Potential of the 15-Minute Peripheral City: Identifying Main Streets and Population Within Walking Distance

Joan Perez(✉) and Giovanni Fusco

Université Côte-Azur, CNRS, AMU, AU, ESPACE, Nice, France
joan.perez@univ-cotedazur.fr

Abstract. The concept of the 15-minute city presents challenges for pedestrian accessibility, particularly in peripheral areas with less pedestrian-friendly street networks. This paper explores the angular continuity of main streets and the population potential around them as crucial elements for the development of the 15-minute peripheral city. By utilizing geoprocessing algorithms, the study aims to identify main streets and verify their demographic potential in two distinct geographic contexts near Lille and Nice, France. The protocol is divided into four steps, as follows: (1) main streets identification through continuity, (2) calculation of morphological indicators on buildings, (3) machine learning to estimate the number of dwellings per building, and (4) population potential estimate within different walking distances from main streets. The findings reveal a network of interconnected main streets with significant population potentials in the outskirts of both test areas. These streets could serve as the development corridors for enhancing commercial activities and services, supporting the vision of the 15-minute city in peripheral areas.

Keywords: 15-minute city · street network · catchment area · pedestrian accessibility · angular continuity

1 Introduction

The 15-minute city poses a challenge to pedestrian accessibility, particularly in the outskirts and peripheries where the street network is less pedestrian-friendly. The Evolutive Meshed Compact City (emc2) project proposes a new model of the 15-minute city for the loose structural networks of peripheral location (Fusco et al., 2023). It envisages compact urban forms as corridor developments based on existing main roads, forming a meshed structure within metropolitan areas. The emc2 project is currently working on the characterization of morphological and demographic preconditions for these developments. The present paper is a first proposal in this direction, focusing on two specific aspects: angular continuity of main streets and population potential in a wider area around them. Indeed, in addition to numerous challenges for the 15-minute city to work effectively, such as inclusive urban design exemplified by the creation of walkable neighborhoods, conditions must be met for the presence of retail and services. Building on

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024
O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14817, pp. 50–60, 2024.
https://doi.org/10.1007/978-3-031-65238-7_4

the theory of natural movement (Hillier et al. 1993), the emc2 model considers a first requirement the existence of a well-connected foreground network of main streets, where retail and services can cluster. However, this begs the question of the potential demand within a walking catchment area, to ensure the presence of proximity-based activities. It becomes thus important to both identify possible elements of the foreground network of main streets and verify that they benefit from the demographic potential to become the backbone of the 15-minute peripheral city. Specific geoprocessing algorithms are needed to achieve these goals, as those presented and discussed within this paper.

For this paper, we decided to focus on two distinct geographic contexts situated on the outskirts of the metropolitan areas of Lille and Nice, in northern and southern France, respectively. The considered outskirt of Lille is made of the following 4 municipalities: Santes, Hallennes-lez-Haubourdin, Haubourdin, and Emmerin, totally accounting for 27.993 inhabitants 22.2 km^2; while within the outskirt of Nice we focused on the municipalities of Drap, Cantaron and La Trinité accounting for 16.572 inhabitants over 27.8 km^2. Building footprints, roads, and administrative boundaries are extracted from the version 3.3 of the French dataset BD TOPO® (IGN, 2023). These two case studies provide interesting geographical differences: a flat terrain with a tradition of linear developments around Lille as opposed to a more constrained hilly landscape where topography induces linear developments around Nice (Fig. 1).

