A TAXONOMY OF INFORMALITY: EXPLORING BLOCK TYPES IN FIVE INFORMAL SETTLEMENTS IN EAST AFRICA

Alessandro Venerandi, ESPACE, University of Cote d'Azur, Nice, France

Johan Mottelson, Institute of Architecture, Urbanism and Landscape, KADK - The Royal Danish Academy of Fine Arts - Schools of Architecture, Design and Conservation, Copenhagen, Denmark

ABSTRACT

Approximately 13% of the world population lives in informal settlements, characterized by limited state control, inadequate infrastructure provision, and lack of planning. While the relevance of studies of informal settlements is widely acknowledged, the urban morphology of such areas is understudied, compromising the development of effective planning and policy targeting such areas. In this paper, we present a taxonomic study at a fine level of spatial granularity of the urban form of five informal settlements, located in major cities of Sub-Saharan Africa. More specifically, a k-means clustering is applied to eight indicators of urban form computed at block level, for each of the settlements under examination. The best clustering identified ten different block types associated with distinctive features, such as blocks on public spaces (small, densely built, abundant public open space), fringe blocks (medium-sized, sparsely built, low local connectivity), blocks in the making (large, sparsely built, high levels of through movement at settlement level). We argue that this taxonomy provides detailed information about the case studies under examination, which can potentially inform design strategies aimed at their upgrading. Finally, it presents some of the first attempts at establishing replicable quantitative data driven descriptions of the urban form of informal settlements. Keywords: informal settlements, taxonomy, urban form, k-means clustering, East Africa.

INTRODUCTION

Informal settlements are urban areas typified by lack of state control built on a land which the occupants have no legal claim to, or areas where construction is not in compliance with current planning and building regulations (Jenkins, 2006; OECD, 2001). These settlements are often characterized by insecure tenure, overcrowding, substandard housing, and inadequate access to water and sanitation (UN-Habitat, 2003). It is estimated that at least one in eight people (roughly one billion dwellers) live in informal settlements worldwide (UN-Habitat, 2015). In Sub-Saharan Africa, the urban majority resides in informal settlements, and the likelihood of continued high population growth, rural to urban migration, and limited state capacity to accommodate the growing urban population will likely lead to a continued proliferation of informal urban development in the coming decades (UN-Habitat, 2013). While the relevance of studies of informal settlements is widely recognized, their urban form remains understudied, compromising urban planning and policies aimed at improving such settlements (Visagie & Turok, 2020).

A taxonomy of urban types based on similarities and differences can provide a more thorough understanding of the development and urban form of informal settlements. Its main advantage lies in its heuristic value as it can structure detailed and complex information in order to reach generalizability (Rapoport, 1990). However, the level of detail, robustness, and generalizability of the outcomes largely depend on the approach utilized and the spatial granularity of the data in input. Existing taxonomies of informal settlements are largely obtained through approaches based on qualitative assessments and mainly focus on entire settlements or on very small fragments. Davis

(2006), for example, developed a taxonomy of slum typologies based on his observations of locational factors, formal/informal features, and tenure status. Dovey and King (2011) defined a classification of informal settlements by interpreting their processes of growth in terms of settling, inserting, and attaching. Similarly, Del Bianco (2014) proposed a classification of housing types in a block of an informal settlement in Sao Paulo, Brazil, based on the interpretations of a field survey. Although these works provide valuable insights into several aspects of settlements and their relation with surrounding contexts, they do not describe the urban form at a fine level of spatial granularity. Furthermore, being based on qualitative assessments, they are hardly replicable thus limiting our knowledge of informal urban development. This paper presents a taxonomy of blocks based on a replicable technique (i.e., k-means clustering) and fine-grained data obtained from high resolution orthophotos and GPS traces to address the following research question: what are the typical urban form features of blocks in informal settlements in East Africa?

METHODOLOGY

The methodology implemented to answer this research question relies on three subsequent steps: (i) collection and processing of spatial data for the five settlements under examination; (ii) computation of eight indicators of urban form at the block level; and (iii) application of a clustering technique to these indicators to obtain block types. We present these steps in more detail next.

