The Effect of Spatial Configuration on the Movement Distribution Behavior

The Case Study of Constantine Old Town (Algeria)

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Abstract-This study examines the correlation between spatial configuration and movement behavior within the traditional urban fabric of Constantine city. The distribution of pedestrian movement was modeled in relation to the syntactic measures of street networks. The results showed a significant correlation between pedestrian volume with integration and choice measures at the global scale (Rn), however, the local scale (R3) did not capture the variance and the presence of the movement. The measures of connectivity that are used to describe the density of street connections also revealed a weak association with the presence of people within the dense traditional layout of the research area. The results support the previous findings of space syntax theory, asserting the important role of the street network structure in assessing the configurational accessibility of a given spatial layout. However, we do not assert its exclusive role in determining the natural-movement patterns. Therefore, consideration should be given to more external indicators, like the interaction with land use and socioeconomic activities. We conclude that examining the network radius-based attributes of street configuration can provide a clear understanding of spatial variations in pedestrian activity within multi-scale walkable areas, which helps planners improve the livability of the city by designing more friendly walkable streets.

Keywords-movement; spatial configuration; walking; pedestrian volume; space syntax

I. INTRODUCTION

Walking is a freely and accessible mode of transportation. It has become a field with a great interest in socially engaged communities. Designing walkable places is gaining more attention for their positive outcomes related to sustainability, social life, health, and economy. Walkability has become one of the most investigated realms, not only in architecture and urban design, but also in the fields of public health and transportation [1]. Because of the growing knowledge of the walking advantages, the concept "walkable" has been newly labeled as encouraging physical activity [2]. Walkability is being evaluated as an "environmental justice issue" and it can be a good indicator of the physical quality of urban areas. As a result, there is an increasing demand to understand the complexity behind the interaction between the different conditions of the built environment and the walking behavior of inhabitants [4-8]. Disciplines from various scientific fields, such as urban design and planning, architecture, traffic management, and public health are taking different approaches and implementing appropriate techniques to capture how people walk in the urban environment.

The association between the spatial configuration and pedestrian behavior at the street level has been investigated mostly within the conceptual and methodological framework of the space syntax approach [9-16]. This theoretical framework is based on a topological-visual analysis of the street network called the axial map, defined as the smallest set of straight axial lines covering the urban street network [12, 13, 17]. These studies have been conducted with respect to the concept of "natural movement," which means that the configuration of the street network determines extensively the distribution of movement within that network independently of other variables [17-20].

The prevalent assumption behind pedestrian volume modeling is that individuals tend to make their trips as short as possible by choosing a short trip length [21]. Therefore, street centrality indices are the most widely used measures to evaluate "natural movement." It is the calculation of the shortest paths between all the network's origin-destination pairs. Based on axial or segment lines, the centrality measures are defined mainly by two main values: first, the closeness of a given axial line to all other axial lines within the network and second, the degree to which a given axial line acts as an intermediary path within the network, or the so-called betweenness. Pedestrian volume models using the space syntax method through the integration level of the axial lines have revealed a squared correlation coefficient (R^2) ranging from 0.55 to 0.75 in London [13] and Dutch urban areas [22]. Nevertheless, there is divergence regarding the dominant role of the street network centrality measures in evaluating pedestrian movement activity, different movement volume models that were applied in different cities investigated other explanatory variables like land-use layout, which is described

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as a non-negligible factor that has a crucial effect on pedestrian movement in urban space [23-26]. Other studies combined land use and spatial variables to explore the extent the built environment influences pedestrian patterns [1, 27-29]. These studies found that spatial configuration has a significantly greater correlation than land use does to pedestrian movement, but the possibility of combining them may produce greater results in capturing pedestrian movement volume [30]. The physical dimension of the street network can also influence the amount and presence of pedestrians. Many studies in this stream have emphasized an association with the sidewalk width, which tends to regulate the number of pedestrians on a given road [31, 32]. From the above, we can say that whatever the methodological framework used to evaluate pedestrian distribution, there is a consensus in the body of literature about the own social logic of space that affects human behavior, such as pedestrian movement from one place to another [33]. Therefore, a clear understanding of the precise nature of the relationship between spatial configuration and movement is more than necessary for better design and planning.

To address how people move in a dense urban area and by adopting appropriate measures which are sensitive to the spatial structure of street networks, we will explore in this study the movement behavior patterns related to syntactic attributes of Constantine's old town. We will attempt to clarify the extent the street network design affects pedestrian distribution movement at the scale of the town and neighborhoods. In doing so, we tend to enrich the body of literature that scrutinizes the aspects of the relationship that link movement behavior to spatial configuration as the long-term framework that influences the evolution of urban function.