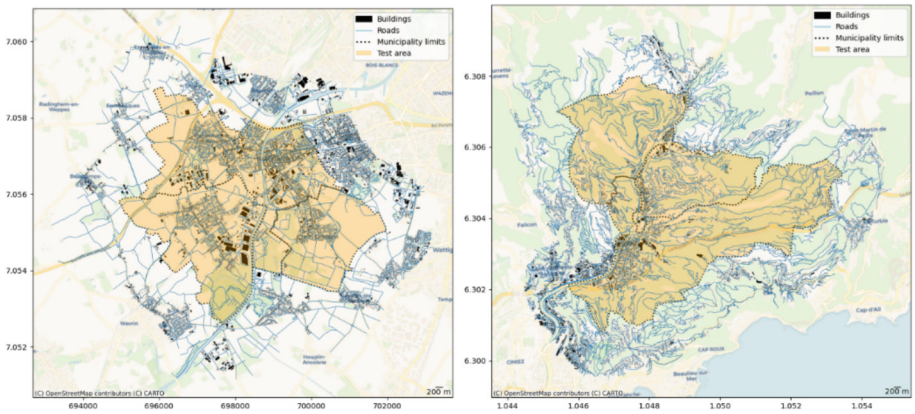

Fig. 1. Test areas, the municipalities of Santes, Hallennes-lez-Haubourdin, Haubourdin, and Emmerin in the the outskirt of Lille (left) and Drap, Cantaron and La Trinité in the outskirt of Nice (right)

A buffer of 1200 m (see catchment areas Sect. 5) has been performed over the administrative boundaries of the test areas in order to include 37.985 buildings and 6.157 road segments in the Lille outskirt, and 24.001 buildings and 6.179 road segments in the Nice outskirt. Highways and highway ramps are manually filtered out of the dataset, as they cannot play the role of pedestrian-friendly main streets for the 15-minute city. In addition, dual carriageways are re-digitized as single carriageways to improve the performances of the identification of main streets (Sect. 2). This paper is organized as follows. Section 2 presents the identification of main streets through an improvement

of the *Morpheo*'s algorithm. Section 3 focuses on the computation of morphometric indicators over buildings. Section 4 uses machine learning (classification + regression) to estimate the number of dwellings per building. Section 5 estimates the population potential around the identified main streets through catchment areas consistent with the 5, 10 and 15 minute-city. Section 6 concludes the paper with a discussion regarding future improvements of the protocol. Input data and the protocol are fully reproducible and available (see Sect. 6).

2 Main Streets Through Continuity

Angular continuity is useful for defining main streets and is normally assessed through intersection continuity negotiation algorithms (Porta et al., 2006). The QGIS plugin *Morpheo* (Lagesse, 2015) proposes a specific algorithm to assemble angularly continuous street segments in new objects called "ways" (i.e. natural streets, Stavroulaki et al. 2017) and hierarchizes them through connectivity measures. Aggregation of street segments uses deletion buffers at segment intersections and deviation angles. After applying the *Morpheo* plugin with the preconized parameters (deletion buffer of 4 m, deviation angles of 60°) over the two test areas, we obtain 1.891 ways for the outskirt of Lille, and 2.006 for the outskirt of Nice. Our proposal extends *Morpheo*'s algorithm, acknowledging that peripheral areas normally have ways with lower values of connectivity than those in central areas. To identify main streets in a local context, we introduce a novel indicator considering the connectivity of surrounding ways: the local relative connectivity (CONN_LocRel). Its purpose is to identify ways with connectivity levels significantly different from their immediate surroundings, highlighting potential connectivity anomalies which become focal elements in local contexts. Prior to calculating the local relative connectivity, two indicators must be calculated.

$$\mathrm{CONN}_{\mathrm{LocSum}} = \sum_{i=1}^{n} \mathrm{CONN}_{\mathrm{i}}$$

$$\mathrm{CONN}_{\mathrm{LocAvg}} = \frac{\mathrm{CONN}_{\mathrm{LocSum}}}{n}$$

$$\mathrm{CONN}_{\mathrm{LocRel}} = \frac{\mathrm{CONN}}{\mathrm{CONN}_{\mathrm{LocAvg}}}$$

where CONNi represents the sum of connectivity values associated with each intersecting buffer, n the number of intersecting ways and CONN the connectivity value of a given way.

The first indicator is the sum of the connectivity values associated with all intersecting buffers for each way identified by *Morpheo*. This indicator, named CONN_LocSum, reflects the overall level of connectivity of all the elements directly connected to a given way. Moving on, the second indicator, CONN_LocAvg, considers the number of intersecting ways when calculating connectivity, thereby providing a weighted average connectivity value for each of them. Finally, the local relative connectivity (CONN_LocRel) is calculated through standardization by CONN_LocAvg. This indicator evaluates connectivity relative to the local connectivity context, allowing for the identification of elements with disproportionately high values compared to neighboring elements.