COLLECTION AND PROCESSING OF SPATIAL DATA

Data at a fine level of spatial granularity for the five settlements under examination were collected with an unmanned aerial vehicle (drone) and a handheld GPS-device (smartphone). The former was used to obtain high-resolution aerial imagery which was then processed with Pix4D[1] to generate georeferenced orthophotos, Digital Surface Models (DSMs), and 3D models. The latter was used to map the street networks of the settlements under examination through SW Maps.[2] Streets were recorded by walking along the boundaries of every block in each settlement. Georeferenced orthophotos and GPS traces were then imported in a GIS software, automatically scaled, and exported in a design software application. Buildings were then traced manually based on the orthophotos. Multi-storey buildings were identified through DSMs and 3D models and separate layers were created for each floor. Finally, street networks and blocks were manually drawn based on both GPS traces and orthophotos. Buildings, blocks, and street networks in vector format were utilized for carrying out the analysis presented in this paper.

INDICATORS OF URBAN FORM

Eight urban form indicators were used to characterize the five settlements under examination at the block level. Six indicators measure aspects of the urban fabric. Two indicators quantify features of the configuration of the street network. The former include:

- Block Size (BS), which measures the block area in square meters;
- Coverage Ratio (CR), which quantifies the percentage of land occupied by buildings;
- Floor Area Ratio (FAR), which measures the built-up density. It is computed by summing the Gross Floor Areas (GFAs)[3] of the buildings in a block and dividing such value by BS;

[1] Pix4D is a photogrammetry software available at https://www.pix4d.com
[2] SW Maps is an app that records GPS traces and is available at http://swmaps.softwel.com.np/#
[3] GFA is obtained by multiplying the building footprint by the number of floors.

- Surface Area to Volume Ratio (SAV), which represents the levels of fragmentation of the building envelopes. SAV is calculated by multiplying the perimeters of the buildings in a block by their heights, summing this value to two times the sum of the building footprints in each block, and by dividing this value by the built-up volume in each block;
- Private Space Ratio (PrSR), which quantifies the amount of private open space relative to the built-up density. It is computed by subtracting the building footprints from BS and dividing this value by the Gross Floor Areas (GFAs) of the buildings in a block;
- Public Space Ratio (PuSR), which measures the amount of public open space relative to the built-up density. The area of public open space in a block is obtained by subtracting BS from the area of the polygon created by the road center lines surrounding a block. PuSR is then computed by dividing such value by the Gross Floor Areas (GFAs) of the buildings in a block;
- Average Node Degree (AND), which measures the level of block connectivity. It is computed by averaging the node degrees associated with the street intersections surrounding a block;
- Average Betweenness at 400m (AB400), which quantifies the average levels of through movement on the edges of blocks. The formula for computing betweenness centrality can be found in the work by Porta et al. (2006). Since the settlements under examination had sizes comparable to that of city neighborhoods, we computed betweenness centrality at 400m radius, a measure commonly associated with the neighborhood scale (Mehaffy et al., 2010). Finally, each block was assigned with the average value of betweenness centrality associated with its surrounding streets.

PrSR and PuSR are variations of Open Space Ratio (OSR) proposed by Berghauser-Pont and Haupt (2010). The advantage of using these indicators is that they distinguish between private and public open spaces. AND and AB400 were computed by adapting scripts contained in momepy, a Python library for the quantitative analysis of urban form (Fleischmann, 2019).

CLUSTERING THE INDICATORS

The k-means clustering was applied to the values of the indicators presented above to obtain a block taxonomy of the informal settlements under examination. K-means is a data mining technique to partition a large number of observations into a small set of representative clusters in which each observation belongs to the cluster with the nearest mean (cluster centroid) (Forgy, 1965). These centroids are selected by minimizing the within-clusters sum-of-squares (WCSS), a measure of variability of observations within each cluster. Since k-means uses distance-based measurements to determine similarities between observations and our indicators have different units of measurement, we standardized the data to have a mean of 0 and a standard deviation of 1. Since k-means requires the number of clusters to be defined, we tested different numbers and used the elbow method to determine the optimal solution. The latter is a heuristic technique consisting in plotting the WCSS as a function of the number of clusters and choosing the sharpest bend of the curve as the number of clusters to use (Thorndike, 1953). Finally, to avoid the overrepresentation of certain aspects of urban form due to a disproportion in terms of number of observations (blocks) across the settlements, a weighting system was applied to the k-means clustering to account for the number of blocks in each settlement. More specifically, weights for the observations in a specific settlement were computed by dividing the number of blocks in the smallest settlement by the total number of blocks in such settlement.

