps are created from the AHP and show area's wildfire risk assessment, however the road network's functionality and the pattern's spatial configuration in emergency cases is analyzed through the maps. As for the AHP process, it is concluded in three separate stages with different number of participant subcriteria in each one of them.

Criteria and Subcriteria Analysis. The criteria/subcriteria are closely related to wildfires in association with road network's configuration. Aiming to an extend analysis of road network's functionality in combination with fire risk factors, AHP is conducted in three stages, where three criteria are used for the First Stage, whereas on Second and Third Stage are used five and four subcriteria respectively. The three main criteria are Topography, Environment and Urban Space. The eleven subcriteria are Elevation, Slope, Aspect, Temperature, Wind Speed, Dominant Leaf Type (DLT), Tree Cover Density (TCD), Population Density, Distance to Settlements, Land Use and Road Network and are calibrated in a scale between 1 to 10 (Table 2). The scores are showing the fire danger with low scores showing low fire danger and high score showing high danger respectively.

Topography is closely related with fire ignition, speed and spread. Slope as a factor plays a crucial part in fire spread due to the fact that fire speed is increased as long as the slope rises contributing to the fire spread [13, 14]. On the other hand, elevation combined with climatic factors as temperature, humidity and wind, effects immensely fire ignition

Table 1. Relative Priorities (Pairwise Comparison) - T. L. Saaty - [13]

Priority Scale	Relations	Explanation
1	Equal Importance	Two activities contribute equally
3	Moderate Importance	One activity is slightly favored over another
5	Strong Importance	One activity is strongly favored over another
7	Very Strong Importance	One activity is very strongly favored over another
9	Extreme Importance	One activity is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate Values	When compromise is needed

danger and spread. Given that aspect of the area and forest play an important role in fire risk and ignition, study area is located in the North hemisphere making south, southern and southwestern aspects more susceptible to fire incidents than northern aspects due to the fact that they receive higher amounts of sunlight [13, 14].

The criterion about Environment refers to the subcriteria of temperature, wind speed, Dominant Leaf Type (DLT) and Tree Cover Density (TCD). More specifically, high temperatures as well as gusty winds result in dry material creating favorable conditions for fire ignition and spread [13, 14]. In this study only temperature and wind speed are participate in the subcriteria. Environmental studies related to fire risk has shown that forest and vegetation type are closely related to fire ignition and evolution in an area. Vegetation is generally a combustible material, however parameters such as its density and moisture have a decisive effect on the speed of spread. Furthermore, leaf type determines vegetation's reaction. Coniferous trees, given their leaf type and the fact that pine needles create a litter layer around trees' trunk which is extremely flammable, are more prone to fire risk than broad-leaved trees whose leafage are moister and have different ignition rate [13, 14].

Urban Space criterion includes the subcriteria of Population Density, Distance to Settlements, Land Use and Road Network. All the above subcriteria are related to urban space, human movement and wildfires. Forests areas near settlements, agricultural lands and areas related to human activities are associated with fire risk. Respectively, population density is strongly connected with fire risk as well [13, 14]. Road network's configuration in Scenarios 1 and 0 is the main variable that examined. Thus, an individual subcriterion is made for every scenario in order to investigate the syntactic and urban patterns that are configured for the two scenarios.

Road Network Subcriteria. For the Scenario 1, according to Yousuf Reja's [28] methodological framework, Angular Choice is chosen for the syntactic pattern's examination for the seven chosen radii. Specifically, only the segments with High Angular Choice values are extracted from every radius and unified in three general scales, Local Scale including 200 m, 400 m and 800 m, Intermediate Scale including 1200 m and 1600 m and Global Scale including 3200 m and 6000 m. Statistical procedures and experiments are conducted for the calculation of the final percentage of the road network's segments

that is going to be extracted. We assume that the 86% of road segments is 3 Standard Deviation (3*S.D.) of the mean in a normal distribution, the rest 14% is the percentage with the highest values that is to be extracted for every radius [28].

For Scenario 0, urban pattern's configuration is investigated from two points of view. The first one is how road network's pattern is configured based on Geofabrik's classification [18] for road network's categories, whereas the second one is based on the classification of road network's segments according to the slope that every segment is on. Table 2 contains the participant factors' calibration in order to create the criteria and subcriteria for the execution of AHP process. Tables 3 and 4 indicate the weights and the proceeding CR of every stage of the process. Furthermore, criteria and subcriteria maps are given in Figs. 5 and 6.