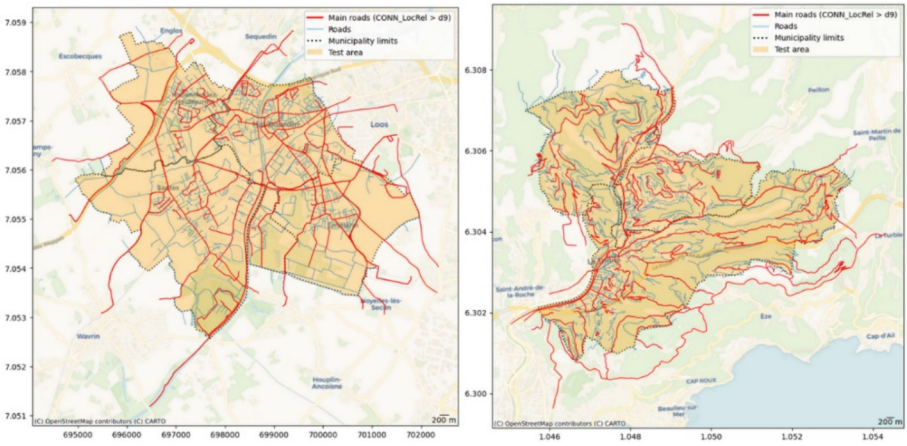

Fig. 2. The main roads in the outskirt of Lille (left) and Nice (right)

Figure 2 illustrates the identification of the main streets in the test areas within the test regions by mapping the ways characterized by a CONN_LocRel value falling within the 10th decile. In both the outskirts of Lille and Nice, results appear consistent with a successful identification of ways with high connectivity values compared to neighboring ways. These streets will serve as the focal elements for aggregating population potential, as outlined in Sect. 5. In Lille, the D9 value is 1.26, whereas in Nice, it is 1.33. Populations will be estimated from dwelling data. However, the number of dwellings is not available for some buildings (see further), which forces us to first implement some morphological indicators (Sect. 3) to assign them an estimated number of dwellings.

3 Morphological Indicators

This section is about the calculation of diverse indicators associated with building morphology. The goal is to collect enough morphological indicators to subsequently assess whether a building contains dwellings or not (Sect. 4). The premise is that buildings with dwellings, whether entirely residential or mixed-use, exhibit distinct morphological characteristics compared to non-residential structures (Steadman 2014, Araldi et al. 2023, Perez et al., 2024). For instance, industrial and logistic buildings often have larger footprints, while their shapes may demonstrate reduced elongation and high convexity, reflecting specific requirements related to their function. Basic indicators, such as surface areas or perimeters are computed using *geopandas*. For advanced indicators, like the ratio of shared walls or the elongation of each building, we use the urban morphology toolkit *momepy*, a library for quantitative analysis of urban form developed by Fleischmann (2019).

We also derive three composite indicators, based on the basic metrics previously calculated. The first, denoted FA (Floor-Area) is the product of floor and area (F.A). ECA (Elongation-Convexity-Area), is made to discern sizable yet non-elongated specialized structures/instances often characteristic of non-residential buildings, distinct

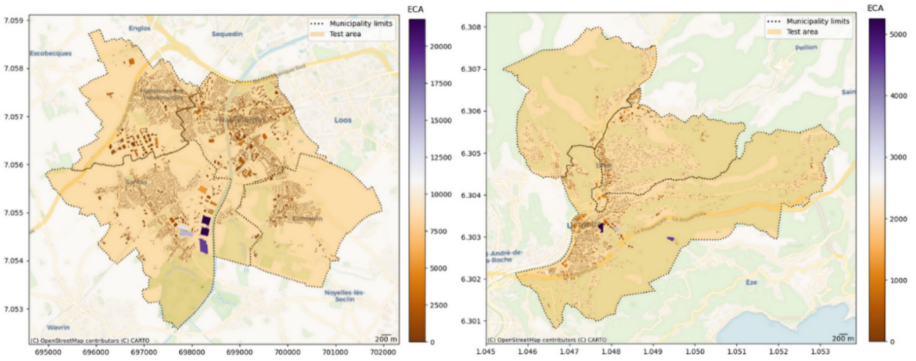

Fig. 3. ECA (Elongation-Convexity-Area) values per building in both test areas

from elongated modernist residential complexes.

$$\mathrm{ECA} = (1 - \mathrm{E}).\mathrm{C}.\mathrm{A}$$

As displayed in Fig. 3, large sized but yet non-elongated buildings are well detected by the ECA indicator. Then, EA (Elongation-Area), which is the product of surface area and elongation (E.A), shall assume significance in estimating the number of dwellings per building. The final feature attributes of the dataset are as follows: F (number of floors), A (surface area of the building footprint), P (perimeter), E (elongation), C (convexity), FA (floor-area), ECA (elongation-convexity-area), EA (elongation-area) and SW (shared walls).

