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DOI
10.1007/978-3-030-87016-4_24

Publication date
2021

Document Version
Final published version

Published in
Computational Science and Its Applications – ICCSA 2021

Citation (APA)
van Nes, A. (2021). Measuring the Degree of Permeability of the Main Route Network with Angular Step Depth Analyses. In O. Gervasi, B. Murgante, S. Misra, C. Garau, I. Blečić, D. Taniar, B. O. Apduhan, A. M. Rocha, E. Tarantino, & C. M. Torre (Eds.), *Computational Science and Its Applications – ICCSA 2021: Proceedings of the 21st International Conference, Cagliari, Italy, September 13–16, 2021, Part X* (pp. 323-336). (Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); Vol. 12958 LNCS). Springer. https://doi.org/10.1007/978-3-030-87016-4_24

Measuring the Degree of Permeability of the Main Route Network with Angular Step Depth Analyses

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Abstract. In this contribution a new space syntax analyses method is presented for analysing the degree of permeability in the main route network of towns and cities. First, a presentation is given on the methodological development of the various approaches taken until the present day. Then, a description is given on how this new analysis method can be used to conduct a permeability analyses of a main route network using the DepthmapX software. Finally, this method is applied to 25 different cities around the globe. As it turns out, the method presents an objective way in which to identify the foreground network in built environments, and to measure the degree of permeability or connectivity to the background network.

Keywords: Main route network · Permeability · Foreground network · Background network · Methodological development · Space Syntax

1 Introduction

The main or primary route network in towns and cities function as the spatial armature of the built environment. These routes connect across neighbourhoods and they are vital links between the surrounding suburbs and urban centres [1]. In many ways, the main route network contributes to wayfinding in large metropolitan areas, connecting suburbs with city centres and neighbourhoods with one another. Moreover, they tend to have a fractal structure, where the main route network operates at the highest level as the overall fractal structure model [2].

There are two issues regarding the of conduction spatial analyses of main route networks. The first issue is about how to identify the network objectively. Often they can be easily identified on maps for some cities, whereas for others it becomes a rather subjective matter [3]. Therefore, throughout the years, the various angular analyses methods developed in Space Syntax since 2001 has contributed to this. The first attempts were done by Turner [4] and Dalton [5] in 2001. Refinements in calculations formulas

O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12958, pp. 323–336, 2021.
https://doi.org/10.1007/978-3-030-87016-4_24

and software improvements were done in 2005 [6, 7]. Later on, the focus on identifying the main route network was done in 2009 [3] and 2012 [8]. This network is not used to identify the through movement potentials in urban areas [8].

The second issue related to the main route network is about measuring or calculating the degree of accessibility and permeability between a neighbourhood and the network. The first attempt was used in a research project on residential burglary and space [9, 10]. Later on, the method was refined in a research project on deprived neighbourhoods in the Netherlands [11].

Applying the identification of the main route network together with degrees of permeability to their vicinity provides information on the spatial properties of the foreground network and how it is connected to the background network of various types of built environments. The purpose of this contribution is to give an objective methodological description on how to process these methods, and to show some examples of different kinds of built environments where this method is applied.

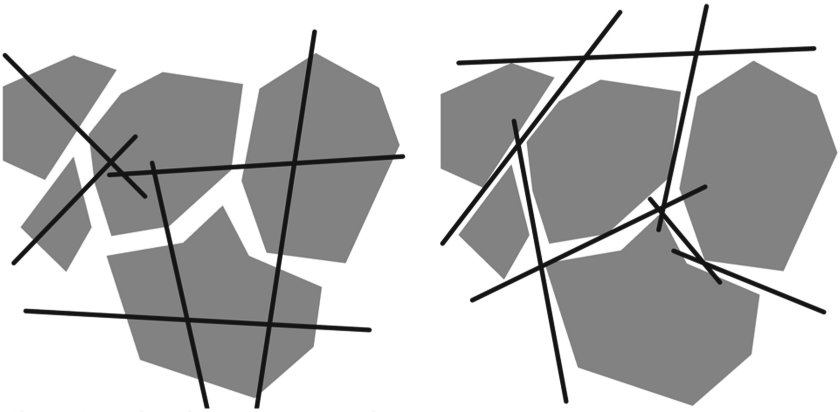
2 Methodological Development Until Present Day

The classic Space Syntax analyses with topological distance (the total number of direction changes) is a powerful tool to measure to-movement potentials. As research has shown, most people frequent streets and most shops locate along these streets with the highest spatial integration values [12–14]. Registrations of pedestrian and traffic flow data could quantitatively be correlated with the various integration values. However, the number of pedestrians and cars registered along a primary route system and the main shopping streets appears to have proportionally higher values than the spatial integration values of an axial analysis [15].