Table 2. Fire Risk Factors

	LOW DANGER								*HIGH DANGER*	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
DLT	No tree				Broad Leaf					Coniferous
TCD	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Aspect	N	NE, NW	E		Flat	SE, W		S		SW
Slope (%)	0-5			5-15		15-25		25-35		>35
Elevation (m)	0-100		100-200		200-400		400-800			>800
Temperature (^{O}C)	25.5-26.0	26.0-26.5	26.5-27.0	27.0-27.5	27.5-28.0	28.0-28.5	28.5- 29.0	29.0-29.5	29.5-30.0	>30.0
Wind Speed (m/s)	<2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	>6.5
Urban Atlas	Water/ Wetlands		Urban Areas			Agricultural Areas				Forests
Distance from Settlements (m)	0-250			250-500		500-1000		1000-5000		>5000
Pop. Density (No)	0-1000		1001-5000		5001-10000		10001-15000		>15000	
RN_AC			Global		Intermediate			Local		
RN_Categories		Major Roads		Highway links	Minor Roads		Very small roads		Paths unsuitable for cars	Dead-Ends
RN_Slopes (%)	0-5			5-15		15-25		25-35		>35

Pearson's Correlation. In Statistics, Correlation is defined as the existing and connecting relationship between variables. In this study, Pearson's Correlation is used to analyze and correlate the functionality among the two scenarios' patterns, as it is defined as r and is used for the measurement of the linear correlation between two variables with normal distributions. The value of r ranges between -1 and 1 ($-1 \leq r \leq +1$) and shows the relative correlation between the examined variables [29].

Table 3. AHP's First Stage Criteria/Subcriteria's Weights

Criterion	*CR*	*Weight*	*Subcriterion*	*CR*	*Weight*
Topography	0.047725	0.11	*Elevation*	0.023496	0.10
			Slope		0.65
			Aspect		0.25
Environment		0.63	*Temperature*	0.049974	0.1443
			Wind Speed		0.4928
			DLT		0.2834
			TCD		0.0795
Urban Space		0.26	*Population Density*	0.012150015	0.28042
			Distance of Settlements		0.07453
			Road Network		0.36353
			Land Use		0.28152

Table 4. AHP's Second and Third Stage Subcriteria's Weights

AHP's Second Stage			*AHP's Third Stage*		
Subcriterion	*CR*	*Weight*	*Subcriterion*	*CR*	*Weight*
Road Network	0.042247	0.3834	*Road Network*	0.023127	0.415
Wind Speed		0.2831	*Wind Speed*		0.299
Slope		0.1770	*Slope*		0.187
DLT		0.1015	*DLT*		0.099
Population Density		0.0549			

4 Results and Discussion

4.1 Syntactic Configuration Mapping

Syntactic Pattern's (Scenario 1) functionality and usability is examined through High Angular Choice and mapping fire risk's configuration of the study area. Figure 7 shows the final fire risk maps for the three stages. The depiction follows the Space Syntax Theory's color palette making the comparison and association between fire risk and area's spatial configuration patterns more observable. In all three stages, it is noticeable that areas with low fire risk values are located along the seaside area leaving areas with higher elevation and slope with increased fire risk values.

As for road network's functionality and usability, they are closely related to low fire risk values indicating that in those areas road network's pattern appears to have increasing functionality favoring human movement. The functionality's configuration appears to match the Angular Choice maps (Fig. 4). However, road network appears