4 Dwellings Estimation

The goal of this section is to estimate the number of dwellings per building based on the morphometry indicators that have been calculated in the previous section. We proceed with two main tasks: classification for evaluating the presence of dwellings and regression for estimating the number of dwellings.

For classification, we use a decision tree classifier to predict whether a building has dwellings or not, based on its morphology indicators. The attribute data from the BD TOPO® contains the number of dwellings per building. Yet, this feature is incomplete. For example, in the Lille subset, 45.93% of the information is missing, while in Nice it reaches 60.11%. We isolate these buildings. Subsequently, for the remaining buildings, a binary encoding is applied: buildings without dwellings are assigned a value of 0, while buildings with dwellings are assigned a value of 1, irrespective of the actual count of dwellings within each building. The datasets for Lille and Nice are partitioned into training (70%) and testing (30%) subsets.

The trained model's accuracy is then evaluated against the test subset using confusion matrices. The proportion of correctly classified instances reaches 95.49% for the subset in Lille, and 87.95% for the subset in Nice, which indicated a relatively good overall performance of the decision tree classifier. Other performance metrics are provided in Table 1, such as the complexity parameter, the number of splits, predicted and

Table 1. Decision tree classifier performance metrics for Lille and Nice subsets

Complexity Param	N_Splits	Predicted	Expected	Accuracy
Lille subset				
0.658247	0	1	0.1818	0.9595
0.040183	1	0	0.0572	
0.017986	3	1	0.0629	
0.015308	5	0	0.0299	
Nice subset				
0.322142	0	1	0.2089	0.8865
0.051785	1	0	0.3347	
0.029285	3	1	0.0922	
0.010000	5	1	0.1176	

expected values. As the number of splits increases, the model becomes more specific in its predictions.

Table 2. Decision tree classifier: variable importance for Lille and Nice subsets

Feature	Lille subset	Nice subset
FA	35	33
A	26	24
P	26	21
FL	8	6
ECA	2	8
EA	2	8
E	1	0
SW	0	0

As evidenced in Table 2, Floor-Area, Area and Perimeter emerge as the most influential variables in determining the presence of dwellings within buildings, with ECA, EA and FL contributing less often, i.e. for more specific subsets of buildings. The models' performance is considered sufficiently robust to extend their application to buildings with missing information regarding dwelling presence, which were identified earlier in this section. The next step is to estimate the number of dwellings for buildings that lack information but have been identified as possessing dwellings by the decision tree classifier. Those buildings are temporarily isolated. Subsequently, we set up a repeated k-fold cross-validation framework to train a stepwise regression model using the *leapBackward* method from the caret library (Kuhn, 2023). The morphology indicators are used as predictors, while the target variable is the number of dwellings.

As the maximum number of variables allowed and incorporated into the regression model increases (nvmax), there is a trend of decreasing Root Mean Squared Error (RMSE) and increasing coefficient of determination (R^2). However, this improvement is marginal. Notably, in Nice, there is a clear advantage in using two regressors, whereas a single regressor suffices for Lille. Table 3 illustrates this fact, also showing slightly higher RMSE values in the Nice subset compared to the Lille subset, accompanied by

Table 3. Stepwise regression performance metrics

	Nice subset			Lille subset		
nvmax	RMSE	R^2	MAE	RMSE	R^2	MAE
1	4.422	0.724	1.324	2.056	0.771	0.654
2	4.100	0.755	1.814	2.062	0.771	0.639
3	4.135	0.751	1.805	2.085	0.765	0.646
4	4.058	0.759	1.732	2.051	0.775	0.631
5	4.065	0.759	1.719	2.040	0.777	0.666
6	4.066	0.759	1.718	2.050	0.775	0.688
7	4.052	0.760	1.705	2.027	0.779	0.705

lower R^2 values, suggesting slightly better accuracy in Lille. However, with R^2 values above 0.7 in both models, the overall performance indicates that the model is effective in estimating the number of dwellings per building.