The first attempt was to apply the integration gradient method [15], based on the calculations of the local integration [16]. These calculations gave indications of the main route network and better correlations with the pedestrian flow data than the global and local axial integration analyses. Since then, some researchers drew the main route network in metropolitan areas by hand [17]. Here the main route network is named ‘the middle-scale network’ and the method is named ‘the flat city model’ [18]. This approach has been criticized to lack objectivity and predictability [3]. However, some discoveries were made regarding how these routes were connected to ost-war and prewar neighbourhoods. As it turned out, the main routes tend to go *through* post-war neighbourhoods, whereas they tend to go *around* post-war neighbourhoods.

Figure 1 shows an example of tracking the main routes for Amsterdam, where they are drawn manually and coloured in black. All streets directly connected to the main routes are coloured in dark grey, whereas the remaining streets are coloured in light grey. The degree of permeability to the neighbourhood can vary, because at that time there were no objective methods for identifying or calculating the main route network.

After the millennium, new attempts were made by adding angular weighting on the spatial relationship between the axes. Alasdair Turner developed some formulas to add angular weighting into the spatial integration analyses of the axial maps [4]. Nick Dalton made a test software, named Meanda, where the formula was applied to the axial map [5]. In 2005, the calculations were improved by breaking up the axial maps into segments.



Abstraction on how the main route network are located in the historic urban areas

Abstraction on how the main route network are located in the modern urban areas

Section of the Pijp area - an example on a historic urban area

Bijlmere area - an example on a modern urban area

Fig. 1. Abstractions on how main routes are located in traditional and modern urban areas (top) and manual registrations of the main route network with one step analyses of two areas in Amsterdam (bottom).

The segment length and a refined method of the angular weighting between segments were added into the earlier versions of the Depthmap software [6]. As the application of this method show, the main route network could now be identified through the angular total depth analyses method.

Some experiments with the total angular depth analyses using various topological radii were made by the author in 2009 for identifying the main route network [3]. However, these methods were replaced with the development of the angular choice analyses in 2012. These new calculation methods, developed by Bill Hiller, Tao Yang, and Alasdair Turner consisted of normalizing the results from the spatial calculations [8]. The authors tested out the calculations on 50 different cities around the globe. The normalised angular choice calculations (NACH) turned out to be useful to identify the main route network, and hence to show the through movement potentials in built environments.

Fig. 2. How to calculate step depth from the main routes (top) and the analyses of the step depth from main routes with the dispersal of burglaries in the Dutch town of Gouda (bottom)

The next step is to reveal the development of various approaches in which to measure the degree of permeability or accessibility from the main route network to the local street network. The calculations of the angular total depth and angular choice were used as a basis for identifying the main route network in a research project of space and crime in the two Dutch towns of Alkmaar and Gouda. Here we wanted to test out how the location of intruded homes was related to the number of direction changes from the main route network. When the main route network was identified, the number of direction changes for every street was counted manually and put into an excel file. When aggregating all the various spatial data with one another and spatial data with the burglary data in SPSS, the following was found. All spatial data on a macro and micro scale and the dispersal of burglaries were dependent on the number of direction changes from the main route network [9, 10]. The higher number of directional changes from the main route network, the higher risk of a burglary. Likewise, the higher number of direction changes from the main route network, the more building entrances are turned away from streets. Figure 2 shows the number of directional changes from the main route network and the dispersal of burglaries for a neighbourhood in Gouda.

In the first years, the step depth from the main routes were done manually. It can be a time-consuming task. Therefore, in 2013 the angular step depth from the main route network could easily be applied with the DepthmapX software. In a research project on space and social security we had to analyse 43 problem neighbourhoods. These neighbourhoods were located in 25 different cities. The position of these problem neighbourhoods in relation to the whole town or city needed to be taken into consideration [11]. At that time, experiments with DepthmapX was carried out to explore the angular choice calculations. It turned out that 90% of the problem neighbourhoods lacked permeability from the main route network [11].