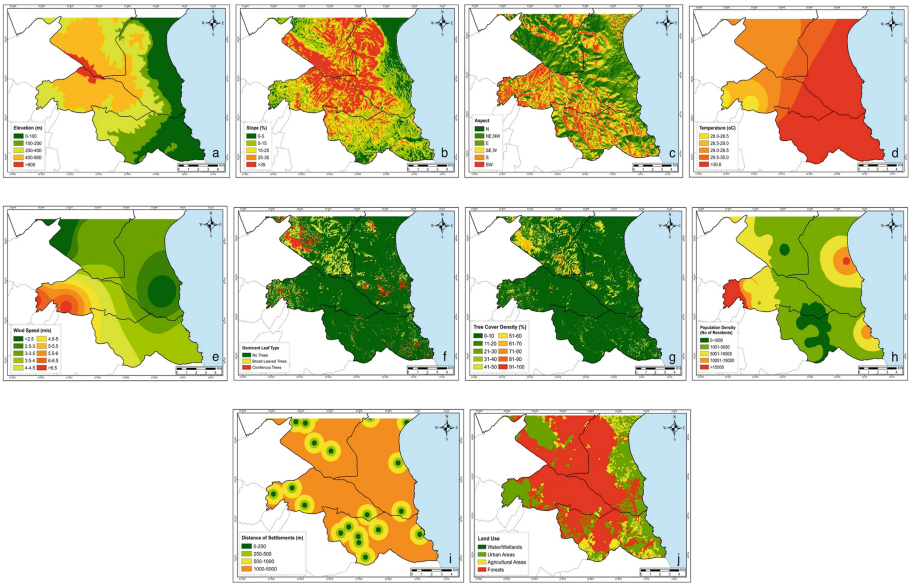

Fig. 5. AHP's Subcriteria Maps: a) Elevation, b) Slope, c) Aspect, d) Temperature, e) Wind Speed, f) Dominant Leaf Type, g) Tree Cover Density, h) Population Density, i) Distance from Settlements and j) Land Use

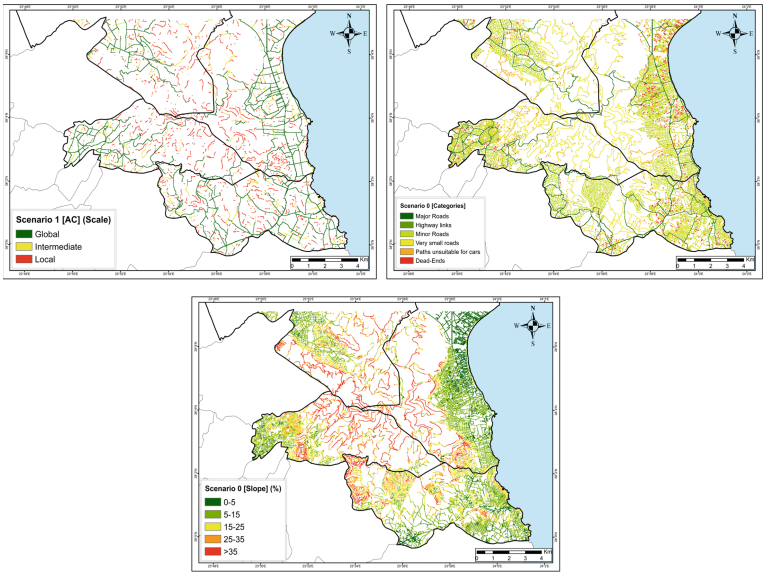

Fig. 6. Road Network's Scenario 1 and 0 Subcriteria

to have limited connectivity within leaving areas disconnected. Local street segments mostly appear disconnected from the main road network forwarding the movement in major roads and inside dense urban space indicating the road network's percentage that is most likely to be used from the population and the areas that is likely to be overcrowded.

4.2 Urban Configuration Mapping

Urban Pattern's (Scenario 0) functionality and usability is examined through road network's categories and road slope, as it was mentioned on the scenarios' analysis. Figure 7 shows the final fire risk maps for the three stages for Scenario 0. As in Scenario's 1 maps, the depiction follows the Space Syntax Theory's color palette. The first observation is that in Scenario 0 maps the road network appears to be connected and available for use in full capacity in contrast with Scenario 1 maps. As in Scenario 1, the general coastal area in Scenario 0 maps appears to have low fire risk values indicating that the functionality and usability appear to be increased favoring the movement in these urban areas, whereas mountainous areas have limited functionality and mobility because of high fire risk values. However, on road categories' maps a lowering functionality in seaside urban area is detected as the study moves through the stages by indicating the dead-end road segments with high fire risk values shifting the human movement in major roads. On road slope maps, slope mainly configures the urban pattern with low slope areas appear to have low fire risk and high functionality, whereas areas with high slope appear to