Table 4. Stepwise regression variable importance

nvmax	FL	A	P	E	C	FA	ECA	EA	SW
Lille subset									
1						*			
2						*		*	
3						*	*	*	
4		*				*	*	*	
5	*	*				*	*	*	
6	*	*	*			*	*	*	
7	*	*	*	*		*	*	*	
Nice subset									
1						*			
2	*					*			
3	*	*				*			
4	*	*				*	*		
5	*	*		*		*	*		
6	*	*	*	*		*	*		
7	*	*	*	*	*	*	*		

Table 4 indicates that both in Lille and Nice, the floor-area (FA) holds the highest predictive power among regressors. However, as Table 3 indicates that a second regressor is needed in Nice to obtain satisfactory predictive power, both floor (FL) and floor-area (FA) will be included in the model. From Table 3, we also know that any additional regressor will only have a marginal effect in Lille. To use a single model, FA and FL will be used both for Lille and Nice. We then generate predictions for the number of dwellings and ensure that negative predictions (resulting from sparse data) are adjusted to 0. Finally, the estimated dwelling numbers are assigned to buildings lacking information about dwellings but identified as possessing dwellings by the decision tree classifier.

5 Catchment Areas and Population Potentials

This section focuses on estimating the population potential within catchment areas around main axes. It begins by importing the main streets as identified as the 10th decile from the Relative Connectivity indicator in Sect. 2 and the buildings with the estimated number of dwellings from Sect. 4. Catchment areas are created around the main roads using buffers of 400, 800 and 1200 m. 400, 800 and 1200 m roughly corresponds to 5, 10 and 15 min of walking time for able-bodied adults. Population potential per building is then calculated based on the estimated number of dwellings, considering an average household size of 1.92 for collective housings and 2.44 for single-family homes in France (Léger, 2019). The methodology aggregates the population count of each building to the catchment areas within the three specified catchment radii. Values are subsequently spatially joined to the main roads thus providing population potential along the latter as highlighted below.

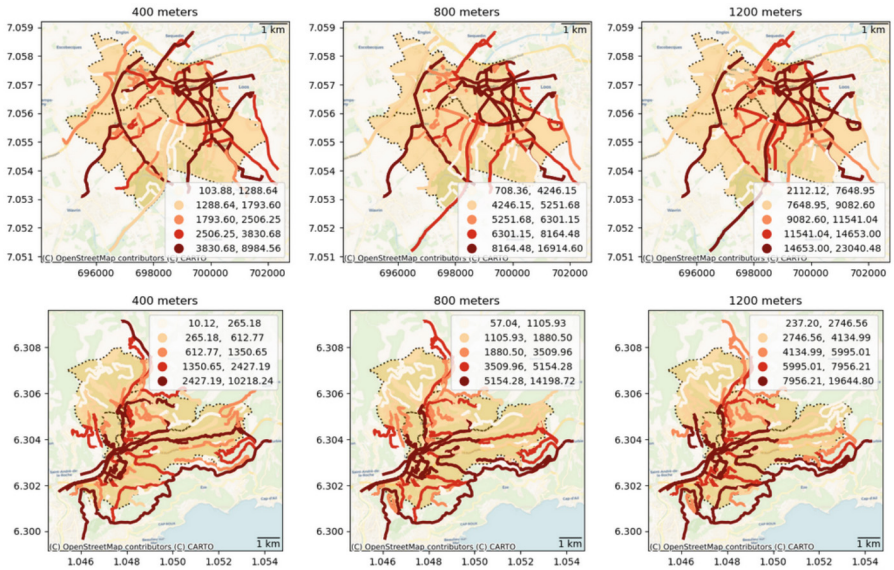

Fig. 4. Population potentials along main axes in the outskirt of Lille (top) and Nice (bottom) for catchment radii of 400, 800 and 1200 m

Figure 4 also shows that a meshed structure of main streets clearly appears in the outskirts of Lille. Main streets also stand out on the outskirts of Nice but due to the topology and to numerous valley dead ends, a meshed structure is less evident. The relative population potentials, standardized per kilometer of road (Fig. 5), highlight focal elements and smaller meshed streets with high demographic potential for the development of the emc2 model.