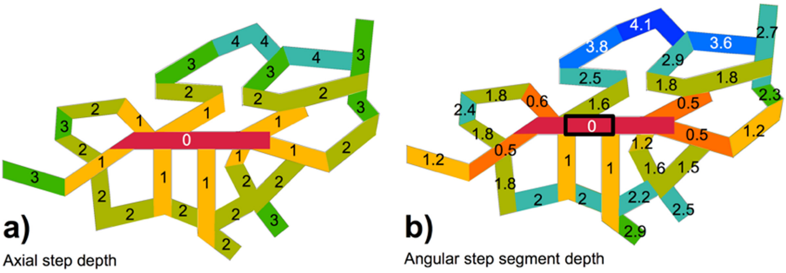

a)
Axial step depth
b)
Angular step segment depth

Fig. 3. The principle of axial a) and angular choice step depth b). (Color figure online)

Before explaining how the method is carried out, an explanation on the basics of angular analyses is needed. Figure 3 shows the principles on how axial a) and angular step depth b) is carried out from the axis and segment on level 0. For the topological step depth analyses from the axial map, each directional change has a value like 1. For example, changing direction three times from the red axis has a value of 3. The angle between the axes is not taken into account in the first image (a). In the angular step depth analyses from the segment in the second image (b) the angular weighting between the segments is take into account. The segments with a low degree of angular deviation from the red segment will receive a low value and will be like a continuous route. Segments with a sharp angular deviation have high values.

According to Hillier, a city consists of a very high number of short lines and a very low number of long lines. Often these long lines are connected to other long lines with a low number of angular deviation [7]. The angular choice analysis is thus able to highlight the continuous main route network in Depthmap X. This creates a starting point to easily calculate the degree of permeability of the main route network to the various neighbourhoods.

Figure 4 shows the angular weighting used in DepthmapX in image a. Image b shows a shallow angle of incidence, which most main routes tend to follow. Image c shows a sharp angle of incidence, which are mostly found on local streets. The basis of calculating angular relationships is the formula for calculating angular mean depth of a segment in relation to all other segments, is shown in image d. As can be seen in the j-graph (below right), the segments that have a shallow angle of incidence tend to demonstrate low values. In this way, segment A, B and C tend to be a part of the main route network due to the low degree of angular deviation.

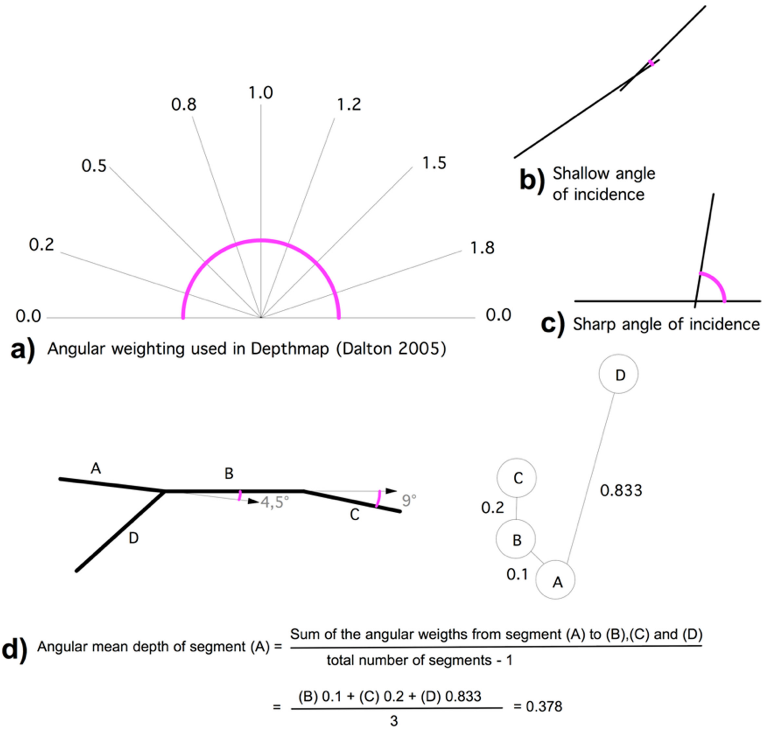


Fig. 4. The angular weighting used in Depthmap a), and examples on a shallow b) and a sharp c) angle of incidence. The calculation of angular mean depth of segment A is shown in image d) with a j-graph.