CASE STUDIES

The methodology presented above was applied to build a block taxonomy of five informal settlements in East Africa. We present processed orthophotos and vectoral maps for each settlement in Figure 1 and brief descriptions next:

- Kibera is the biggest informal settlement in Africa (Desgroppes & Taupin, 2011). It is located 5 km from the Central Business District (CBD) of Nairobi, the capital of Kenya, and is characterized by large blocks, small public spaces, large-scale buildings of 1 to 3 floors, and poor public hygiene due to lack of infrastructure.
- Antohomadinika is located 1 km from the CBD of Antananarivo, the capital of Madagascar, and is characterized by multi-storey buildings, high ground occupation, small public space, and poor public hygiene due to frequent flooding.
- Maxaquene is located 3 km from the CBD of Maputo, the capital of Mozambique. The urban fabric of this settlement is mainly characterized by large blocks, single-storey detached buildings, and large open private spaces.
- Katanga is located 2 km from the CBD of Kampala, the capital of Uganda and near the main city hospital. It occupies an interstitial space in the formal urban fabric. The settlement is mainly characterized by dense single-storey buildings, parking areas, and a large soccer field.
- Hananasif is located 3 km from the CBD of Dar es Salaam, the biggest city in Tanzania. The settlement is characterized by single-storey detached buildings and relatively wide streets, which allow car access.