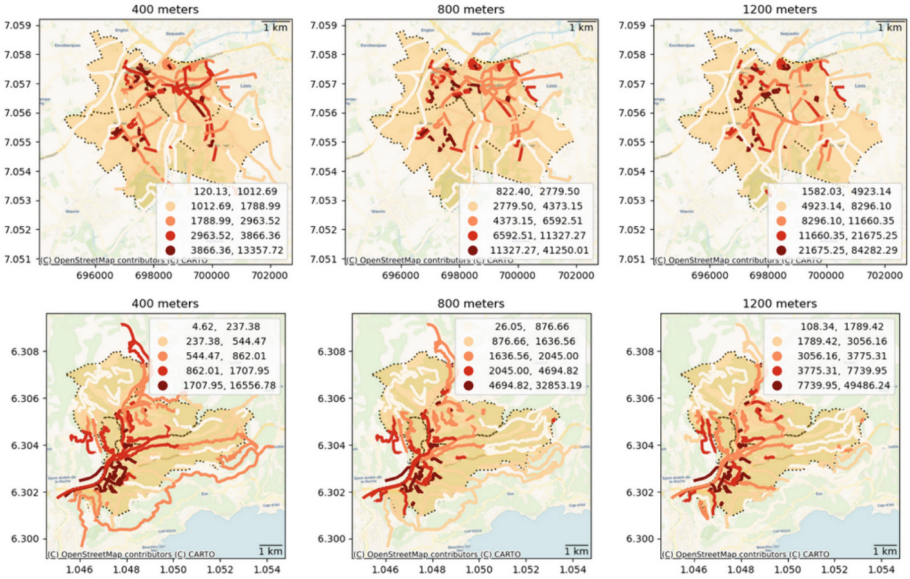

Fig. 5. Population potentials per kilometer of road along main axes in the outskirt of Lille (top) and Nice (bottom) for catchment radii of 400, 800 and 1200 m

6 Catchment Areas and Population Potentials

The findings are in line with the real-world situations in both the outskirts of Lille and Nice and with our intended objective: identifying a network of interconnected main streets with population potential conducive to targeted densification efforts. These identified main streets could serve as the backbone for enhancing commercial activities, services, and amenities in the area. Yet, we stress the importance of investigating other factors, such as population heterogeneity or kinds of services/retail activities. The protocol has been made available on GitHub (Appendix 1) and the datasets for Lille and Nice on Zenodo (Appendix 2). On Zenodo, both inputs and outputs are available within two GeoPackages. The protocol is divided into 4 main steps and one appendix as follows: (1) the identification of main streets - R Script (2) morphometry on buildings – Python script (3) evaluation of the number of dwellings within inhabited buildings – R Script (4) projecting population potential to main streets – R Script (Appendix) thematic maps presented in this paper – Python script.

The protocol outlined in this paper represents an exploratory phase, providing preliminary results derived from two extremely different geographical contexts. It is clearly subject to several improvements that we would like to discuss in what follows. Firstly, angular continuity analysis shall be combined, or replaced by configurational analysis that is used to identify what is described as the foreground network (i.e. main streets) in space syntax research; Hillier, 1996). The latest research highlights the importance of the urban environment's configurational characteristics for the 15-minute city at all scales (Murgante et al., 2024). More specifically, the multiscale configurational protocol proposed by Berghauser Pont et al., (2019) allows for the identification of local main

streets with no regards to the street typology. Since we manually filtered highway and highway ramps (Sect. 1), configurational analysis could significantly improve the protocol. Second, the morphology indicators could be calculated at different spatial lags to add indicators for the classification and regression models. Spatial lags could help detect buildings that are exceptions amongst local areas. Third, the null hypothesis of complete spatial randomness (CSR) shall be tested regarding the distribution of buildings with missing values of dwellings. Fourth, the estimation of the number of dwellings per building could be improved with, for example, using a count regression model for which the value zero cannot occur, such as the zero-truncated Poisson or negative binomial regressions. The population assigned to the different dwelling types could also be calculated with more place specific data and should be validated with available disaggregated census data to consider the presence of dwelling units used as secondary homes. Lastly, while catchment areas are currently calculated using Euclidean distance, employing network distance would yield more precise outcomes, given that individuals walk along paths and streets.