As world-wide research has shown since 2012, it is clear that the main route network is highlighted through the angular choice value analyses. The next step is to describe how to calculate the degree of permeability from this main route network to the local streets of the various neighbourhoods.

The following steps are taken in DepthmapX software. First, run the angular choice analyses with radius ‘n’ or a high radius. Then open up the scatterplot. Make sure that the X and the Y axis have the same values, thus that it is the choice values with radius ‘n’ on each axis in the scatterplot. Then a straight diagonal line is shown in the scatterplot. Mark all the dots that are not dark blue. Then open up the processed map. Most of the main routes are now marked in yellow. Then you press the step depth button. Even though not all main routes are marked, those with a shallow angular deviation receive values close to 0 in the angular step depth analyses. Remember to rename the column from ‘angular step depth’ to ‘angular step depth main routes’. A separate column is now made in the table. To make the map more visible, go to colour range and manually invert it so that the main routes are red, and the streets with around 90 degrees from the main routes have a green/blue colour.

In the following section, examples from the findings are shown.

3 Analysis of 25 Different Cities

First, the angular step depth analysis map of a few of the 25 cities will be shown and discussed. At the end, the various mean values from the whole city, the historic city centre or downtown area, and a modern area/neighbourhood will be presented from all 25 cases.

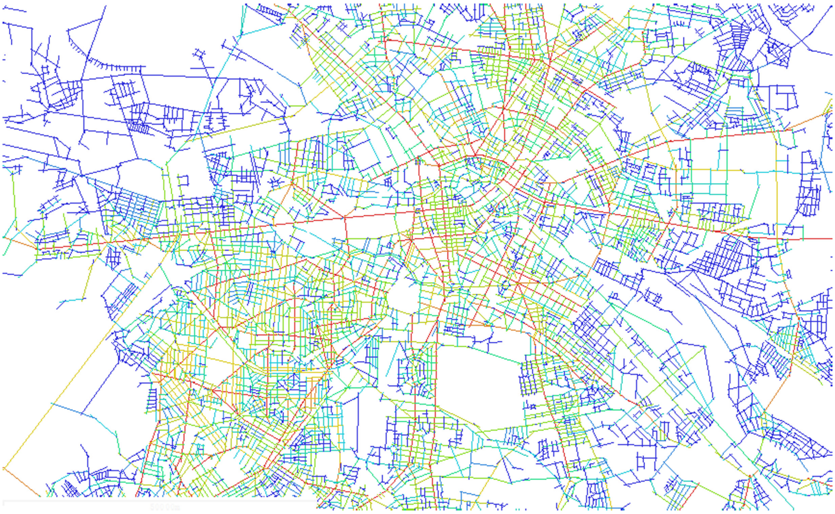


Fig. 5. Angular step depth from main routes in Berlin

The first case presented is Berlin, a typical European city with old and new areas. Figure 5 shows an angular step depth analysis from the main route network of Berlin. In the historical areas, the main route network is well embedded in the neighbourhoods. The post-War neighbourhoods are poorly accessible from this network. This pattern can be seen in most cities. Examples on this are Amsterdam, Auckland, Curacao, Oslo, Prague, Rome, Rotterdam, and Shenzhen.

The next step is to test the angular step depth from main routes in cities with a strict orthogonal street structure. Barcelona present one example, shown in Fig. 6. As can be seen from the figure, the neighbourhoods in the Cerda grid are well connected to the main routes. The remaining streets are poorly connected to the main route network.

Another atypical city is Venice, shown in Fig. 7. At first sight this city might look like a labyrinth, however, the main routes are clearly visible in the angular choice analyses. However, the degree of permeability to the surrounding neighbourhoods are rather low.

In a city located within a hilly landscape, several side streets tend to have sharp angles. Figure 8 shows the case of the Norwegian city of Bergen. The city is squeezed between seven mountains. However, the main routes are still highlighted in the choice analyses, and the permeability from the main routes to local streets to pre-War neighbourhoods are much higher than in the post-War neighbourhoods.