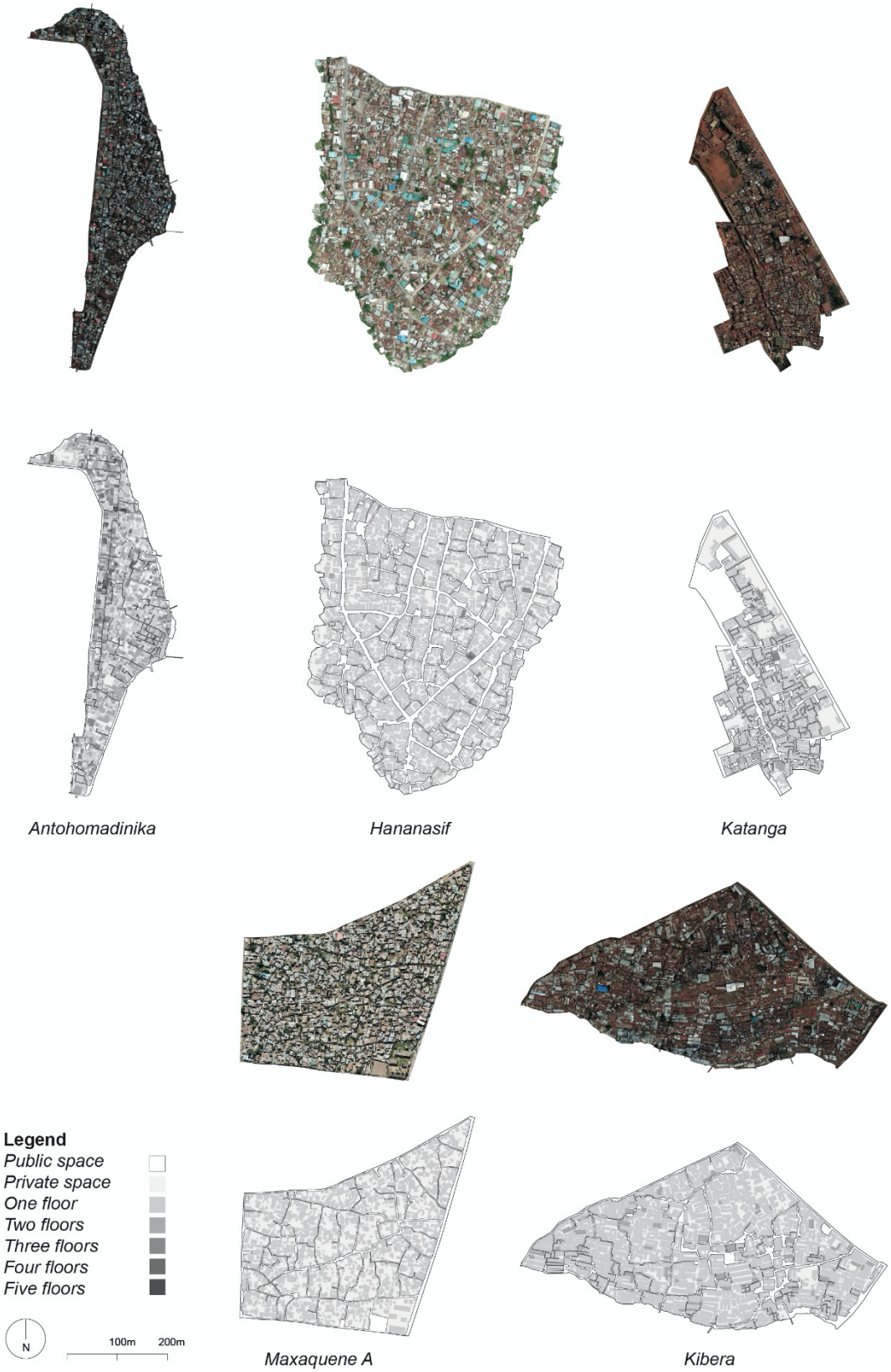

Figure 1. Orthophotos and vectoral maps of the five settlements under examination.

A BLOCK TAXONOMY

After having computed and standardized the values of the indicators of urban form across all settlements, we computed weights to assign to each observation with the method described in *Clustering the indicators*. By doing so, the observations in Kibera were assigned 0.67; the ones in Antohomadinika 0.90; the ones in Maxaquene 1.00; the ones in Katanga 0.28; the ones in Hananasif 0.27. The k-means technique was then implemented with these weights and for solutions from 2 to 20 clusters. The plot in Figure 2 was then used to detect the sharpest bend of the function and the optimal number of clusters/block types (i.e., 10). In Figure 3, we present maps for each of the settlements under examination with blocks color-coded according to their types. To understand the typical features of each block type, we computed the average values of the indicators of urban form for the blocks pertaining to each cluster/type and compared such values to quartiles computed across all settlements (Table 1). We present 3D representation of each block type in Figure 4 and brief descriptions based on this data next:

- Connected blocks (type 0 and 7). These tend to be small, densely built, with small private and public open spaces, compact, averagely connected at the local level, with high levels of through movement at settlement level. These are mainly located in Kibera and Antohomadinika in both central and peripheral parts, very well connected across scales. Due to their small size, we suggest that some of these blocks may be merged without compromising mobility in the settlement in order to increase private and public open spaces. Type 0 and 7 were merged into the same category because only 2 indicators (i.e., FAR, PrSR) on 8 had significantly different values.
- Balanced blocks (type 1). These are medium-sized, moderately dense, with mid-sized open private and public spaces, averagely compact, with medium levels of connectivity at the local level and through-movement at settlement level. These blocks are located in central and peripheral parts of the settlements under examination, but mostly in Hananasif.
- Blocks in the making (type 2 and 4). These tend to be large, characterized by low densities, large private open spaces, medium-sized to large public open spaces, fragmented building layouts, averagely connected at block level, with low to moderately high through movement at settlement level. They are mainly located in Maxaquene and at the periphery of Katanga. We labeled such blocks "in the making" as their features suggest that they were only recently established and will probably undergo processes of further densification and subdivision. Type 2 and 4 were put in the same category because only 2 indicators on 8 (i.e., PuSR, AB400) showed significantly different values.
- Blocks on public spaces (type 3). These are very small, characterized by high densities, small private open spaces, very large public open spaces, very fragmented building layouts, very well connected at the local level, but with poor through movement at settlement level. These blocks are mainly located in Katanga and Hananasif near squares of different sizes and canal banks.
- Secluded blocks (type 5). These are small, very dense, with small private and public open spaces, averagely compact, averagely connected at the block level, but poorly at the settlement level. These blocks can be found across all settlements but most of them are in Katanga. They tend to be located in more segregated/enclosed spaces with poor through movement at settlement level.
- Fringe blocks (type 6). These are medium-sized, characterized by a relatively low built-up density, abundant private open space, medium-sized open public spaces, moderately fragmented building layouts, and low local connectivity and through movement at

settlement level. By inspecting Figure 3, we observe that these blocks are indeed located at the peripheries of the settlements under examination and face natural or artificial barriers, such as wetlands, canals, or major roads. Furthermore, since settlements tend not to have access for cars, some of these blocks are used for parking by residents or people working locally.

- Blocks with potential (type 8 and 9). These are large to very large, characterized by average densities, mid-sized open private spaces, relatively compact building layouts, small public open spaces, low local connectivity, and high levels of through movement at the settlement level. Due to their large size, above average number of dead end streets, and presence of unbuilt spaces, we suggest that these blocks hold the potential for being subdivided to increase accessibility and enlarge public open spaces, which, in turn, might favor new commercial and recreational activities at the street level. Type 8 and 9 were merged into the same category because only FAR had significantly different values.