II. METHODOLOGY

A. Study Area

Our research area is the old town of Constantine City in Algeria. It is the city's earliest settlement. It was founded on a rock at an altitude of 700 meters, surrounded by a cliff at a depth of 200 meters. The urban form is a mixture of different civilizations (Roman, Ottoman, and colonial). Each of them has left an imprint on the overall layout of the city. Its street network is mainly made up of an organic grid penetrated by long rectilinear commercial roads. At the back of the town, we find the residential neighborhoods as a compact fabric with winding and straight Derbs, or alleys, to allow transitioning from private to public spaces.

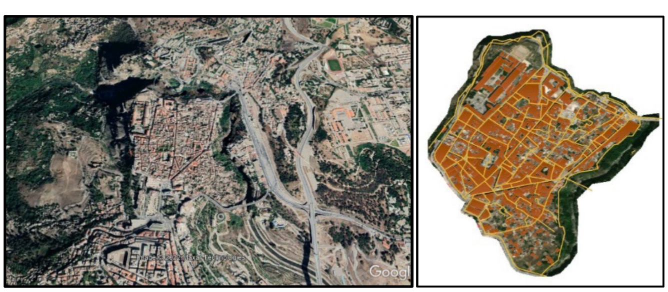

Fig. 1. The old town's street network in the context of Constantine city (© 2022 CNES/Airbus, Maxar Technologies).

Like in the Arab Medina configuration, the old town has busy roads and quiet parts [34]. It has also traditional markets, where artisans keep their workshops half inside, half on the street. A big part of the old town is car-free, which attracts daily familiar and unfamiliar visitors. The traditional town keeps confirming Constantine's urban and historical identity due to its outstanding location and unique spatial shape. Based on its specific urban network, we will attempt to investigate the walking behavior in such a complex fabric by exploring the extent this network affects the amount and the distribution of pedestrian movement.

B. Research Method

To investigate the effect of spatial layout configuration on pedestrian movement, we used the space syntax method by establishing an axial map based on the street network as demonstrated in Figure 2. An axial map is a set of axial lines that refers to an abstract representation of the street network. Each axial line represents the fewest and longest visible line of the street. It is equal to the smallest human-perceivable unit of space [21]. The next step was to generate a space syntax analysis by using Depth Map software (X) with the Space Syntax Toolkit, see Figures 2-4. Depth Map is a multi-platform software developed to perform multiple spatial network analyses in order to explore the complexity of social behavior in a given built environment. Normally, the preliminary results of the axial analysis will show how urban space is structured and how human behavior can be predicted. According to space syntax theory, there is a strong and significant relationship between spatial layout and movement patterns, or what we call "natural movement," which means that spatial configuration orients and regulates the presence and the distribution of movement in a given open space without the intervention of any other factors [11]. Based on this assumption, we will investigate the relationship between spatial pattern attributes and movement patterns in our research area. Through this work, we would like to assert that our objective is not to test the already well established Space Syntax principles, but rather to seek a new understanding of natural movement in different urban areas with different geographically and socially built environments.

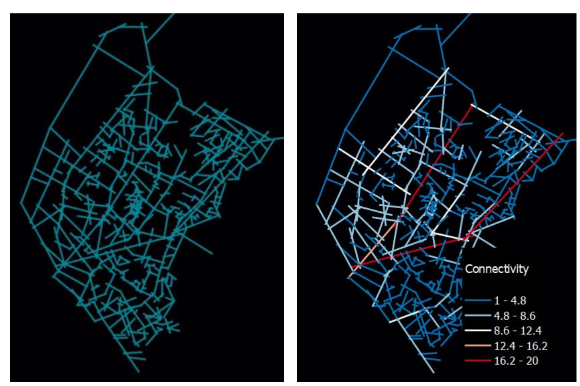

Fig. 2. Axial map (left) and connectivity map (right).

C. Data Collection

To realize our pedestrian movement model, we have used the gate count observation technique, which consists of counting the average number of pedestrians per hour on a given axis of the spatial network. The measurement locations in the research area are selected according to the degree of the people's presence and use of street space, as shown in Figure 5. The street sample represents different syntactic measures and ranges from busy to lightly used. The counting was applied to specific points in each street axis, where an imaginary crossing line was drawn virtually from these points to the other side of the street space. The number of the moving pedestrians was recorded in a prepared table to be further analyzed. The counting was carried out for 5 minutes every hour for 6 hours (9-10, 10-11, 11-12, 2-3, 3-4, 4-5) at each location on major streets, and for 10 minutes every hour on minor streets to reduce the variance of movement values between different types of roads, see Figure 9. The counting was done simultaneously for all survey points on each street. The observations took place on sunny weekdays between 9 am and 5 pm. These times are chosen for two reasons: the operability of commercial activity during those time periods and because pedestrian traffic increases during rush hours, especially at the end of the workday and after school.