To test out the role of hills, Fig. 9 shows an angular step depth analysis from the main routes of the Chilean city Valparaiso. The city is located along the coast of Chile in

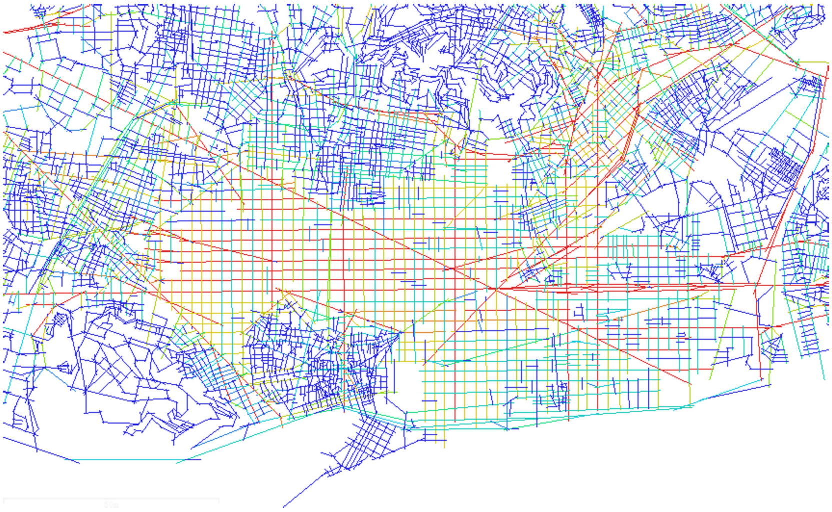


Fig. 6. Angular step depth from main routes in Barcelona

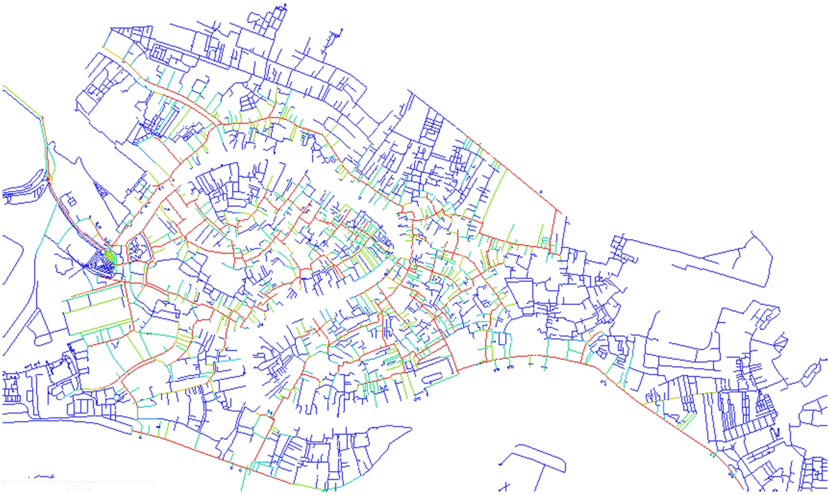


Fig. 7. Angular step depth from main routes in Venice

a hilly landscape. Most informal settlements are located on these hills. The two centres are highlighted in the analyses (coloured in red), whereas the informal settlements are poorly connected to the main route network. The centres are located in less hilly areas and have an orthogonal street structure.

Seemingly informal areas tend to be poorly connected to the main route network. Bangkok, shown in Fig. 10, represents a case in Asia. Here all the informal areas have low degree of accessibility from the main route network.