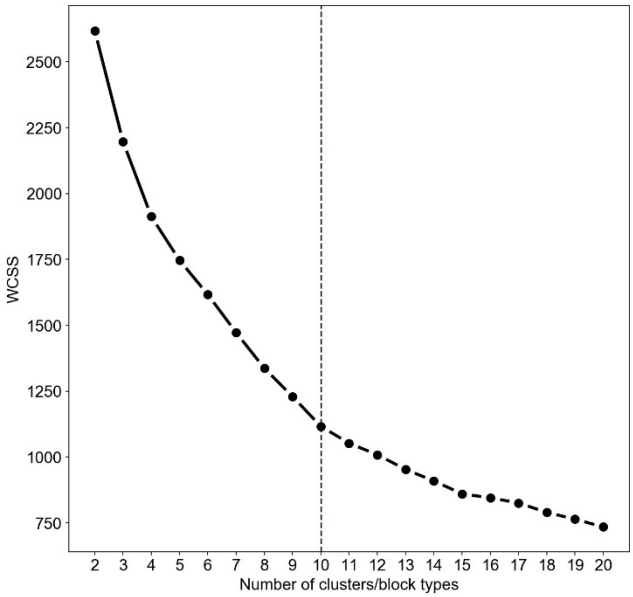

Figure 2. Optimal number of clusters/block types.

cluster/block type	*no. of blocks*	*BS*	*CR*	*FAR*	*PrSR*	*PuSR*	*SAV*	*AND*	*AB400*
0	*22*	*417*	*93*	*1.49*	*0.056*	*0.178*	*0.930*	*2.859*	*0.109*
1	*105*	*1276*	*68*	*0.69*	*0.471*	*0.435*	*1.150*	*2.983*	*0.079*
2	*33*	*2966*	*47*	*0.47*	*1.168*	*0.313*	*1.304*	*2.850*	*0.104*
3	*19*	*76*	*92*	*0.93*	*0.100*	*1.576*	*1.437*	*2.945*	*0.053*
4	*4*	*1578*	*20*	*0.20*	*4.223*	*1.170*	*1.181*	*2.786*	*0.023*
5	*115*	*263*	*92*	*0.94*	*0.093*	*0.411*	*1.168*	*2.794*	*0.052*
6	*48*	*1020*	*54*	*0.54*	*0.912*	*0.440*	*1.206*	*2.232*	*0.056*
7	*27*	*679*	*88*	*0.91*	*0.145*	*0.349*	*1.074*	*2.799*	*0.171*
8	*26*	*4574*	*75*	*0.93*	*0.287*	*0.146*	*1.023*	*2.624*	*0.115*
9	*4*	*15436*	*75*	*0.79*	*0.319*	*0.140*	*1.013*	*2.552*	*0.155*
	Min	*15*	*15*	*0.15*	*0.000*	*0.054*	*0.576*	*1.667*	*0.000*
	1st Qu.	*201*	*64*	*0.64*	*0.088*	*0.234*	*1.075*	*2.581*	*0.043*

quartiles across all case studies	*Mean*	*1308*	*75*	*0.81*	*0.435*	*0.438*	*1.162*	*2.778*	*0.080*
	3rd Qu.	*1544*	*91*	*0.97*	*0.563*	*0.499*	*1.228*	*3.000*	*0.107*
	Max	*19554*	*100*	*2.00*	*5.776*	*2.896*	*1.822*	*3.333*	*0.288*

Table 1. Average values of the indicators of urban form for each block type and quartiles across all settlements.

CONCLUSIONS

Taxonomies of different urban types in informal settlements have been proposed by several scholars. However, these were largely based on qualitative evaluations and mainly focused on entire settlements or on very small parts. The difficulty of replicating these works and the uneven levels of spatial information limit our knowledge of informal urban development. In this paper, we presented a block taxonomy of five informal settlements in Sub-Saharan Africa based on a replicable technique (weighted k-means) and indicators of urban form at the block scale. Outcomes suggest the existence of ten different block types associated with distinctive traits, positional factors, and different levels of development. While these findings may not cover all block types in informal settlements due to the limited number of cases, the taxonomy presents one of the first attempts to develop more generalizable quantitative descriptions of the urban form of such areas. In fact, the methodology presented in this paper is replicable. Accordingly, further analyses of informal settlements can be carried out to confirm, amend, or reject the block types found in this work and thereby improve our understanding of informal urban development.