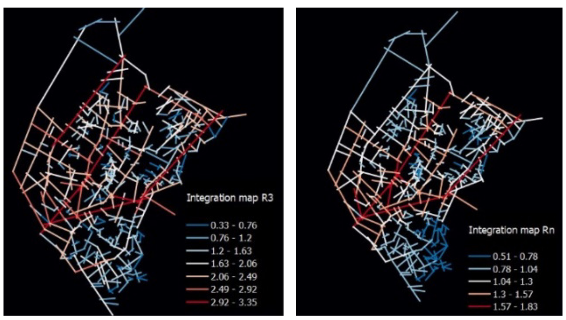

Fig. 3. Integration_(R3) map (left) and Integration_(Rn) map (right).

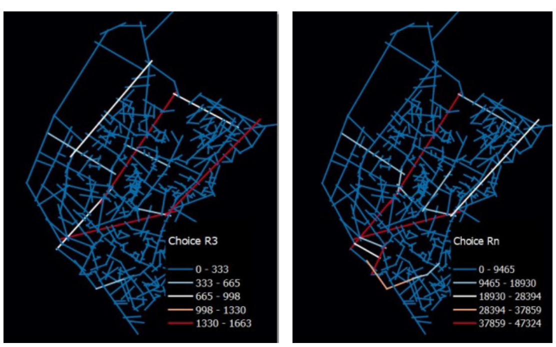

Fig. 4. Choice_(R3) map (left) and Choice_(Rn) map (right).

The entire research data set included 20 road segments where pedestrian movement volume was sampled in different parts of the town, namely: La Kasbah and Souika neighborhoods, La Rue De France street, Etrik Edjdida Street, Zighoud Youcef street, Eressif, and Souk Elasser sub-neighborhoods. The 20 sampled street segments were encoded according to the depth map output reference as the following: (26, 32, 34, 36, 38, 39, 43, 62, 80, 145, 174, 188, 227, 287, 289, 296, 308, 382, 383), see Figure 7. In order to explore the relationship between pedestrian movement and space configuration, an assumption of correlation was established between the two variables by using the outcomes of gate count observation with the syntactic attributes of the research area. The association of variables was checked through the JMP package and was visualized through the Geographical Information System (GIS).

III. RESULTS AND DISCUSSION

In order to examine the effect of spatial configuration on natural movement patterns, and after making an axial analysis of the urban network, Pearson correlation was performed to test whether there is an association between the pedestrian volume and the syntactic properties of the urban layout as shown in Table II. The results showed significant disparities in pedestrian distribution among the different streets in the research area, Figure 6 illustrates the average pedestrian volume per road section in the research areas, where we observed a higher volume of pedestrian movement in the town's major commercial streets, such as La Rue De France, Etrik Edjdida, and Eressif streets, which are characterized by a high rate of retail and shops, compared to the other streets, such as Swika, Zighoud Youcef, and La Kasbah. Figure 8 shows the distribution frequency of the average pedestrian volume per hour. This distribution can be described as heavy-tailed, in other words, most of the survey points have a low volume, while only a few survey points have a high volume of pedestrian movement. This finding is mentioned in [32, 33], which found that a minor percentage of roads have significant traffic movement, whereas their majority have low traffic volumes. Since the pedestrian movement has a heavy-tailed distribution, it was normalized by using the log function (with the natural logarithm).

Figure 10 reveals the correlations between spatial configuration variables and pedestrian movement volume distribution. The results showed that the correlation with the street connectivity variable, which is based on the number of roads connected directly to each street, is not significant (P-value = 0.43), so there is no association between the number of pedestrians and the degree of connectivity in the street network. However, the pedestrian volume variable was found to positively and strongly correlate with two spatial variables, which are the global integration (with $r = 0.799$ and $p < 0.01$) and the global choice (with $r = 0.842$ and $p < 0.01$). These two spatial variables tend to have the highest squared correlation coefficient. The correlation model explained this association at 63% for integration and 70% for choice. Surprisingly, no correlation was found between movement distribution and spatial variables at the local scale (R3), corresponding to 400 meters, which is an appropriate distance for walking. The P-value in this case is ($P = 0.433$) for integration and ($P = 0.436$), so correlation is not significant at this level.