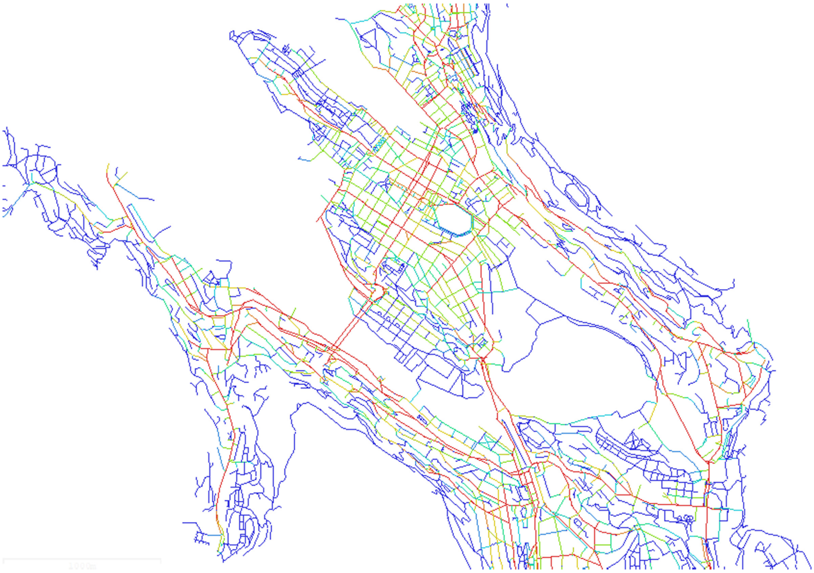


Fig. 8. Angular step depth from main routes in Bergen

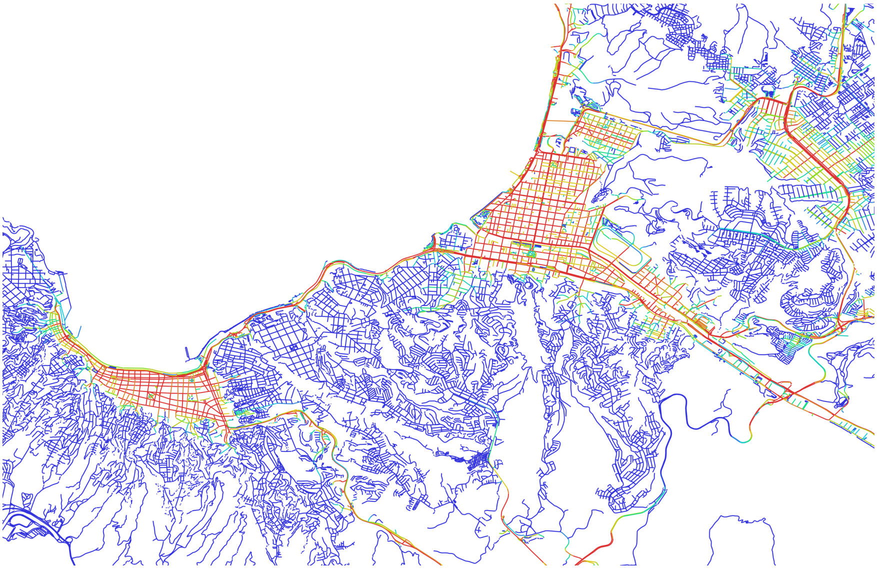


Fig. 9. Angular step depth from main routes in Valparaíso (Color figure online)

Figure 11 shows an angular step depth analysis from the main route network in the Jordanian city of Amman. Amman is a typical Arabic city with a labyrinth-like street network. However, the main route network is clearly visible. The residential areas are very segregated and have low degree of permeability to the main route network.