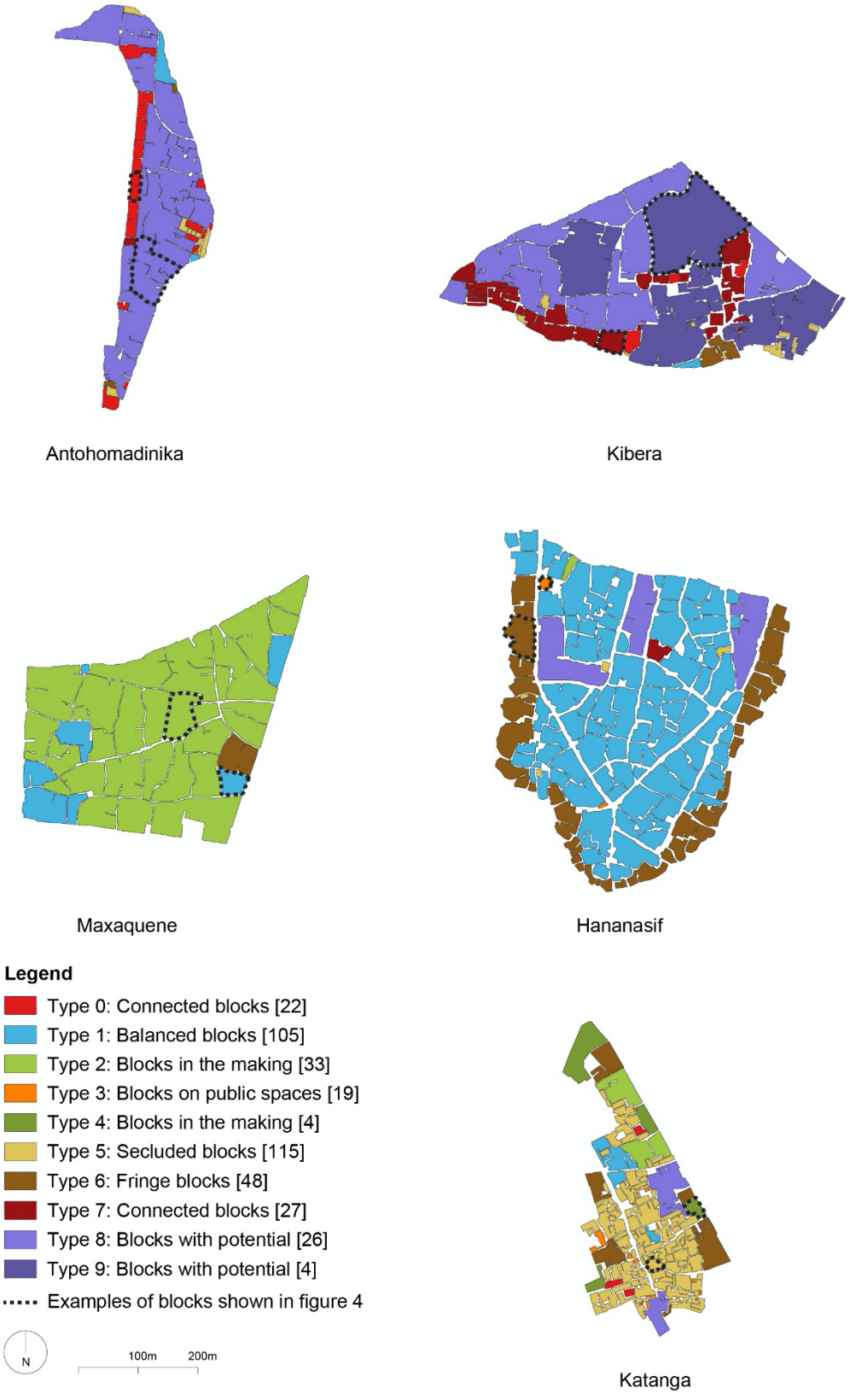

Figure 3. Settlements under examination with blocks color-coded according to their types.

Figure 4. Examples of block types.

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CORRESPONDING AUTHOR

Alessandro Venerandi, Postdoc, ESPACE, University of Cote d'Azur, 98 Bd Herriot, 06200, Nice, France. alessandro.venerandi@univ-cotedazur.fr @dooluoz (twitter)