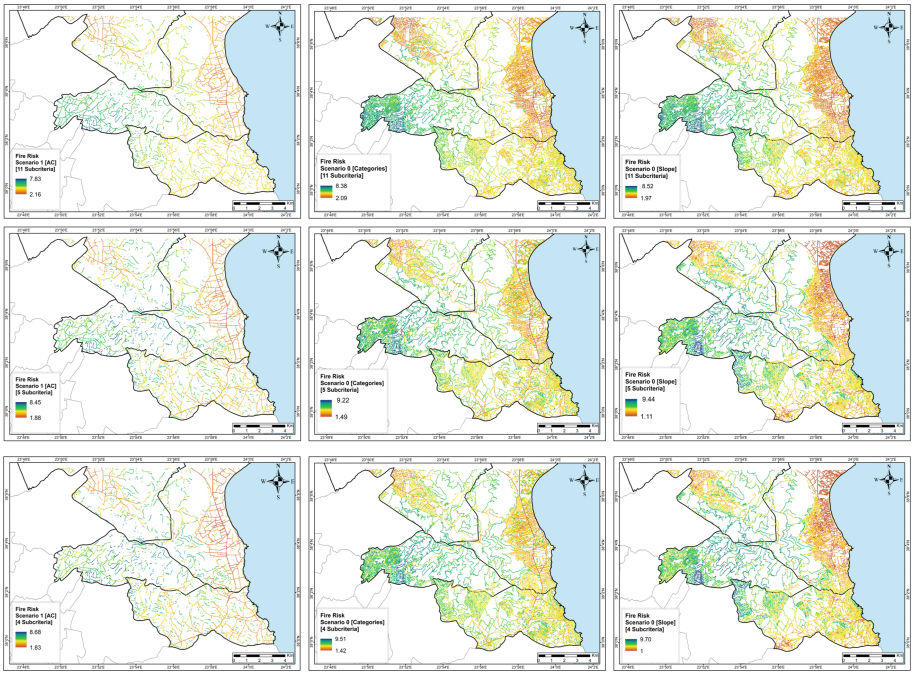

Fig. 7. Final Maps Scenarios 1 and 0 – First (1st line), Second (2nd line) and Third Stage (3rd line)

have low functionality and usability. The progress of the stages indicates through the maps that there are high slope areas in the seaside lowering the area's functionality and limiting the movement in these locations.

Pearson's Correlation Analysis. The comparative analysis is done between the Syntactic Pattern (Scenario 1) and the Urban Pattern (Scenario 0) and is consisted of two parts. The first part analyzes and compares the patterns' functionality between High Angular Choice and the Categories. The second part analyzes and compares the patterns' functionality but as it configures after the AHP's Third Stage.

First Part of Analysis. In order to simplify the calculations, Table 5 shows the classification between the two pattern's functionality. The fire risk calibration scale for the subcriteria is adjusted (0 to 10) and used for the functionality's classification, with 0 meaning low fire risk and high functionality and 10 meaning high fire risk and low functionality respectively. Pearson's Correlation coefficient is calculated to be 0.05, indicating that there is no correlation between the two scenarios' functionality.

Second Part of Analysis. As in first part, the same classification for functionality is used in order to compare and correlate the two scenarios' functionality after the AHP's Third Stage. Table 6 shows functionality's distribution between the two scenarios while Pearson's Correlation coefficient is calculated to be 0.94. Coefficient's value indicates that there is perfect positive linear correlation between the variables, thus as Scenario's 1 functionality increases so does Scenario's 0.

Table 5. Correlation of the Patterns' Functionality (Before AHP Process)

Functionality	AC (No of Segm.)	AC %	Categories (No of Segm.)	Categories %
0–2 [Very High]	0	0%	9909	12.5%
2–4 [High]	13759	45%	260	0%
4–6 [Moderate]	5215	17%	28949	36.5%
6–8 [Low]	11773	38%	29842	38%
8–10 [Very Low]	0	0%	10391	13%
Total	**30747**	**100%**	**79351**	**100%**

In a comparison of Pearson's correlation coefficient before and after AHP process, an increase is observed. Figure 8 shows the combined fire risk map for the two Scenarios after the third stage of AHP.