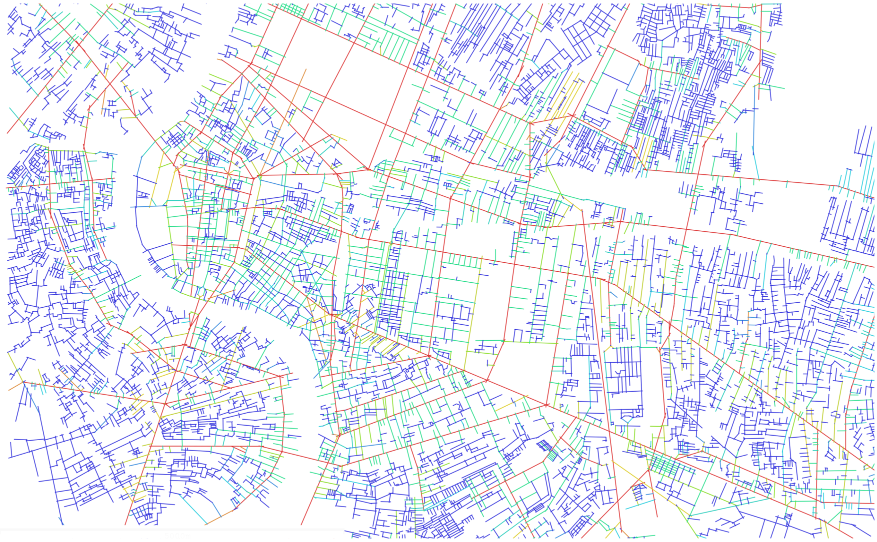


Fig. 10. Angular step depth from main routes in Bangkok

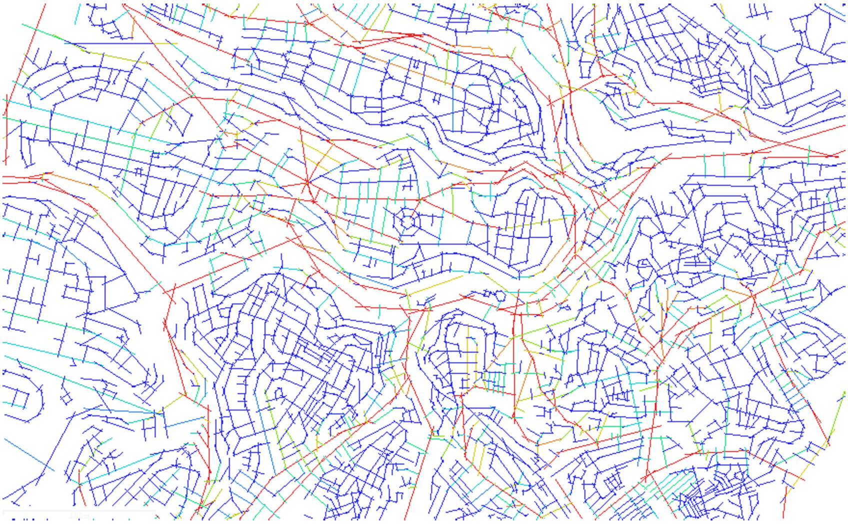


Fig. 11. Angular step depth from main routes in Amman

Often Persian and Arab built environments have a segregated background network in comparison with other cities. This becomes visible when analysing the angular step depth from the main route network. Examples on this is Banda Ace, Cairo, and Kumasi.

How is it then, in a city with an extreme orthogonal street structure? Figure 12 shows an angular step depth analysis from the main routes in Manhattan in New York. Event

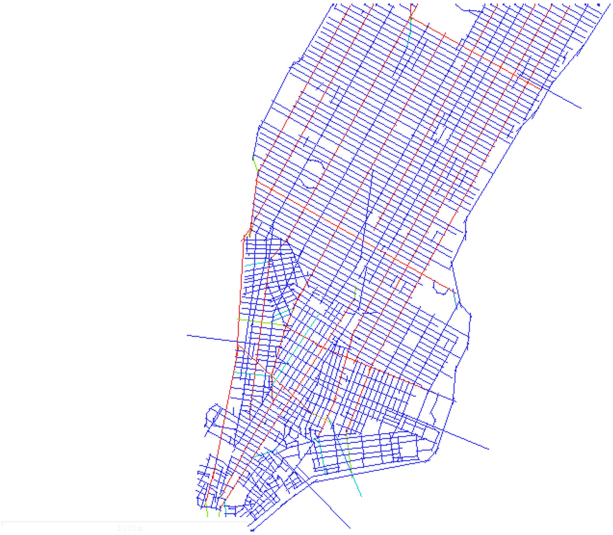


Fig. 12. Angular step depth from main routes in Manhattan, New York

through it looks like that every street is poorly connected to the main route network, we need to reveal the numerical values of the segments.

The next step is to reveal then numerical data for 25 different cities around the globe. The first column shows the mean values from the angular step depth analyses taken from the main routes for the whole city. Then the mean values for a selection of streets from a historical area or city centre, and one modern area is taken for each city.

Table 1 shows all the mean depth values from the main routes for all cases. All the lowest values are coloured in red and the highest value are coloured in blue. Regarding whole cities, values close to 1 means that the foreground network is well connected to the background network. Values higher than 3 means that the background network is poorly accessible from the main route network. Thus, there is a higher degree of permeability in the foreground network towards the background network.

As can be seen from the table, cities with strict orthogonal street pattern have high levels of permeability between the foreground and the background network. Examples of this are Manhattan, Buenos Aires, Vienna, and Barcelona. Conversely, cities that have low permeability to their main routes are Cairo, Kumasi, Kyoto, Prague, Valparaíso, and Venice Santa Lucia. Often these cities have a labyrinth-like background network. Even though Kyoto seems to have a strict orthogonal street pattern in its city centre, the surrounding suburbs possess a segregated street network due to their location in the surrounding hills.