Acknowledgments. This paper is part of the emc2 project, which received the grant ANR-23-DUTP-0003–01 from the French National Research Agency (ANR) within the DUT Partnership.

Appendix 1

https://github.com/perezjoan/emc2-WP2/tree/main.

Road continuity - Dwellings - Population - Catchment areas/ICCSA protocol version.

Appendix 2

https://zenodo.org/records/10946415.

15-minute city, street network, catchment area, pedestrian accessibility, angular continuity.

This upload contains two Geopackage files of raw data used for urban analysis in the outskirts of Lille and Nice, France. The data include building footprints (layer "building"), roads (layer "road"), and administrative boundaries (layer "adm_boundaries") extracted from version 3.3 of the French dataset BD TOPO®3 (IGN, 2023) for the municipalities of Santes, Hallennes-lez-Haubourdin, Haubourdin, and Emmerin in northern France (Geopackage "DPC_59.gpkg") and Drap, Cantaron and La Trinité in southern France (Geopackage "DPC_06.gpkg").

References

Araldi, A., Emsellem, D., Fusco, G., Tettamanzi A., Overal D.: Building types in France. Clustering building morphometrics using national spatial data, Revue Internationale de Géomatique **31**(3–4), 265–302 (2023). ISSN 1260-5875, https://doi.org/10.3166/rig31.265-302

Berghauser Pont, M., et al.: The spatial distribution and frequency of street, plot and building types across five European cities. Environ. Plann. B: Urban Anal. City Sci. **46**(7), 1226–1242 (2019)

Fleischmann, M.: Momepy: urban morphology measuring toolkit. J. Open Source Softw. **4**(43), 1807 (2019). https://doi.org/10.21105/joss.01807

Fusco, G., Berghauser Pont, M., Cutini, V., Psenner, A.: The evolutive meshed compact city – a new framework for the 15mC in peripheral areas. In: Proceedings of ECTQG2023, Braga, pp. 85–87 (2023). https://ucpages.uc.pt/site/assets/files/1249198/ectqg_2023_proceedings_final.pdf

Hillier, B., Penn, A., Hanson, J., Grajewski, T., Xu, J.: Natural movement: or, configuration and attraction in urban pedestrian movement. Environ. Plann. B. Plann. Des. **20**, 29–66 (1993)

Hillier, B.: Space is the Machine. Cambridge University Press, Cambridge (1996)

IGN: BD TOPO® Version 3.3, Descriptif de contenu. Institut national de l'information géographique et forestière, 387 p. (2023)

Kuhn, M.: Package 'caret': classification and Regression Training (Version 6.0–94) [Software] (2023). https://github.com/topepo/caret/

Lagesse, C.: Lire les Lignes de la Ville : Méthodologie de caractérisation des graphes spatiaux. Géographie. Université Paris Diderot-Paris VII, Thèse, 566 p. (2015)

Léger, J.-F.: Le lien logement-population à l'échelle locale. I – Le « rendement démographique » des logements. Espace populations sociétés, 2019/3 (2019)

Murgante, B., Valluzzi, R., Annunziate, A.: Developing a 15-minute city: evaluating urban quality using configurational analysis. The case study of Terni and Matera, Italy. Appl. Geogr. **162** (2024)

Perez, J., Fusco, G., Sadahiro, Y.: Population and morphological change: a study of building type replacements in the Osaka-Kobe City-Region in Japan. Geograph. Anal. , Early View, Online Version of Record before inclusion in an issue (2024)

Porta, S., Crucitti, P., Latora, V.: The network analysis of urban streets: a dual approach. Physica A **369**(2), 853–866 (2006)

Stavroulaki, I., Marcus, L., Berghauser Pont, M., Carl Staffan Nilsson, L.: Representations of street networks in space syntax towards flexible maps and multiple graphs. In: 11th International Space Syntax Symposium. SSS 2017, Lisbon, Portugal, 3–7 July 2017, vol. 5, pp. 174.1–174.16 (2017)

Steadman, P.: Building Types and Built Forms. Troubador Publishing Ltd., Leicestershire (2014)