TABLE I. DESCRIPTIVE STATISTICS OF THE STUDY VARIABLES

Variable	N	Min	Max	Mean	Std. Deviation
Choice_Rn	20	28	1663	631.75	564.227
Choice_R3	20	3	1663	481.59	564.126
Integration_Rn	20	11.525	18.320	14.131.	2.148
Integration_R3	20	2.257	33.549	21.436	9.619
Connectivity	20	3	20	9.24	5.618
Pedestrian Volume	20	383	3138	1215.24	918.610

Fig. 5. Survey points in the search area.

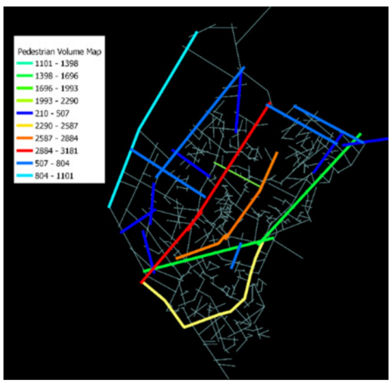

Fig. 6. The Average observed movement volume on 20 axes of the research area.

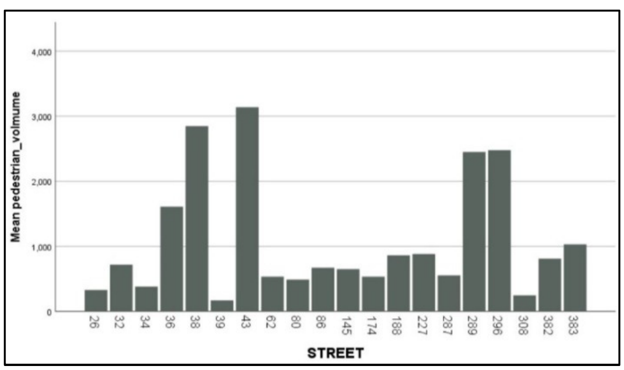

Fig. 7. The average pedestrian movement volume per street section.

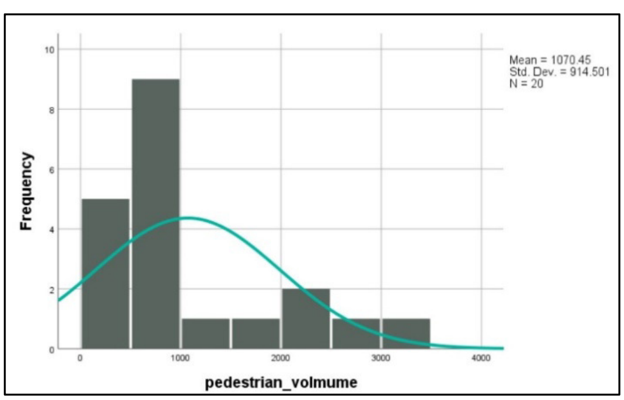

Fig. 8. Pedestrian volume frequency.

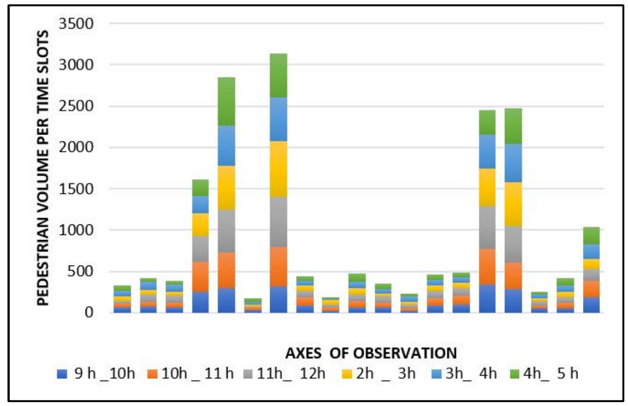

Fig. 9. Distribution of pedestrian volume on the six-time slots on each selected street.