The middle column shows the mean values for the various historic city centres of all 25 cities. Here, most cities score much lower mean values than the whole city, except Manhattan. Here, the downtown area has a less strict orthogonal street pattern than the uptown areas around central park, which affects the mean values of the angular step depth numbers.

Table 1. Mean values for the angular step depth analyses taken from the main route network of 25 cities.

Name city	Whole city	City centre	New area
Amsterdam	2,2478	1,5825	2,4923
Amman	2,02188	1,93251	2,20938
Annaba	2,05184	0,801747	1,96466
Auckland	2,85923	1,66449	2,59099
Banda Aceh	2,18964	1,20436	1,89563
Bangkok	2,33625	1,50212	1,62153
Barcelona	1,69178	0,705555	1,73358
Beijing	2,47926	1,44686	1,73106
Bergen	2,65356	1,68042	2,2245
Berlin	2,2159	1,16706	2,27712
Biskra	2,18677	1,48748	1,87917
Buenos Aires	1,60948	1,75528	1,12891
Cairo	3,08287	2,37121	2,32297
Curacao	2,24119	1,58604	3,24073
Iowa City	2,79248	2,15661	1,38503
Kumasi	3,90077	2,08806	4,12918
Kyoto	3,36705	1,06573	1,854
Manhattan	1,04709	1,16277	0,855865
Oslo	2,55071	1,15036	2,14669
Prague	3,44805	1,54576	2,16
Rotterdam	2,79008	1,29618	1,88321
Rome	2,49263	1,76955	1,90366
Shenzhen	2,15641	1,34339	1,88282
Valparaíso	14,0341	2,43736	6,64219
Venice	3,23003	1,42988	5,21389
Vienna	1,33824	0,775668	1,31193

The left column shows the values from the newer areas or city centres of all 25 towns. The areas scoring 3 and higher have very low degree of permeability of their main routes. Often informal settlements or segregated modern housing areas with gated communities, contribute to poor levels of permeability. In, the city is located in a hilly landscape and has several informal areas scattered around the hills. The city centre, located in the flat areas, has an orthogonal street grid with high degree of permeability. However, the surrounding neighbourhoods are poorly accessible from the main routes.

4 Conclusions and Discussion

The experiment with 25 different cities has proven that it is possible to measure the degree of permeability between the foreground and background network. The findings of the investigated cities from various cultures shows the following.

Arab cities tend to have lower degree of permeability between the foreground and background network. Even though cities like Cairo and Banda Ace tend to have historic central areas with European planning influences, the overall spatial layout shown that these cities have a highly segregated background network in comparison with other cities. It is related to various cultural contexts [19].

Cities with orthogonal grids tend to have a high degree of permeability between the foreground and the background network. However, this is not always the case. Beijing and Iowa City demonstrate that these urban areas have a highly integrated foreground network, but are poorly connected to an orthogonal background network. Conversely, cities that do not have an orthogonal street pattern can still have high level of permeability between the main routes and the surrounding neighbourhoods. Vienna has a dense network of primary routes with an extremely high degree of permeability to the various surrounding neighbourhoods. Vienna even scores better than the downtown area of Manhattan.

Hills and slopes can influence the degree of permeability of the main route network towards the background network. However, this must be seen together with the cultural context. The hilly city of Bergen still has an average permeability between the main routes and the various local neighbourhoods. In the case of Valparaíso, issues of poverty, in combination with a hilly landscape contributes to the extreme low levels of permeability between main routes and low-income neighbourhoods.

What is the usefulness of this method? First of all, it is now possible to quantify the relationship between the foreground and background network of cities. In 2016 Hillier attempted to build a theory or understanding on the generic function of cities [19]. Hillier's concept of the foreground network explains the location of micro economic activities, whereas his concept of the background network provides understandings on the relationship between culture and space [20].

The next step is to apply this method to various socio-economic data, such as crime data, public transport accessibility, the degree of functional mixing, degree of building density, the location pattern of shops, property, and rental prices, socio-economic data on inhabitants, registrations of gender differences in public spaces, sexual harassment data, perception of safety, registrations of social, optional, and necessary activities, etc. Systematic empirical testing of this method contributes to creating further operational spatial analyses tools for evaluating planning and urban design proposals, creating a spatial diagnosis of poorly functioning neighbourhoods, and for option testing in urban renewal projects.

Acknowledgements. The author is grateful to all students throughout the years and colleagues that have provided a set of axial maps for testing out the method.

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