Table 6. Functionality's Distribution for Scenarios 1 and 0 (After AHP Process - Third Stage)

Functionality	AC (No of Segm.)	AC %	Categories (No of Segm.)	Categories %
0–2 [Very High]	309	1.3%	799	1.2%
2–4 [High]	11030	45.1%	22302	34.8%
4–6 [Moderate]	9727	39.8%	33220	51.9%
6–8 [Low]	3345	13.7%	7490	11.7%
8–10 [Very Low]	34	0.1%	255	0.4%
Total	**24445**	**100.0%**	**64066**	**100.0%**

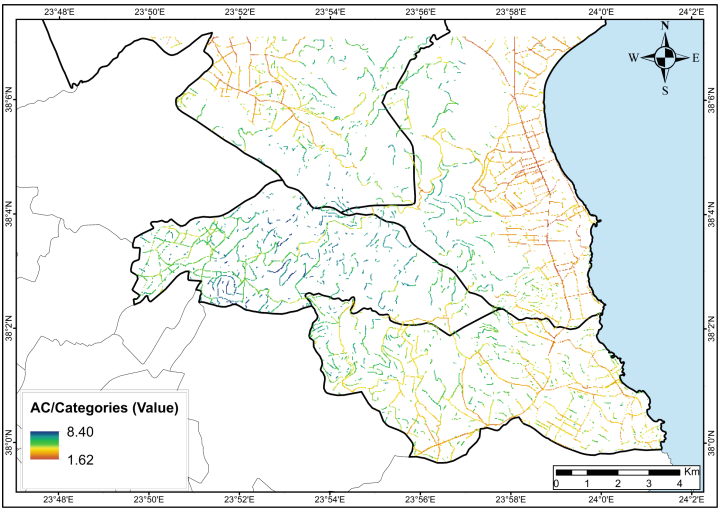

Fig. 8. Combined Fire Risk map for Scenario 1 and 0 (Third Stage)

5 Conclusion

This paper follows a scenario-based methodology in order to investigate the Space Syntax Theory and its potential integration in methodological plans about prevention, mitigation and management in emergency cases, thus its participation in urban planning related to safe movement within urban environment. A comparative analysis between two spatial configuration Scenarios was conducted. Scenario 1 examined the configuration of the syntactic pattern with Angular Choice and Scenario 0 examined the configuration of urban pattern as it occurred from road categories and road slope. Space Syntax's particular characteristics were associated with AHP method in order to examine and compare the functionality and usability of the two scenarios' patterns. Subcriteria and criteria closely related to wildfires were added to the method.

The AHP method was conducted in three stages with a different number of participant subcriteria in each one. Analyzing all the maps that were created from the procedure, this study concludes that Space Syntax theory and techniques can be important tools in urban design. High Angular Choice, provided that it depicted the road segments with the highest angular choice values, pointed out the percentage of the road network that has the higher possibility to be used by people. This percentage was lesser in comparison with the Scenario's 0 pattern which showed that all road network is potentially available for use. Considering the aftermath of the wildfire in Mati, the congestion and high slopes in seaside area leading to people's trapping and casualties, Scenario's 1 final maps seem to match with the references about the conditions that prevailed that day and depicted the spatial configuration of study area's urban space. Therefore, Space Syntax approach depicts a perspective of human movement within urban environment through spatial configuration which can provide important information and potential solutions in urban planning in order to prepare and prevent future consequences from future disaster incidents and design urban movement with the view to safe movement and evacuation if needed.

Positive correlation between the two scenarios' patterns after the AHP method leads to the assumption that the integration of quantitative variables into Scenario's 0 qualitative analysis leads to an increasing correlation between the patterns. Thus, Space Syntax is a technique that can be combined with multiple variables and provide an outcome, however a further research is needed for an extended analysis.

In conclusion, a number of potential improvements could be applied in future relative researches aiming to upgrade the present study. Provided that road network is the main factor, the integration of more features like the road width could allow a more detailed analysis and be a configural factor for the scenarios. An extended analysis of the area's elevation can provide information about the correlation between road network's configuration and people's movement in emergency cases. Given that technology is an important aspect in daily life, the creation of an application for smartphones as a preventative tool which is going to provide safe routes based on user's location through GPS and live feedback for the road networks' situation can be a useful measure in disaster management.

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