TABLE II. PEARSON'S CORRELATIONS BETWEEN SPATIAL ATTRIBUTES AND PEDESTRIAN MOVEMENT VOLUME

Variable	P-value	Significance	(R)	(R^2)
Street Connectivity	0.434	Not significant	-0.436	0.190
Street Integration_Rn	0.000	Significant	0.799**	0.639
Street Integration_R3	0.433	Significant	-0.204	0.004
Steet Choice_Rn	0.000	Highly significant	0.842**	0.709
Street Choice_R3	0.434	Not significant	-0.203	0.041

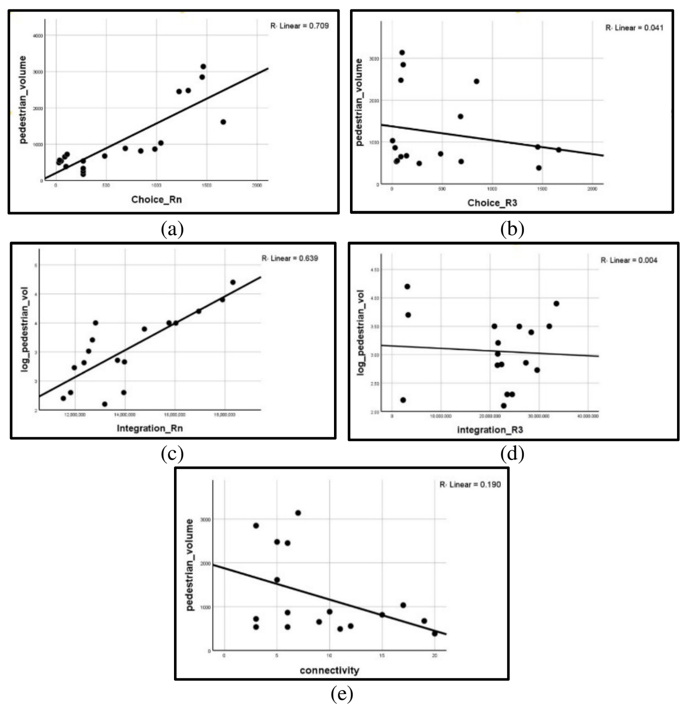

Fig. 10. Correlation of spatial variables with the average pedestrian volume per street: (a) Pedestrian volume per choice_Rn, (b) pedestrian volume per choice_R3, (c) pedestrian volume per integration_Rn, (d) pedestrian volume per integration_R3, (a) pedestrian volume per connectivity.

From the results, we conclude that the movement rate in the research area is showing a positive and significant correlation with spatial configuration only at the global scale. However, the local scale configuration cannot capture the distribution of the natural movement. The old town has the potential to attract "through-movement" through the major streets because of its central location near the active and alive colonial center. Thus, configurational accessibility could be a need for a pedestrian-friendly environment. In other words, street networks with a high degree of configurational accessibility (in our case represented by Radius (n) integration) may satisfy one or more people's requirements when they are about to walk. However, walking in the old town's local neighborhoods cannot benefit from this potential because it is seen as confusing and difficult to grasp by unfamiliar users. But in some parts of the same neighborhoods, despite the fact that the attention of users can be evaded in dense and winding roads, as in the cases of Eressif and Rahbat Essouf, which are characterized by a high level of commercial activity and handicraft shops, we can still find a high rate of pedestrians. In other parts, however, walking activity is very low, especially in Swika neighborhood, which has some local socio-cultural features. From this, we can say that part of our results goes against the natural movement theory, which stipulates the exclusive role of spatial configuration in explaining the distribution patterns of movement.

IV. CONCLUSION

In this study, we have examined the correlation between spatial configuration and pedestrian traffic volume by using the configurational accessibility of the street network in the old town of Constantine city. The results showed that pedestrian volume in main commercial streets with a high rate of choice and integration is more significant. However, some segment streets located inside the local residential neighborhoods carry weaker pedestrian traffic. It was also observed that by going inside the dense residential fabric, where the network has a tree-like structure and the integration has its lowest values, movement distribution rates are significantly high, especially throughout the roads having commercial activities and craft shops as in Eressif, Rahbat Essouf, and a big part of Eswika neighborhood. Hence, we deduced that spatial configuration is an important but not sufficient parameter to capture movement behavior in all types and levels of configuration. In residential neighborhoods, for instance, walking depends more on previous experiences for wayfinding than on the street network configuration itself. However, movement in major business areas is generally captured by the spatial network configuration itself. These results do not totally agree with Hillier's to-movement principle, asserting the independent role of the street network design in explaining movement behavior. For that reason, consideration should be given to the correlation of more external indicators as the interaction between land use and population density, which will be investigated in further research. Finally, it can be said that examining the movement distribution patterns of a given spatial layout can provide a clear insight into understanding the dysfunction of certain urban fabrics that can be directly linked to the inequity of walking behavior.

The current study can be a contributing factor in revising the way settlements are planned or revitalizing the existing ones by mixing land use within the segregated urban fabrics and designing streets in a way that allows safety and comfort, which will motivate walking activity, which in turn will regenerate livability.

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